Economic Assessment of Road Infrastructure Safety Schemes in Greece Using Crash Prediction Methodology

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ABSTRACT

The economic assessment of intervention projects at hazardous locations aims to maximize road safety benefits by exploiting the full potential of limited available funds for road safety. The study presents a case study for the economic assessment of road safety schemes in crash prone locations in rural highways in Viotia and Imathia sub-regions in Greece, using crash prediction models from the AASHTO Highway Safety Manual. The models were suitably adjusted, calibrated and adapted according to data availability, and were used, along with findings from road safety inspections of the locations under consideration, to estimate expected reductions in fatalities and casualties due to the implementation of specific road safety schemes. Road safety benefits were then translated into monetary terms, and, taking also into account construction and maintenance costs for each scheme, the economic rate of return (ERR) of the project was estimated. The economic rates of return were estimated at 27.1% for Viotia sub-region and 18.2% for Imathia sub-region, thus demonstrating the very high cost effectiveness of road safety intervention schemes in hazardous locations.

Keywords: Road Safety, Economic Analysis, Cost Effectiveness, Crash Prediction Models

INTRODUCTION

The economic assessment of road safety projects is considered a valuable tool that allows decision makers to increase the efficiency of their policies, maximize the contribution of transport to the economy in general and achieve a safer and more balanced relationship between transport stakeholders, road users, society and the environment (1). Taking into account that funds for road safety are limited, decision makers and road safety stakeholders need to prioritize activities and base their decisions on evidence and data, using appropriate criteria. Especially for road safety, the economic efficiency of measures is a widely used criterion to identify good policies (2).

Within the above context, the aim of the study is to present a methodology for the economic assessment of road infrastructure safety projects using international crash prediction models, adjusted for local conditions and to account for limited data availability. The development and implementation of the methodology was commissioned and funded by the European Investment Bank (EIB) and carried out in order to assist Egnatia Odos SA (a state owned highway company) in the assessment of the economic viability of the Greek Road Rehabilitation and Safety Project, a large road safety project for the treatment of hazardous locations in the rural road network of Greece.

The paper is structured as follows: the first section presents important information on the Greek Road Rehabilitation and Safety Project, thus setting the background of the study. Then, the developed methodological approach is presented, which involves both a technical and an economic appraisal of the project. The third section of the paper focuses on the implementation of the methodology (case study) in the sub-regions of Imathia and Viotia in Greece; all steps of the assessment are presented, from data collection and crash analysis to the estimation of the project's economic rate of return. Finally, in the last section of the paper the conclusions of the study are summarized.

THE GREEK ROAD REHABILITATION AND SAFETY PROGRAM

The Greek Road Rehabilitation and Safety Project was designed during the period 2012-2015 by Egnatia Odos SA (a state owned company) with the aim to improve road safety and reduce the number and severity of road accidents in the rural highway network of Greece. The project was based on an extensive technical and visual review of the national and regional road network to identify sections with increased crash risk. A total length of 15,000km of roads was examined, including 4,200km of national roads and 10,800km of regional roads, spreading over all 13 regions of Greece. The roads examined were mostly rural two-lane two-way roads and did not include motorways and roads inside urban areas (e.g. with sidewalks, traffic signals, etc.).

The project resulted in the identification of approximately 7,000 hazardous locations (HL) spread over 2,500 km of the aforementioned road network, on 80 different roads. These locations were categorized in three categories:

1. Hazardous Locations - Proven (HL-PR): Hazardous locations identified using accident analysis approach (approximately 400 locations). This approach was applied only on the national road network, therefore all HL-PR were located on national roads.

2. Hazardous Locations - Testimony (HL-T): These were identified based on the testimonies of local police stations and relevant regional road maintenance authorities collected through a questionnaire survey (approximately 3,000 locations).
3. Hazardous Locations - Potential (HL-P): These were identified based on the inspection and assessment of road geometric characteristics, from GPS measurements, video recording of the reviewed road, on site inspections and analysis of the deviation of road geometric design features from relevant design guidelines (approximately 3,600 locations).

For each identified hazardous location, low cost road safety interventions were proposed, selected from a pre-developed list of countermeasures. Emphasis was placed on measures that could be implemented quickly without the need for further designs, land expropriation or other permits. Examples of the proposed interventions are: repair of pavement defects, provision of new asphalt layers or anti-skid asphalt layers, road signage, road markings, delineators, retro-reflecting road studs, new EN-1317 compliant safety barriers, refurbishment of road shoulders, clearing of road sides, etc. A total net project cost of 470 million € was estimated for the treatment of all identified hazardous locations with short-term road safety interventions.

Prior to the actual implementation of the road safety schemes, the funding authorities requested that an economic assessment and investigation of the economic viability of the project was performed. Within this context, the present study describes the methodological approach for assessing the project's economic rate of return, as well as its pilot implementation in two sub-regions of Greece, Viotia and Imathia.

METHODOLOGICAL APPROACH

The economic assessment methodological approach is graphically presented in **Figure 1**. It comprises two pillars: Pillar 1 (Technical Assessment) focuses on the analysis of the proposed road safety schemes and the estimation of the resulting reduction in terms of accident numbers, fatalities and injuries, while Pillar 2 (Economic Appraisal) focuses on the estimation of costs and benefits in monetary terms, leading to the calculation of the project's Economic Rate of Return (ERR).

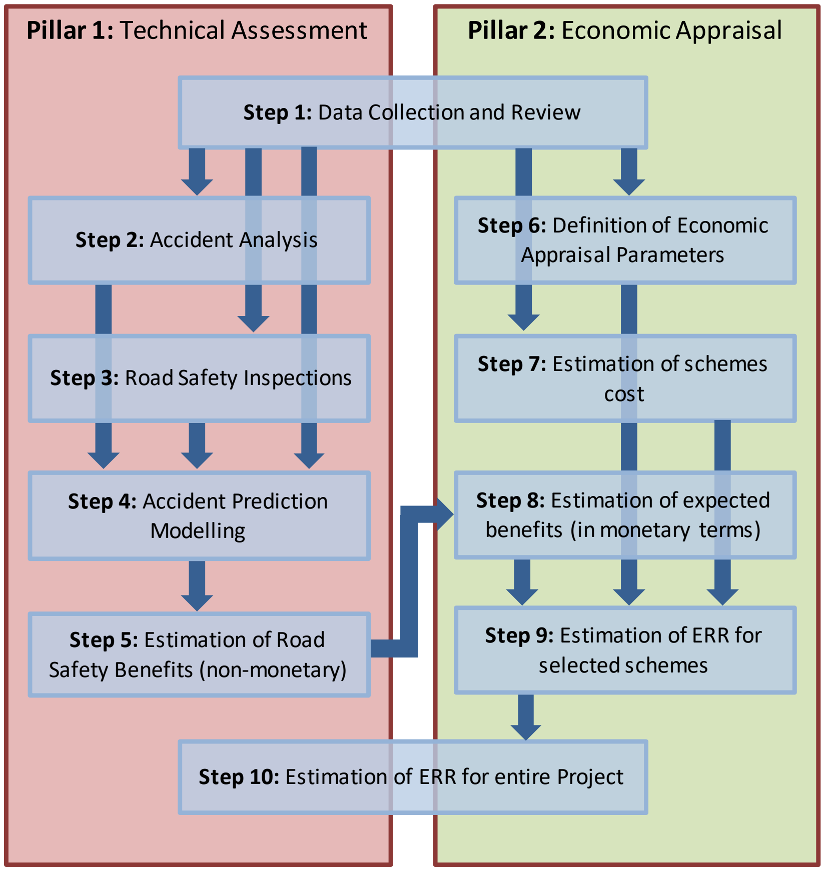

Figure 1: Methodological approach

The technical assessment pillar combines two engineering approaches in road safety, namely reactive and proactive engineering in a holistic method to reliably estimate the benefits of road safety schemes. According to the reactive approach (Step 2: Accident Analysis), historic crash data are used to identify hazardous locations and assess the magnitude and nature of the road safety problem. In Step 3 of the methodology, Road Safety Inspections (proactive road safety engineering) are also used to identify road safety deficiencies and assist in addressing them even before accidents occur. The accident prediction methodology applied in Step 4 combines input from both approaches to quantify the road safety issues in each location as well as the expected crash and casualties reduction (Step 5).

The individual steps of the above methodology are briefly presented in the following paragraphs, whereas their actual implementation is reported in the case study description and results.

Step 1: Data Collection and Review

The first step involves the establishment of contacts with relevant authorities for data collection, and the gathering, organization, review and assessment of project documentation and required data and information to enable an economic feasibility assessment.

Step 2: Accident Analysis

The second step of the methodology involves the analysis of recent crash data. This analysis constitutes a reactive approach to road safety, i.e. after the accident has occurred. Accidents in urban areas and accidents in motorways are to be excluded and the remaining accidents are allocated to the examined hazardous locations according to the road code and station recorded in the database. The results of this step include the number of accidents, fatalities, serious injuries and slight injuries that occurred at each one of the hazardous locations.

Step 3: Road Safety Inspections

The objective of this step is to conduct a site visits on the hazardous locations with the following aims:

- to obtain an overall understanding of the project and the types of road safety interventions proposed by the designers,
- to verify that local conditions still pertain,
- to verify that no additional road safety deficiencies have been overlooked by the designers that may adversely affect the road safety impact of the project,
- to verify that the suggested road safety measures are appropriate and can actually be implemented,
- to verify estimations (e.g. on roadside conditions) and measure geometric characteristics of the sites that are required in crash prediction modeling

Step 4: Accident Prediction Modelling

Objective of the accident (crash) prediction modelling is to estimate the number of accidents, and at a second level that of fatalities and casualties, at the examined hazardous locations, with and without the project. After consideration of several alternative methods, the application of the crash prediction methodology of the AASHTO Highway Safety Manual (3) was applied, calibrated according to actual crash data of the selected sites.

Step 5: Estimation of Road Safety Benefits (non-monetary)

This step completes the Technical Assessment Pillar of the methodology as far as the two selected sub-regions are concerned and provides the input required in step 8 of the Economic Appraisal Pillar for the estimation of benefits in monetary terms and the calculation of the project's economic rate of return. Based on the results of the accident prediction modelling, the expected road safety impact of the project is quantitatively estimated, in terms of reduction in the annual number of injury accidents, fatalities, serious injuries and slight injuries.

Step 6: Definition of Economic Appraisal Parameters

At this stage of the analysis, all the parameters required to calculate the Economic Rate of Return of each scheme as well as the whole project are determined. The period of the economic analysis for the project was 15 years, starting from 2017 as base year and 2032 as a target year.

Step 7: Estimation of schemes cost

The costs of each scheme involve the initial cost of road safety interventions and potentially the annual maintenance cost. The initial cost refers to the implementation of all interventions at each location; labor and material prices are determined by the cost estimation included in the bidding documents. Maintenance costs involve the operation and maintenance of the road at the location of the intervention after the year of initial construction. These costs are increases year-on-year in line with the estimated economic growth.

For the purpose of the economic analysis, increased maintenance costs were considered to account for the maintenance burden of the new interventions. For example, if the suggested interventions included pavement repairs, it was expected that regular maintenance in the future will need to ensure that the pavement is kept in appropriate condition. Generally, postponing road maintenance results in high direct and indirect costs, whereas if road defects are repaired promptly, the cost is usually modest.

Step 8: Estimation of expected benefits (in monetary terms)

Benefits are calculated with a positive sign for each year of the economic life of the project. The main benefits of this economic analysis derive from the reduction of crash related fatalities and injuries. Regarding other socio-economic benefits, only the increase of employment is taken into account, but not included in the estimation of ERR.

Step 9: Estimation of ERR for selected schemes

Applying the cost benefit analysis involves considering alternative cost-benefit scenarios (optimistic and pessimistic forecasts) taking into account the time in which they occur. In order to apply the ERR method, all cash flows should be rolled at $t = 0$. Redeeming requires the use of the market rate. The Net Present Value (NPV) is defined as the difference between the benefits and the costs. Given the fact that the interest rate is a rather precarious prediction of the future for large investments, it is preferable to examine the economic rate of return, for which the net present value is zero.

Step 10: Estimation of ERR for entire Project

For the estimation of the entire project's economic rate of return, the individual costs for each sub-region were considered, along with a preliminary estimation of benefits for the entire project, based on the experience of the pilot case in the two selected sub-regions: Imathia and Viotia.

CASE STUDY DESCRIPTION AND RESULTS

The aforementioned methodology was implemented for the economic assessment of the project in the sub-regions of Imathia, in northern Greece, and Viotia, in central Greece. A total of 116 hazardous locations covering 38.6km of road network were proposed for improvement in Imathia and 111 hazardous locations covering 42.9km of road network in Viotia. Respective countermeasures, as proposed by the designs, included the installation of 20.1km of safety barriers, construction of 560,000m^2 of anti-skid asphalt wearing course and 1,570m^2 of road markings in these two sub-regions.

The road safety treatments most commonly proposed by the respective designs included the following (more than one treatments were to be implemented in the selected sites):

- Construction of road markings (delineation);
- Installation of traffic signs;
- Construction of new asphalt pavement;
- Construction of anti-skid asphalt course;
- Installation of roadside delineator posts;

- Installation of centerline roadway deflectors;
- Installation of transversal rumble strips (for speed reduction at intersection approaches);
- Installation of safety barriers;
- Installation of side roadway deflectors;
- Improvement of roadside conditions (e.g. reconstruction of shoulders, removal of vegetation, removal of roadside obstacles);
- Installation of road lighting;
- Installation of speed limit signage

Data Used in the Pilot Study

In order to perform the economic analysis according to the developed methodology, the following four types of data are required:

1. Road infrastructure data, regarding both road geometry and equipment, on the existing situation as well as the designed countermeasures;
2. Crash data;
3. Traffic volumes;
4. Construction cost estimations

Road infrastructure data were retrieved from the respective intervention design studies for Imathia and Viotia, that included maps and surveys of the hazardous locations, longitudinal profiles of the roads, survey of existing signage, lighting, safety barriers, etc. as well as detailed designs of the interventions.

Regarding crash data, the analysis was based on data collected by the Police and codified into the National Road Accident Database by the Hellenic Statistical Authority (ELSTAT - www.statistics.gr). More specifically, in Greece, Traffic Police officers attend the crash site and complete the road crash data in high detail in standardized templates, i.e. the Accident Data Collection Forms, immediately after the occurrence of a crash, providing information on prevailing conditions, as well as on characteristics related to the road, the involved persons or vehicles. The Accident Data Collection Forms are then forwarded to ELSTAT, which is responsible for the final checking and codification into the official National Road Accident Database. Copy files of the National Road Accident Database are provided to the Department of Transportation Planning and Engineering of the National Technical University of Athens (NTUA) (with personal identification removed), which developed a system of efficient queries to extract any combination of data. This NTUA database consists of disaggregated data for all road injury accidents in Greece for the period 1985-2017, is updated on an annual basis and was used for the purposes of this study. Data for injury crashes of the most recent five years included in the database (2013-2017) were considered in the sub-regions of Imathia and Viotia. Crashes in urban areas and in motorways were excluded and the remaining were allocated to the examined hazardous locations according to the road code and station recorded in the database.

With regards to traffic volumes, it is noted that traffic data are not systematically collected in rural highways in Greece. Therefore, data from local traffic counts were used, wherever available, provided by the respective authorities. In locations where no such data were available, AADT estimated from National Traffic Model for Greece were used, suitably adjusted since this model is of "strategic" nature and the modeling zones are defined at a municipal level; therefore it does not adequately represent mobility inside municipalities. However, strategic model data were very appropriate for the estimation of the average annual AADT change to be taken into account in the analysis: an average annual traffic increase of 1.58% for Imathia and 3.37% for Viotia was thus considered.

Finally, intervention construction costs were retrieved from the bidding documents of the respective intervention projects.

Accident Analysis

Accident data used in the analysis concern only the road sections in Imathia and Viotia for which road safety interventions were suggested. These were assigned to the respective hazardous locations based on the recorded road code and station of the crash. However, it was found that for some crashes included in the database there was no indication of the road on which the accident occurred and/or the specific location (chainage) of the accident. Specifically, in the sub-region of Imathia, out of 103 injury accidents for years 2013-2017, 4 (4%) were missing road code indication and 9 (9%) had road code indication but not a specific location (station) indication. In Viotia, out of 190 injury accidents, 31 (16%) were missing road code indication and 16 (8%) had road code indication but not a specific location (station) indication.

In order to obtain a realistic estimation of the actual number of accidents, two scenarios were assumed, depending on the handling of accidents with unknown location:

- Scenario 1 includes only the accidents for which the recorded road and station match those of the respective hazardous location.
- Scenario 2 includes, in addition to the accidents of Scenario 1, a percentage of accidents with known road (matching the roads for which interventions have been suggested) but unknown station, estimated as follows: for each examined road, the ratio of the length of hazardous locations per total road length was calculated. Then, the number of road accidents which occurred in this road but at unknown station was multiplied by the ratio of lengths and the resulting road accidents were assigned to hazardous locations in proportion to their length.

Another issue for consideration during the accident analysis was underreporting. It is not uncommon for discrepancies to be observed between crash data provided by different data sources. The problem is known as road accident injury under-reporting and is typically identified when comparing Hospital and Road Traffic Police data on road accident injuries. Such comparisons reveal that only a limited proportion of non-fatal hospitalized injuries are recorded by the Police, while even less is known about the reporting of less severe (e.g. non-hospitalized) injuries. Several, mostly regional, studies provide evidence that an appreciable proportion of road accident injuries are not reported at all by the Police, whereas the level of under-reporting may differ among different levels of injury severity or different road user groups.

In Greece, ELSTAT is responsible for collecting injury accident data from Police, double-checking the collected data, updating and keeping the Road Accident Database and finally publishing aggregate statistics. Moreover, in the context of demographic statistics, ELSTAT keeps the Vital Registration Database, with data on time and cause of death provided by hospitals. Comparison of police and hospital data (fatalities also within more than 30 days) shows variation over time and the under-reporting correction coefficient (Hospitals/ ELSTAT) for fatalities has been estimated (4) as 1.15. Concerning the under-reporting for serious and slight injuries, the weighted averages of seven countries' correction coefficients have been calculated at 1.74 and 1.54 respectively (4).

In order to also account for under-reporting, two additional scenarios were defined: in Scenario (a) under-reporting was not considered, whereas in Scenario (b) under-reporting was taken into account according to the aforementioned coefficients. Therefore, four scenarios in total were assumed in the accident analysis:

- Scenario 1a: Only road accidents for which recorded road and station match those of the respective hazardous location are considered, without taking into account under-reporting.
- Scenario 1b: Only road accidents for which recorded road and station match those of the respective hazardous location are considered, taking into account under-reporting.
- Scenario 2a: Accidents for which recorded road and station match those of the respective hazardous location and part of the accidents in the examined road but at unknown station are considered, without taking into account under-reporting.
- Scenario 2b: Accidents for which recorded road and station match those of the respective hazardous location and part of the accidents in the examined road but at unknown station are considered, taking into account under-reporting.

Site Inspections

Site inspections were performed on selected hazardous locations in Viotia and Imathia sub-regions to verify the suggested measures and identify any additional safety features needed. Out of a total of 255 sites, 103 sites were inspected: 61 in the sub-region of Viotia and 42 in the sub-region of Imathia, representative of all site categories: type (HL-P, T or T), national and regional network, roadway sections and intersections, terrain type (level, moderate, steep). Overall, it was verified that locations were appropriate for treatment, that local conditions still pertain in the vast majority of cases and that the proposed countermeasures were appropriate. Specific findings that were considered in the economic assessment were the following:

- In 9 locations it was noticed that a new asphalt course has already been laid, and the pavement damages mentioned in the designs (completed in 2015 at the latest) were no longer evident.
- In 10 locations, the additional installation of EN-1317 barriers was deemed necessary, in accordance to relevant design guidelines.
- The need for a few minor improvements and additions in signage was identified, such as the addition of regulatory signs on access roads and the consistent signing of speed limits in neighboring locations.
- Particularly in Imathia sub-region, 27 sites were located inside urban areas (villages, small towns), in contrast to the project guidelines. These locations were excluded from the economic assessment.

Accident Prediction Modelling

The objective of the accident prediction modeling was to estimate the number of crashes at the examined hazardous locations if the suggested countermeasures are implemented and if not. The procedure was based on the Highway Safety Manual (3) predictive method, providing equations to estimate the expected average accident frequency at a location, as a function of traffic volume and road infrastructure characteristics (e.g. number of lanes, type of median, traffic control). The implementation of the method is described in the following paragraphs.

Segmentation of examined sites and data coding

According to the requirements of the HSM predictive method, the roadway is divided into individual sites that were either homogenous roadway segments or intersections. The elaboration of the identified hazardous locations and suggested interventions in Imathia and Viotia revealed the following issues:

In both sub-regions, certain hazardous locations required splitting. For example, there were sites that included two intersections; these were appropriately split. In other cases, a site referred to a road segment with several horizontal curves, and had to be split to smaller segments, one for each curve. Other hazardous locations were split in order to have uniform characteristics or to eliminate intermediate sections in which no treatments had been suggested.

In Imathia sub-region, the designer has included 13 "fabricated" hazardous locations, one for each examined road axis, with lengths equal to the total length of each road (up to 33.5km). The purpose of this fabrication of locations was to group together various minor interventions (mostly individual signs) to be installed at scattered locations on each road. These 13 "locations" were excluded from the accident prediction modeling, since it can be safely assumed that the impact on accidents will be negligible. Due to the very low construction cost, any impact on the economic rate of return of the project was also expected to be negligible.

Taking into account the above considerations, an extensive data coding worksheet was developed, into which all data required for accident modeling were inserted for each hazardous location. The coding of infrastructure characteristics (before and after the project) for each site was based on the detailed design drawings and documents of the designs, verified during the site inspections and also using Google Earth maps and Street View.

Estimation of the predicted number of accidents for the period 2013-2017

Using the HSM predictive method and taking into account all available data (AADT, geometric characteristics, existing road equipment, etc.) the number of accidents for period 2013-2017 was estimated, separately for each hazardous location. For roadway sections, the Safety Performance Function (SPF) for rural two-lane two-way roadway segments (**Equation 1**) was used:

$$N_{spf} = (AADT) \times (L) \times (365) \times (10^{-6}) \times e^{(-0.312)} \qquad \textbf{(1)}$$

where:

N_{spf} = predicted average crash frequency determined for base conditions using a statistical regression model

AADT = average annual daily traffic volume (vehicles/day) on examined roadway segment

L = length of roadway segment (miles)

Crash Modification Factors (CMF) to account for lane width, shoulder width and type, horizontal curve, superelevation, grades, driveway density, passing lanes, roadside design

(Roadside Hazard Rating) and road lighting were used, according to the HSM. The predicted average crash frequency estimated using this method accounts for all accidents in the examined road sections. In order to exclude property-damage-only accidents, for which there are no reliable data available in Greece and model calibration is not possible, the default HSM distribution for accident severity on rural two-lane roadway segments was used, resulting in a 32.1% of injury crashes.

Regarding intersections, the SPFs shown in **Equation 2** (three-leg intersections with minor-road stop control) and **Equation 3** (four-leg intersections with minor-road stop control) were used, also from (3):

$$N_{spf} = exp\ [-9.86 + 0.79 \times ln(AADT_{maj}) + 0.49 \times ln(AADT_{min})] \quad \textbf{(2)}$$

$$N_{spf} = exp\ [-8.56 + 0.60 \times ln(AADT_{maj}) + 0.61 \times ln(AADT_{min})] \quad \textbf{(3)}$$

where:

N_{spf} = intersection related predicted average crash frequency for base conditions;
$AADT_{maj}$ = average annual daily traffic volume (vehicles/day) on the major road;
$AADT_{min}$ = average annual daily traffic volume (vehicles/day) on the minor road.

No suitable SPF for intersections with no traffic control was identified in existing literature; four such intersections were included in the examined hazardous locations and they were treated as intersections with STOP control.

Crash Modification Factors (CMF) to account for Intersection Skew Angle, Left- and Right Turn Lanes and lighting were used. The predicted average crash frequency estimated using this method accounts for all accidents in the examined intersections. In order to exclude property-damage-only accidents, for which there are no reliable data available in Greece and model calibration is not possible, the default HSM distribution for accident severity on rural two-lane intersections was used, resulting in a 34.0% of injury accidents.

Model calibration using historic crash data

After estimation of the predicted number of accidents for each one of the hazardous locations, the actual (observed) total number of accidents in all hazardous locations for each sub-region (period 2013 to 2017) was used as a comparison and a calibration ratio for each sub- region was estimated as the ratio of the sum of police recorded accidents to the sum of predicted accidents. This calibration ratio is different from the Calibration Factor (C) suggested in the Highway Safety Manual, in the sense that HSM's calibration factor refers to sites with base conditions in order to calibrate the Safety Performance Function (SPF) itself prior to consideration of specific CMFs. Using the exact HSM procedure would require having a large number of other regular sites (not hazardous locations) with characteristics close to "base conditions". Such data were not available and thus the aforementioned alternative approach was followed, which was considered adequately reliable and fully appropriate for the scope of the project.

Accident prediction without the project

After calibration of the model for Imathia and Viotia, the predicted number of accidents without the project ("Business-As-Usual" scenario) at each hazardous location for each year between 2017 (base year) and 2032 (target year) was estimated. This estimation was performed by re-application of the calibrated models for each site with consideration of an annual AADT increase as well as an overall trend of crash numbers reduction in developed countries.

Regarding traffic volumes, revised AADT estimations for each site were used, taking into account the expected annual increase in traffic volumes, according to the estimations of the National Traffic Model for Greece: 1.58% annually for Imathia and 3.37% for Viotia. Furthermore, it is commonly acknowledged that even if no infrastructure road safety interventions are implemented, road safety figures improve over the years due to several factors: improvement of vehicle safety features, increased enforcement of traffic regulations, change of drivers' attitude towards road safety, etc. In order to estimate this trend, the UNECE SafeFITS tool (5), (6) was used, which is capable of forecasting the trend for the fatalities per population in a country (with or without interventions) through the years, alongside with the confidence intervals. Assuming that the accidents trend is equal to the fatalities trend, a 17% reduction in the number of accidents in Greece is expected, between the base and target year, regardless of infrastructure improvements. Therefore, an equivalent average annual reduction rate of -1.03% was assumed in the economic assessment.

Taking the above considerations into account, the predicted number of accidents without the project ("Business-As-Usual" scenario) at each hazardous location was estimated for each year between base year 2017 and target year 2032.

Accident prediction with the project

The estimation of the impact of the suggested interventions to the number of accidents involves the application of the calibrated models at each hazardous location for each year between 2017 (base year) and 2032 (target year), assuming full implementation of the road safety schemes as designed.

Estimated AADT changes over the years and the expected nationwide annual reduction in the number of accidents are still taken into consideration, as described in the "Business-As-Usual" scenario. The impact of suggested interventions is captured through the use of appropriate additional Crash Modification Factors (CMFs), either from HSM or from international literature (**Table 1**), to account for the effect of the suggested road safety improvements according to the designs.

TABLE 1 Crash Modification Factors used

Topic	Source	Value / Range of values
Roadway segments:		
Lane width	(3) - Part C	1.000 - 1.172
Shoulder width and type	(3) - Part C	0.987 - 1.287
Horizontal curvature	(3) - Part C	as in "Business As Usual" scenario
Superelevation	(3) - Part C	as in "Business As Usual" scenario
Grade	(3) - Part C	as in "Business As Usual" scenario

Topic	Source	Value / Range of values
Driveway Density	(3) - Part C	as in "Business As Usual" scenario
Installation of centerline rumble strips	(3) - Part C	0.94
Passing lane	(3) - Part C	0.75
Road lighting	(3) - Part C	0.841 - 0.857 (calculated according to recorded night crash rates in each sub-region)
Improvement of vertical signage (including posting of speed limit)	(3) - Part D	0.87
Anti-skid asphalt wearing course	(7)	0.99 (national roads), 0.98 (regional roads)
Roadside improvements	(8)	exp(0.185*RHS), where RHS=change in Roadside Hazard Rating
Installation of EN-1317 compliant road safety barriers	(9)	0.78
Improvement - rehabilitation of road markings	(3) - Part D	0.94
Installation of roadside delineator posts	(10)	0.98 (calculated according to ratio of roadway departure crashes)
Installation of transverse rumble strips (as a measure for speed reduction)	(11)	0.66
Intersections:		
Skew angle	(3) - Part C	as in "Business As Usual" scenario
Left-turn lane	(3) - Part C	as in "Business As Usual" scenario
Right turn lane	(3) - Part C	as in "Business As Usual" scenario
Road lighting	(3) - Part C	0.892 - 0.919 (calculated according to recorded night crash rates in each sub-region)
Removal of sight obstructions	(12)	0.95
Anti-skid asphalt wearing course	(13)	0.94 - 0.98 (depending on number of intersection legs and ratio of crashes in wet conditions)

Estimation of Road Safety Benefits

For the estimation of the benefits of the suggested road safety schemes, the predicted number of accidents for Viotia and Imathia assuming project implementation is compared to the predicted number of accidents if the project is not implemented ("Business-As-Usual") and accident reductions per year are estimated.

In order to estimate the number of fatalities, serious and slight injuries saved by implementation of the schemes, the following severity indices were used, based on 2008-2017 data for the rural road network of Greece (not including motorways):

- number of fatalities per 100 crashes: 22.01
- number of seriously injured per 100 crashes: 20.76
- number of slightly injured per 100 crashes: 122.14

In **Table 2**, the expected road safety benefits of the project, for the 2017-2032 time period under consideration are summarized.

TABLE 2 Estimated road safety benefits from project implementation

	Viotia sub-region				Imathia sub-region			
Reduction in:	**Scenario 1a**	**Scenario 1b**	**Scenario 2a**	**Scenario 2b**	**Scenario 1a**	**Scenario 1b**	**Scenario 2a**	**Scenario 2b**
Fatalities	10	12	11	13	9	10	9	11
Seriously injured	10	17	10	18	8	14	9	15
Slightly injured	58	89	62	95	48	74	51	79

Economic Appraisal

For the economic appraisal (Pillar 2 of the methodology), a reference interest rate of 5% was assumed. Regarding the service life of countermeasures, according to relevant international literature (14, 15), the life of road safety treatments similar to the ones suggested in the designs ranges from approximately 5 to 20 years. An average service life of 15 years was considered a reasonable assumption.

Costs for the project include initial construction costs and maintenance costs. The first was retrieved from the bidding documents prepared within the project designs, whereas the latter was estimated as 0.5% of the construction costs annually for the first five years, 2.5% for the next five years and 4.5% for the last five years of the assessment period.

In order to express road safety benefits in monetary terms, the estimations of a relevant study in Greece applying a willingness-to-pay methodology were used. According to Kourtis et al. (16), death is estimated at 2,148,034.20€, serious injury at 273,574.25€ and slight injury at 51,372.70€. These estimations are compatible to similar research in Europe (17, 18), according to which in 31 European countries the valuation of human life loss in a road crash ranges from 0,7M€ to 3.0M€, with Greece in the 9th place with an approximate valuation of 2M€.

The economic rate of return for the project is defined (19) as "*the interest rate at which the project's discounted benefits equal discounted costs*"; a project is considered economically viable and is accepted if the ERR exceeds a minimum threshold. The results of the estimation of the ERR for each examined sub-region, along with a preliminary estimation of the ERR for the whole project in Greece (based on the weighted average reduction of fatalities and casualties in Viotia and Imathia and the actual number of fatalities and casualties in each other sub-region) is presented in **Table 3**.

TABLE 3 ERR estimation Results

Scenario	Viotia	Imathia	Estimation for the whole Project in Greece
Scenario 1a	19.5%	11.6%	11.2%
Scenario 1b	25.2%	16.6%	16.7%
Scenario 2a	21.1%	13.1%	12.6%
Scenario 2b (proposed)	27.1%	18.2%	18.2%

DISCUSSION AND CONCLUSIONS

On the basis of the above analysis and the experience from the case study in Imathia and Viotia sub-regions, the following aspects are worth noticing.

In **Table 3**, a considerable difference between the ERRs in Viotia and Imathia is evident. In both sub-regions, the estimated reduction of accidents in the examined locations attributed to the road safety schemes was similar: 38.5% in Imathia and 41.0% in Viotia. However, in Viotia approximately 7.3M€ are to be spent for the treatment of 39.3Km of hazardous locations, resulting in 0.19M€ per Km, whereas in Imathia 9.1M€ are to be spent for 27.5Km (for locations outside built-up areas), resulting in 0.33M€ per Km. Also, the examined road network of Viotia has higher traffic volumes and a higher estimated annual increase of AADT according to the data from the National Traffic Model and therefore more road users are expected to benefit from the road safety interventions. All these factors contribute to the increased ERR for the Viotia road safety scheme.

The results of the economic analysis are not particularly sensitive to changes in the input data and assumptions. This is evident in **Table 3**: Scenarios 1b and 2a and particularly Scenario 1a constitute extreme variations from the suggested Scenario 2b, yet the project in all cases is considered economically viable.

Finally, it can be concluded that, in accordance to relevant international experience, road infrastructure safety investments and especially low cost measures suitable for rapid implementation are characterized by a very high economic rate of return, i.e. are very cost-effective. This can be attributed to the combination of the low implementation and maintenance costs with the high valuation of their benefit (e.g. 2.15M€ for every fatality saved). An additional factor is that measures are targeted specifically to locations that exhibit serious safety deficiencies and therefore have a significant impact on crash numbers.

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AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: G. Yannis, A. Dragomanovits; data collection: A. Dragomanovits, D. Nikolaou; analysis and interpretation of results: G. Yannis, A. Dragomanovits, J. Roussou; draft manuscript preparation: A. Dragomanovits. All authors reviewed the results and approved the final version of the manuscript.

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