Development and implementation of a methodology for the economic appraisal of road infrastructure safety schemes

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Word Count: 6,748 words + 0 figures (above 6) + 3 tables = 7,063 + 3*250 = 7,498 words (pages 1 & 2 not counted)

Submitted on October 20th, 2019

ABSTRACT

The economic appraisal of transport projects is a vital component of decision making in road infrastructure investments. The economic appraisal of road safety schemes however is not common practice; aspects such as the estimation of the expected reduction in crashes and casualties, as well as the monetary valuation of human life and injury must be addressed in order to produce reliable results. The paper presents a methodology for the economic appraisal of road safety schemes on two-lane rural road sections and intersections in Greece. The methodology combines two approaches in road safety, namely reactive and proactive engineering in a holistic method to estimate the benefits of road safety schemes. According to the reactive approach, Accident Prediction Models, based on the AASHTO Highway Safety Manual are used, calibrated for Greece using local crash and traffic data, to estimate the expected crash, fatalities and casualties reduction if the suggested interventions are fully implemented. Road Safety Inspections (proactive road safety engineering) are also used to identify road safety deficiencies and assist in addressing them even before accidents occur. Results of both approaches are combined and the expected road safety benefits are translated into monetary terms; finally, considering relevant costs, the project's economic rate of return is estimated. A pilot implementation of the methodology was performed for the economic appraisal of suggested low cost interventions in two sub-regions of Greece. The economic assessment concluded that a very high economic rate of return can be expected in both sub-regions.

Keywords: Road Safety, Crash Prediction Models, Infrastructure Countermeasures, Economic Analysis

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 project was designed during the period 2012-2015 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 a technical and visual review of 15,000km of 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. 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.

The paper is structured as follows: the first section presents the development of the methodological approach for the economic assessment, along with a presentation of alternative approaches considered in the process. The second section of the paper focuses on the pilot implementation of the methodology for the assessment of proposed infrastructure countermeasures in two sub-regions of Greece, followed by the conclusions of the study.

DEVELOPMENT OF METHODOLOGY

The methodological approach includes two main parts: technical assessment of the proposed countermeasures, leading to the estimation of the resulting reduction in terms of accident numbers, fatalities and injuries, and economic appraisal estimating costs and benefits in monetary terms and calculate the project's Economic Rate of Return (ERR). The economic appraisal is largely described in cost-benefit assessment manuals of the EIB (3) and the EC (4). However, no specific methodology for estimating the safety benefits of infrastructure countermeasures is systematically applied, either in Greece or in Europe. Therefore, four alternative approaches were considered, based on accident prediction methods available in international literature, and also taking into consideration data availability. All methods require as input data the road geometry and road equipment information, traffic volumes and historical crash data (for model calibration); yet the level of accuracy required differs.

Alternative Approaches Considered

iRAP software (ViDA)

Within the International Road Assessment Programme (iRAP) an online software tool (ViDA) has been developed that can be used to estimate Star Rating Scores (SRS) for road sections. The SRS represents the relative risk of death and serious injury for an individual road user (5). Fatalities and serious injuries can then be derived from SRS according to a procedure determined by iRAP in (6), requiring the knowledge of traffic volumes per user category and calibration based on historical accident data. The iRAP methodology is generally well accepted in Europe and a demonstrator version of the software is freely available online. The use of the software at its full potential is also free, subject however to approval by iRAP organization. Also, all results of the analysis must be fully disseminated to iRAP and will be open to public view. However, there is a considerable shortcoming in using iRAP software in the context of this study: the statistical/ mathematical background of the software is not known and cannot be assessed. ViDA software exhibits a "black box" type of operation and iRAP has not published the scientific background of the prediction models. Therefore, the results, in terms of expected accident frequency at the examined hazardous locations, cannot be assessed, cannot be easily calibrated for Greece and potential modelling errors may remain unnoticed and uncontrolled.

Highway Safety Manual Predictive Method

The AASHTO Highway Safety Manual (7) provides a predictive method for estimating the expected average crash frequency (by total crashes, crash severity or collision type) of a network, facility or individual site. In the predictive method, the roadway is divided into individual sites that are either homogenous roadway segments or intersections, and the estimate for each site, based on traffic volume and geometric design characteristics of the roadway, can refer to the existing conditions, alternative conditions or proposed new roadways.

The estimate relies upon regression models developed from observed crash data for a number of individual sites. Different regression models, called base Safety Performance Functions (SPFs) have been developed for specific facility types and "base conditions", that are the specific geometric design and traffic control features of a "base" site. SPFs in the HSM have been developed through statistical multiple regression techniques using historic crash data collected over a number of years at sites with similar characteristics and covering a wide range of AADTs.

SPFs are typically a function of only a few variables, primarily average annual daily traffic (AADT) volumes and segment length. Adjustment to the prediction made by an SPF is required to account for geometric design or traffic control features differences between the base conditions of the model and local conditions of the site under consideration. For this, Crash Modification Factors (CMFs) are used, defined as the ratio of the crash frequency of a site under two different conditions and they represent the relative change in crash frequency due to a change in one specific condition (when all other conditions and site characteristics remain constant). CMFs can therefore provide an estimate of the effect of a particular geometric design or traffic control feature or of the effectiveness of a particular treatment or condition. Finally, a Calibration Factor (C) is used to account for differences between the road network for which the models were developed and the one for which the predictive method is applied.

Interactive Highway Safety Design Module (IHSDM)

FHWA has released a software package with the name of Interactive Highway Safety Design Module (IHSDM) that uses road geometry and equipment along with traffic volumes as input and estimates expected crash rates. The software is fully available, free of charge and licensing restrictions and is able to produce crash prediction results on both road sections and intersections, by application of the aforementioned HSM predictive method.

A drawback on using IHSDM software for the study is that the required input data are very detailed, while not fully available in the examined hazardous locations, and data entering procedures are cumbersome.

PRACT Research Project Tool

The PRACT research project (http://www.practproject.eu/) aimed at developing a European accident prediction model structure that could be applied to different European road networks with proper calibration (8; 9; 10; 11; 12).

The developed model builds on the HSM predictive method, providing procedures to adapt APMs and CMFs to local conditions based on locally available crash, geometric and traffic data and producing a guidance document and a computer based tool allowing the user to calibrate models based on local accident data, calculate the predicted crash frequency and calculate the expected accident frequency by means of an Empirical-Bayes evaluation.

The tool can only be applied for accident prediction on freeway sections and two-lane rural road sections (not intersections); therefore its usefulness for the study is limited, since approximately one third of the examined hazardous locations are intersections.

Finally, within the PRACT project, an online repository of the most recent Accident Prediction Models (APMs) and Crash Modification Factors (CMFs) was also developed (https://www.pract-repository.eu/). The repository was based on an extensive review of pertinent international literature, focusing on high quality studies, and emphasis was placed on providing the end user with all the available background information on the APM or CMF development, in order to assist in the assessment of the quality and suitability of the provided data. Furthermore, as far as CMFs are concerned, a set of inclusion criteria were applied to ensure that specific minimum quality standards are fulfilled.

Overview of Methodological Approach

After consideration of the strengths and weaknesses of the aforementioned methods in relation to data availability for the project and local conditions, it was decided that the most appropriate accident prediction method is the application of the HSM predictive method, suitably adjusted for the needs of the preliminary economic analysis. For the identification of additional relevant CMFs required for estimating the impact of various road safety improvements, the PRACT repository would be exploited.

The final 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).

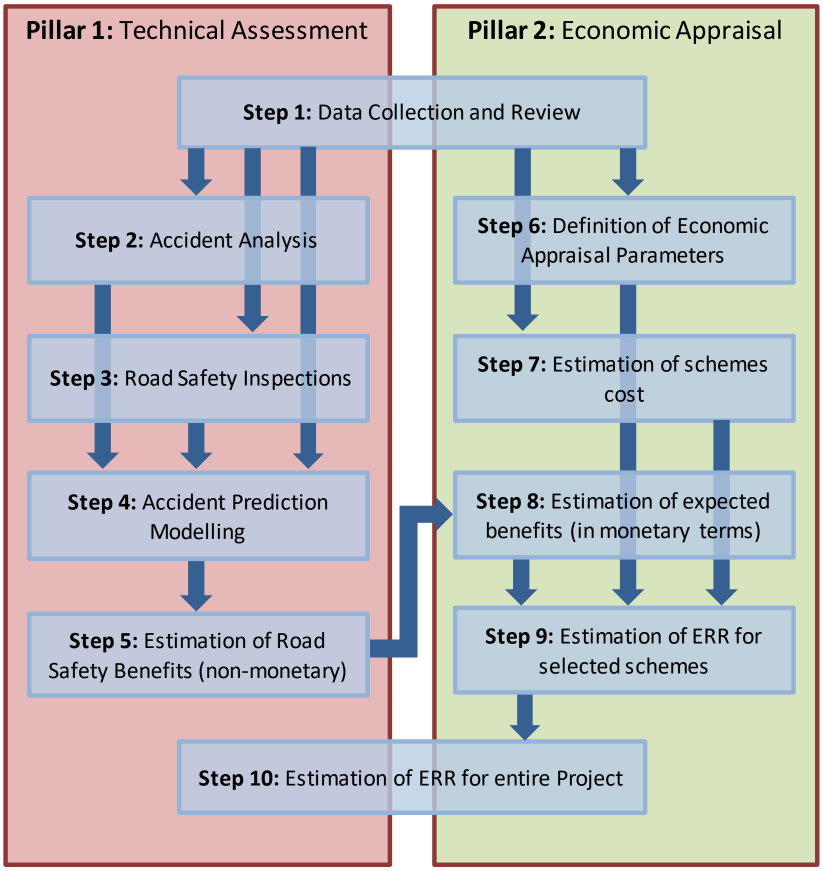

Figure 1: Methodological approach

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. Proactive engineering (Step 3: Road Safety Inspections) is also applied to identify 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 safety benefits (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 available data.

Step 2: Accident Analysis

The second step of the methodology involves the analysis of recent crash data. Accidents in urban areas and accidents in motorways are excluded (in accordance to project specifications) 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 site visits with the aims of:

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

Step 4: Accident Prediction Modelling

Objective of the accident prediction modelling is to estimate the number of accidents at the examined hazardous locations, with and without the project. As previously mentioned, the HSM crash prediction methodology was implemented, calibrated according to actual crash data of the selected sites.

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

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 ERR 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.

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

The main benefits of this economic analysis derive from the reduction of crash related fatalities and injuries. Regarding other socio-economic benefits, the increase of employment was considered, but not included in the estimation of ERR.

Step 9: Estimation of ERR for selected schemes

In order to apply the ERR method, all cash flows are taken into account the time they occur, and 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 extrapolation of the results of the pilot case in the two examined sub-regions.

PILOT IMPLEMENTATION OF METHODOLOGY

Interventions Overview

The methodology was implemented for the economic assessment of interventions located 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. The road safety treatments most commonly proposed by the designers included:

- 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, relocation of obstacles);
- Installation of road lighting;
- Installation of speed limit signage.

Data and Data Sources

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). Copy files of the National Road Accident Database (with personal identification removed) are regularly provided by ELSTAT to the Department of Transportation Planning and Engineering of the National Technical University of Athens (NTUA), 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 study. Crashes in urban areas and motorways were excluded and the remaining were allocated to the examined hazardous locations according to the road code and station recorded in the database.

As traffic data are not systematically collected in rural highways in Greece, 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 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 considered during the accident analysis was under-reporting. It is common 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. 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 (13).

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 pertained 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.

Implementation of Accident Prediction Modelling

Segmentation of examined sites and data coding

According to the requirements of the HSM predictive method, the roadway was divided into individual sites that were either homogenous roadway segments or intersections. 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, and verified initially using Google Earth maps and Street View and ultimately during the site inspections.

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 was applied, taking into account Crash Modification Factors (CMFs) 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, according to the HSM (7). 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 (percentage of injury crashes: 32.1%)..

Regarding intersections, the SPFs for three-leg intersections with minor-road stop control and for four-leg intersections with minor-road stop control were used, also from (3\7). 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 (14), (15) 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	(7) - Part C	1.000 - 1.172
Shoulder width and type	(7) - Part C	0.987 - 1.287
Horizontal curvature	(7) - Part C	as in "Business As Usual" scenario
Superelevation	(7) - Part C	as in "Business As Usual" scenario
Grade	(7) - Part C	as in "Business As Usual" scenario
Driveway Density	(7) - Part C	as in "Business As Usual" scenario
Installation of centerline rumble strips	(7) - Part C	0.94
Passing lane	(7) - Part C	0.75
Road lighting	(7) - 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)	(7) - Part D	0.87
Anti-skid asphalt wearing course	(16)	0.99 (national roads), 0.98 (regional roads)
Roadside improvements	(17)	exp(0.185*RHS), where RHS=change in Roadside Hazard Rating
Installation of EN-1317 compliant road safety barriers	(18)	0.78
Improvement - rehabilitation of road markings	(7) - Part D	0.94
Installation of roadside delineator posts	(19)	0.98 (calculated according to ratio of roadway departure crashes)
Installation of transverse rumble strips (as a measure for speed reduction)	(20)	0.66
Intersections:		
Skew angle	(7) - Part C	as in "Business As Usual" scenario
Left-turn lane	(7) - Part C	as in "Business As Usual" scenario
Right turn lane	(7) - Part C	as in "Business As Usual" scenario
Road lighting	(7) - Part C	0.892 - 0.919 (calculated according to recorded night crash rates in each sub-region)
Removal of sight obstructions	(21)	0.95
Anti-skid asphalt wearing course	(22)	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. Numbers in parentheses do not include the aforementioned adjustment for under-reporting.

TABLE 2 Estimated road safety benefits from project implementation

	Viotia sub-region		**Imathia sub-region**	
	Scenario 1	**Scenario 2**	**Scenario 1**	**Scenario 2**
Reported accidents 2013-2017 (average per year)	(6,00)	(6,40)	(8,80)	(9,20)
Predicted accidents without project (final year)	(6,40)	(6,83)	(9,25)	(9,66)
Predicted accidents with project (final year)	(4,42)	(4,71)	(5,67)	(5,89)
Reduction in fatalities (total 2017-2032)	12 (10)	13 (11)	10 (9)	11 (9)
Reduction in seriously injured (total 2017-2032)	17 (10)	18 (10)	14 (8)	15 (9)
Reduction in slightly injured (total 2017-2032)	89 (58)	95 (62)	74 (48)	79 (51)

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 (23, 24), 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. (25), 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 (26, 27), 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 (3) 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 ERR estimation for the whole project (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) are presented in **Table 3**. Numbers in parentheses do not include the aforementioned adjustment for under-reporting.

TABLE 3 ERR estimation Results

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

The results indicate a noticeable difference between ERRs in Viotia and Imathia, although the estimated reduction of accidents 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, 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 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.

CONCLUSIONS

On the basis of the pilot implementation it is concluded that the developed methodology is suitable for the economic assessment of road infrastructure safety improvements, and can provide reasonable results even in cases where input data is limited. This is because the results of the economic analysis are not particularly sensitive to changes in the input data and assumptions. This is evident in Table 3: the scenarios examined (including consideration or not of under-reporting) constitute extreme variations, yet the project in all cases is considered economically viable.

A further conclusion is that, in accordance to relevant international experience, road infrastructure safety investments and especially low cost measures 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.

ACKNOWLEDGMENTS

The project was commissioned and funded by the European Investment Bank (Task Assignment TA201866 GR HUB). The authors would like to extend their gratitude to: Gioti Helen, Kargakos Konstantinos, Mathiasen Per and Makoriwa Collins (European Investment Bank), as well as to Saridaki Kiriaki and Maravas Alexandros (Egnatia Odos SA), for their valuable assistance and useful remarks throughout the duration of the project.

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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