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A systematic review of road safety investment appraisal models

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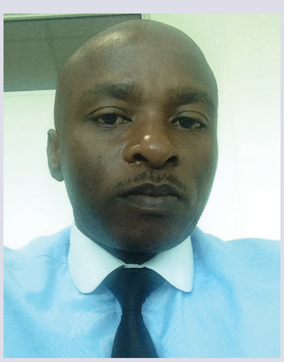
Abstract: It is estimated that 1.35 million people die annually due to road traffic crashes and these crashes cost most countries 3–5% of their gross domestic product (GDP). The economic appraisal of roads considers safety aspects to some extent, but a more explicit approach could add significant value. Therefore, in an attempt to develop a safety-focused model based on the life cycle of measures, this review examines the available models with the view of documenting the current knowledge and its gaps. The review followed the procedures and guidelines developed at the Evidence for Policy and Practice Information and Co-ordinating Centre (EPPI-Centre) together with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The searching and screening process resulted in 12 studies that documented and described the guidelines and methodological framework for SafetyAnalyst, Economic Efficiency Evaluation (E^3), the Benefit Cost Analysis (BCA) and the International Road Assessment Programme (iRAP) road safety models. There are no standardized methods for combining life cycle costs of road safety countermeasures during appraisal, and all approaches ignore end of infrastructure life costs. There is neither uniformity nor universally accepted standards to estimate crash or casualty unit costs and the life cycle performance of road safety countermeasures.



Chris Bic Byaruhanga

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Chris Bic Byaruhanga is a Doctoral Researcher in the Department of Civil Engineering, University of Birmingham, UK. He received his MSc (Eng) in Transport Planning and Engineering from the University of Leeds, UK, in 2012 and further trained in Infrastructure, Development and Finance from the Transport Studies Unit, University of Oxford, UK, and Road Safety from Delft University of Technology, the Netherlands in 2018. His areas of interest are road safety, transport infrastructure planning and policy. Harry Evdorides is a Lecturer and a Module Lead for Road Safety in the Department of Civil Engineering, University of Birmingham, UK. He obtained a Dipl. Ing. in Civil Engineering from the Aristotle University of Thessaloniki, Greece. He joined the Highways Group in 1990 as a research student and thereafter obtained his PhD (Civil Engineering) in 1994. His areas of interest are road safety, highway asset management and engineering.

PUBLIC INTEREST STATEMENT

Road safety is a major challenge worldwide with an estimated 1.35 million fatalities annually and these traffic crashes cost most countries 3–5% of their Gross Domestic Product (GDP). Road traffic crashes are largely preventable with a comprehensive package of cost-effective measures introduced through improved business cases. The need to scale up road safety investment to reduce the high social costs requires a model that can compute accurately the economic benefits of countermeasures. However, there is still a debate regarding the most accurate approach to determine crash costs, benefit from multiple treatments and costs of countermeasures. This systematic review identified and compared some of the models used with a view of documenting the current knowledge and gaps. The findings demonstrate lack of standardisation and uniformity in the approaches used. Therefore, enhancing the existing models or developing an advanced model to compute accurately the costs and benefits of countermeasures over their life cycle is required.

Subjects: Transport & Vehicle Engineering; Transportation Engineering; Engineering Economics

Keywords: Model; countermeasure; economic analysis; road safety; systematic review

1. Introduction

It is estimated that 1.35 million people die annually due to road traffic crashes ([WHO] World Health Organisation, 2018) that costs most countries 3–5% of their gross domestic product (GDP). In most cases, there are limited resources and budgets for implementing road safety countermeasures ([PIARC] Permanent International Association of Road Congresses, 2019). Therefore, a systematic process supporting safety infrastructure investment across the road network to produce the optimum safety benefit for the cost is urgent.

However, there has been considerable debate regarding the most accurate approach to determine crash costs, benefit from multiple treatments and costs of countermeasures ([PIARC] Permanent International Association of Road Congresses, 2019). Road traffic crashes are largely preventable provided that a comprehensive package of cost-effective measures are included in the planning, design and operation of the road network. To present improved business cases to scale up road safety investment and to reduce the high socio-economic price paid by society, an advanced model capable of calculating costs and benefits of road safety countermeasures over their life cycle is required.

The economic appraisal of roads is well-documented and supported by a number of models such as the Highway Development Management (HDM-4) model (Morosiuk & Kerali, 2001) developed by the World Bank where road safety aspects are to some extent considered. However, a more explicit approach could add significant value. Therefore, in an attempt to develop a safety-focused model based on the life cycle of countermeasures, a systematic literature review presented in this paper examined the available road safety investment appraisal models with the view to compare and contrast them and ultimately demonstrate the lack of standardization and uniformity in the approach used. This paper describes the results of the review and discusses the structure and principles of the identified models and the methods used to define the life cycle of road safety countermeasures.

2. Methods

2.1. Systematic review

A systematic literature review is an examination of the available evidence in a particular area of study based on a clearly formulated question and using a methodical approach to identify, select, critically appraise all the relevant studies, and synthesize the findings. The following questions guided this review: (i) what road safety investment appraisal models are available and used as decision support systems? (ii) What is the structure and principle of these models? (iii) What are the methods used to define the life cycle of road safety countermeasures? The procedures and guidelines developed by Gough et al. (2017) at the Evidence for Policy and Practice Information and Co-ordinating Centre (EPPI-Centre), a research unit at the Institute of Education, University College London, United Kingdom (UK), and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al., 2009) were used in this review. The EPPI—Reviewer 4 tool (Thomas et al., 2010)—performed a number of tasks such as storing retrieved studies, screening and data extraction.

2.2. Search strategy

Twenty-two electronic bibliographic databases and 17 organization websites (Appendix A), search engines such as google, google scholar, etc. were searched using search terms (Appendix B) and search operators (phrase searching, truncation, brackets and adjacency or proximity). Boolean operators (AND/OR) were also used to combine the keyword searches. The snowballing technique using the reference lists of relevant studies also leads to other studies in this review. Finally, some key road safety professionals also shared some information regarding documentation and appropriate source of data.

2.3. Inclusion and exclusion criteria

Published, grey literature and studies in any country relating to the different concepts of the review questions in English language irrespective of the date of study and publication were included. Studies excluded in this review were those in other languages and those not related to road safety investment models or tools, investment appraisal and economic evaluation of road safety measures/countermeasures.

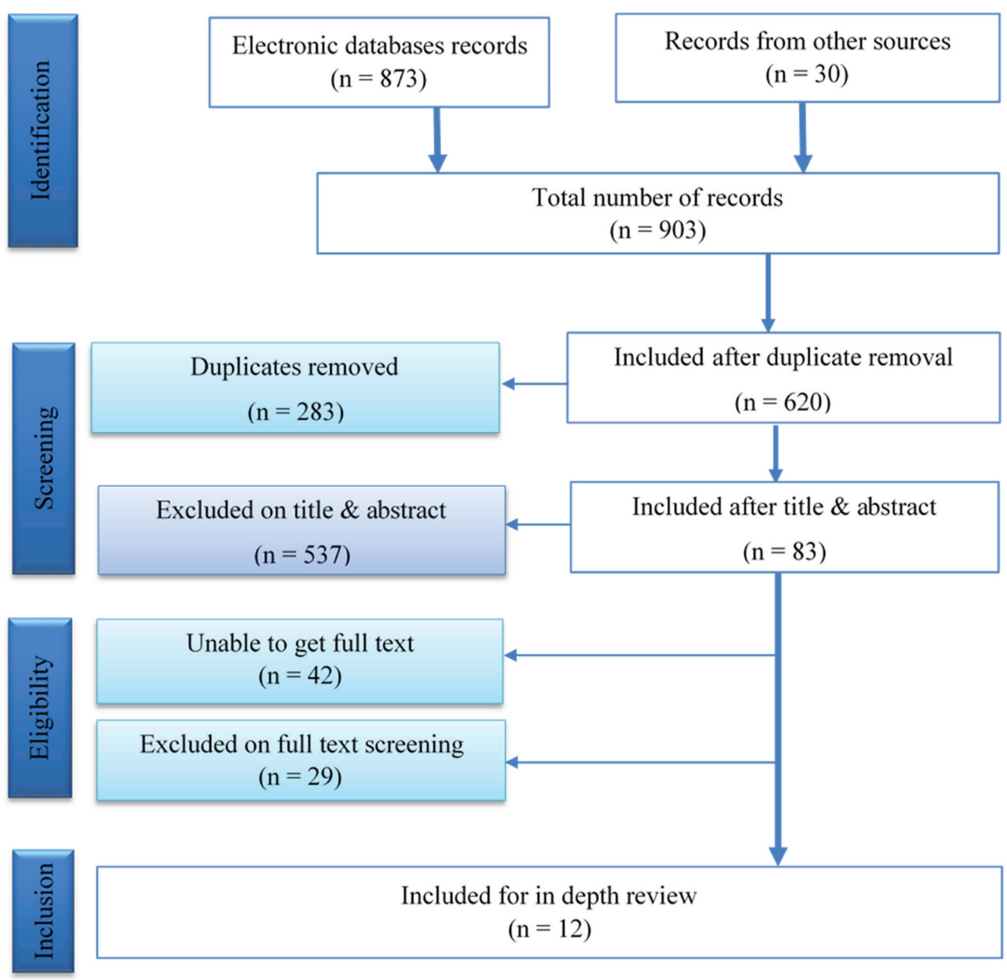
2.4. Synthesis

Ultimately, the data extracted from the included studies using the EPPI—Reviewer 4 software tools were organized and interpreted to answer the review questions, an approach referred to as configurative synthesis (Gough et al., 2017).

3. Results

The ultimate aim was to find longitudinal studies indicating the popularity of such models in road management systems used by the road industry. Searching resulted in 903 records (Figure 1) being uploaded into the review software. The results of the screening process as per the PRISMA guide

Figure 1. PRISMA flow chart for screening of studies.



(Moher et al., 2009) shown in Figure 1 resulted in 12 records meeting the inclusion criteria and thus considered for in-depth review. Of these 12 records, 2 records ([AASHTO] American Association of State Highway and Transportation Officials, 2020; Harwood et al., 2010) documented the SafetyAnalyst model and 4 records (Martensen et al., 2018; Martensen & Lassarre, 2017; Martensen et al., 2016; Van Den Berghe et al., 2017) described the guidelines and methodological framework for the Economic Efficiency Evaluation (E^3) model. The other 4 records ([iRAP] International Road Assessment Programme, 2013, 2015a, 2015b; McMahon & Dahdah, 2008) described the International Road Assessment Programme (iRAP) model and 2 records [FHWA] Federal Highway Administration, 2019; Lawrence et al., 2018) documented the Benefit Cost Analysis (BCA) model.

3.1. Question 1: Available road safety investment appraisal models

3.1.1. SafetyAnalyst model

SafetyAnalyst is a set of computerized analytical tools comprising network screening, diagnosis and countermeasure selection, economic appraisal and priority ranking, countermeasure selection and systemic site selection. The tool developed for the FHWA aids state and local highway agencies in the United States (US) in safety improvements (Harwood et al., 2010). The software is available for licensing by the AASHTO.

3.1.2. E^3 model

E^3 is a European Union (EU) standard model included in the Safety CaUsation, Benefits and Efficiency (SafetyCube) decision support system developed with funding from the European Commission under the Horizon 2020 research framework programme with support from 17 partners from 12 EU countries. The model performs economic evaluation of single measures related to infrastructure, vehicle and human behaviour and not programs of several countermeasures (Martensen et al., 2018).

3.1.3. BCA model

BCA is a model developed to support state and local highway agencies in the US to implement procedures described and documented in the Highway Safety Benefit Cost Analysis Guide developed by the FHWA Office of Safety. The model conducts simple economic analysis of infrastructure projects by quantifying costs as well as the direct and indirect safety-related benefits of project alternatives ([FHWA] Federal Highway Administration, 2019).

3.1.4. iRAP model

The iRAP model tackles challenging social and economic costs of road crashes. Risk maps, star ratings, safer roads investment plans (SRIP) and performance tracking are the four main protocols used in iRAP to assess and improve safety of roads. The iRAP performs economic analysis of single or multiple countermeasures during the preparation of SRIP ([iRAP] International Road Assessment Programme, 2015a). iRAP has conducted programmes in over 100 countries across Europe, Asia Pacific, North, Central and South America and Africa.

3.2. Question 2: Structure and principle of the models

The following criteria (Robinson, 2008) that distinguish modern road management systems were the basis in examining the constituent components of these models as summarized in Figure 2:

(1) Road network sectioning
(2) Intervention level
(3) Countermeasure options that may be considered
(4) Complexity of economic analysis and
(5) Countermeasures' prioritization method.

3.2.1. Road network sectioning
SafetyAnalyst divides the road network into road segments of variable lengths, ramps and intersections unlike iRAP that divides the road network into 100-metre road segments. The other two models (E^3 and BCA) appear not to consider such road management concepts.

3.2.2. Intervention level
SafetyAnalyst uses a crash-based approach whereby the crash frequencies are estimated using safety performance functions (SPFs). SPFs predict crash frequencies for all crash severity levels combined—i.e. fatal and all injury (FI) crashes—as a function of the annual average daily traffic (AADT). In contrast, iRAP uses a systemic approach whereby existing road attributes for every 100-metre segment are the basis for any intervention.

3.2.3. Countermeasure options
SafetyAnalyst provides for selection of a possible array of countermeasures based on the safety problem, crash summary statistics, collision diagrams, statistical crash frequency tests and analyst's knowledge. Similarly, iRAP considers multiple countermeasures for 100-metre segments of road based on a star rating system and road attributes. However, in iRAP, each countermeasure must generate a benefit cost ratio (BCR) exceeding a set threshold by the analyst and thus, the number of deaths and serious injuries prevented by each countermeasure are required in this process. The E^3 model analyzes single road safety measures, while the BCA model analyses a maximum of two countermeasures.

3.2.4. Complexity of economic analysis
Figure 2 shows the summary of the basis of the economic analysis conducted by these models. Fatal, serious injury, slight injury and property damage only (PDO) are the severity levels considered in the E^3 model. However, in SafetyAnalyst and BCA models, an additional severity level of possible injury is considered. The iRAP model analyzes only two severity levels (fatal and serious injury).

3.2.5. Countermeasures' prioritization methods
All the models use cost benefit and cost-effectiveness analyses except BCA that uses cost-benefit analysis only. In cost-benefit analysis, the costs of countermeasures and their monetized safety benefits determine the benefit-to-cost ratio (BCR) and the net present value (NPV) of the investment, where a countermeasure is economically justified if its BCR is greater than 1.0 and its NPV is a positive value. Cost-effectiveness is generally expressed as the money spent per reduced crash and countermeasures with lower cost per crash reduced are desirable.

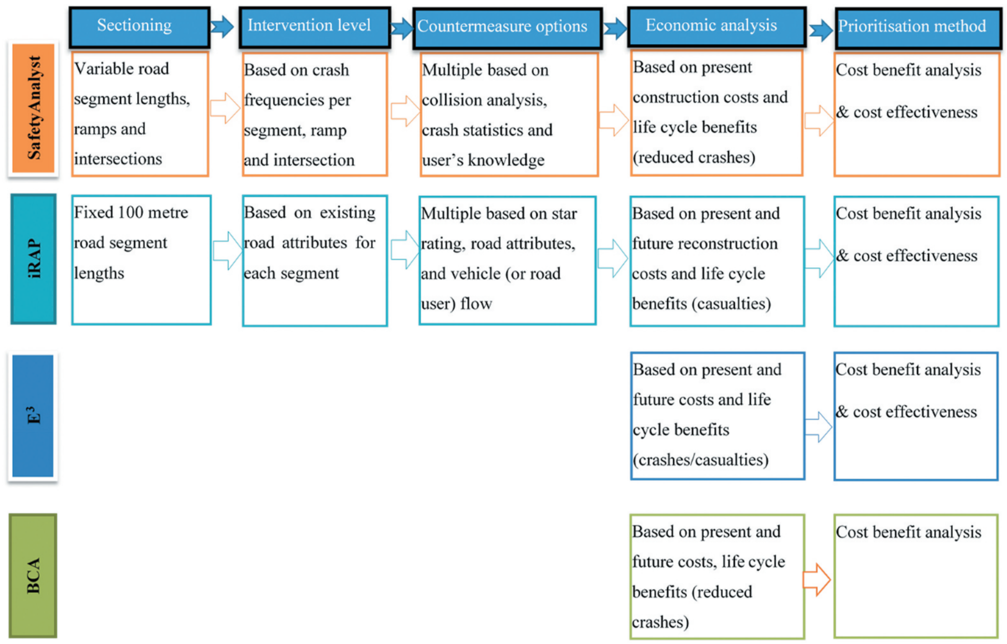
3.3. Question 3: Methods for defining the life cycle of road safety countermeasures
Cost and performance of road safety countermeasures during their life cycle was the focus in answering this review question.

3.3.1. Cost of road safety countermeasures
In SafetyAnalyst (Harwood et al., 2010), an annual construction cost (ACC_v) in Equation (1) for implementing a single countermeasure is computed using its construction cost (CC_V)and a crash reduction factor (CRF) in Equation (2), obtained using service life (S_V) and annual rate of return or discount rate (R).

$$ACC_v = CC_V * CRF \tag{1}$$

$$CRF = \frac{R(1+R)^{S_v}}{(1+R)^{S_v}-1} \tag{2}$$

Figure 2. Structure of the models.



If multiple countermeasures implemented together with the same service lives, the combined cost is the sum of the construction costs of the individual countermeasures. According to [AASHTO] American Association of State Highway and Transportation Officials (2020), if the service lives are different assuming two countermeasures, the combined cost($CC_{(A+B)}$) in Equation (3) is

$$CC_{(A+B)} = (CC_A) + (CC_B)CRF(R, S_B)USPWF(R, S_A), \tag{3}$$

$$CRF(R, S_B) = \frac{R(1+R)^{S_B}}{(1+R)^{S_B} - 1}, \tag{4}$$

$$USPWF(R, S_A) = \frac{(1+R)^{S_A} - 1}{R(1+R)^{S_A}}. \tag{5}$$

where CC_A and CC_B are the costs of countermeasures with longer and shorter service lives, respectively, S_A and S_B are the longer and shorter service lives, respectively, and USPWF in Equation (5) is the uniform series present worth factor.

In the E^3 model (Martensen et al., 2016), the total cost equals the sum of one-time investment costs and running costs. The BCA model considers the total cost as the initial cost (project support, right of way and construction) plus subsequent costs for maintenance, operation, rehabilitation and mitigation. The model provides an adjustment in the case of two countermeasures by standardizing the service life using the least common multiple of the service lives, which becomes the analysis period.

In iRAP ([iRAP] International Road Assessment Programme, 2015a), the economic costs are construction and reconstruction costs based on service life data for each countermeasure. This method supports a typical analysis period of 20 years such that a countermeasure with a service life of 20 years gets constructed once, then the one with a service life of 10 years is constructed at the start and reconstructed 10 years later ([iRAP] International Road Assessment Programme, 2015b).

3.3.2. Performance of road safety countermeasures

Performance of the countermeasures over their life cycle is measured by effectiveness (E) given by Equation (6), which relates to the reduced number of crashes measured by a crash modification factor (CMF). A CMF is a multiplication factor, which indicates the number of crashes that would remain after implementing a countermeasure (Martensen & Lassarre, 2017),

$$E = 100(1 - CMF) \tag{6}$$

In the case of multiple countermeasures, SafetyAnalyst uses a single CMF value to represent the combined effect, which is simply the product of individual CMFs (Harwood et al., 2010). In BCA, when two countermeasures are applied to a crash of the same type and severity, they are analysed to decide whether the two are truly independent, have some overlap or have a counteractive effect. Then, the combined factor (CMF_c) is given by Equations (7), (8) and (9), respectively (Lawrence et al., 2018), where CMF_1 is the factor for the most effective countermeasure and $CMF_2$is for the second most effective countermeasure. In case of complete overlap, the dominant effect method that applies the most effective countermeasure is used.

$$CMF_c = 1 - [(1 - CMF_1) + (1 - CMF_2)], \tag{7}$$

$$CMF_c = (CMF_1 * CMF_2)^{CMF_1}, \tag{8}$$

$$CMF_c = CMF_1 * CMF_2. \tag{9}$$

The iRAP model ([iRAP] International Road Assessment Programme, 2013) makes use of a multiple countermeasure correction factor (MCCF) providing a reduction for each individual countermeasure given by Equation (10). Further illustration of this adjustment is available in iRAP.

$$\text{Reduction} = \text{Reduction}_{\text{SIMPLE}} * \text{MCCF}, \tag{10}$$

$$\text{MCCF} = \frac{\text{Reduction}_{\text{MULTIPLIED}}}{\text{Reduction}_{\text{ADDITIVE}}}. \tag{11}$$

3.4. Economic analysis applicability

To examine the economic analysis applicability of the models, the study analyzed cost components, valuation methods and crash or casualty unit costs. The crash unit costs were computed using the iRAP methodology and compared with those used in other models.

Figure 3. Crash/Casualty cost components for the models.

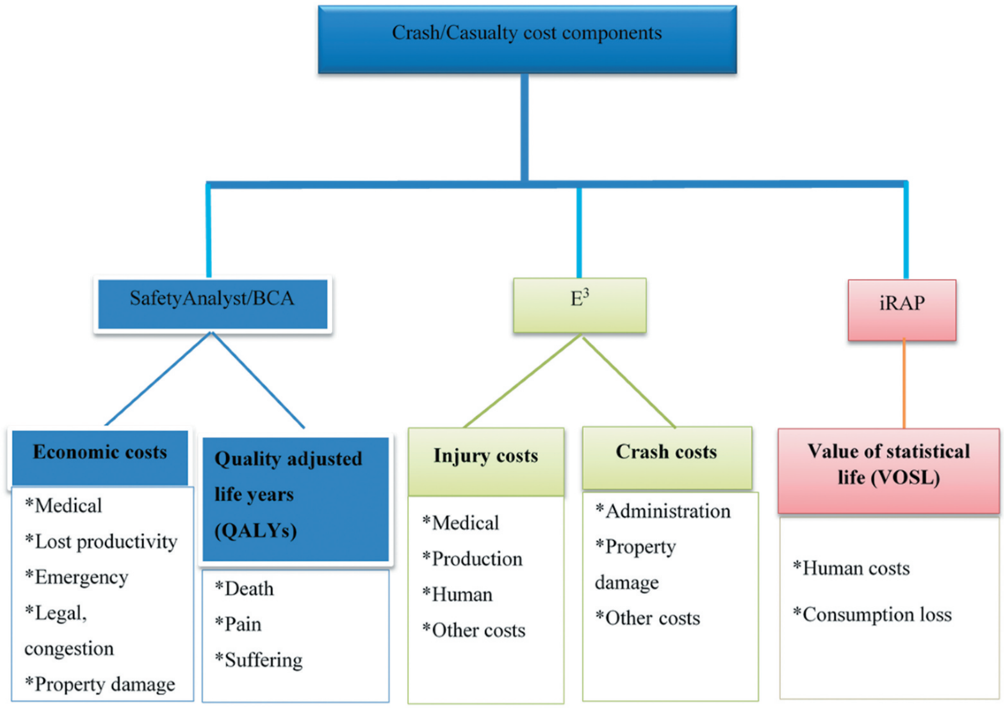
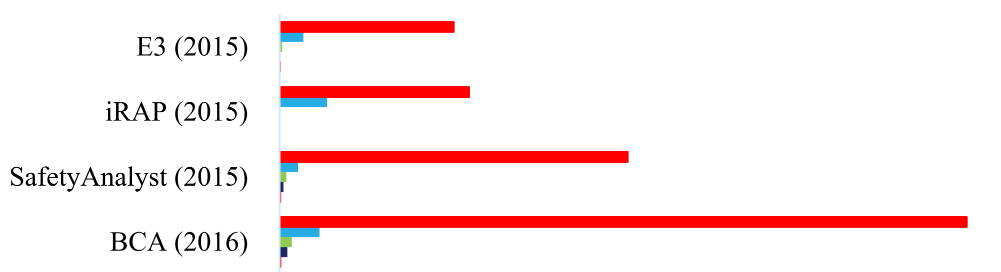


Figure 4. Comparison between crash and casualty unit costs used in the models.

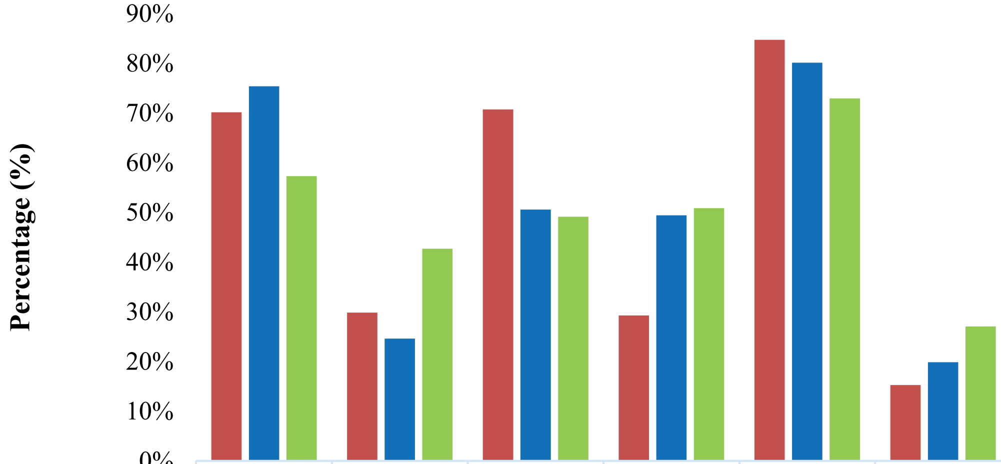


	BCA (2016)	SafetyAnalyst (2015)	iRAP (2015)	E3 (2015)
Fatal	11,295,400	5,722,300	3,114,650	2,862,789
Severe	655,000	302,900	778,663	389,384
Minor/Slight	198,500	110,700	-	41,447
Possible	125,600	62,400	-	-
PDO	11,900	10,100	-	4,396

3.4.1. Cost components

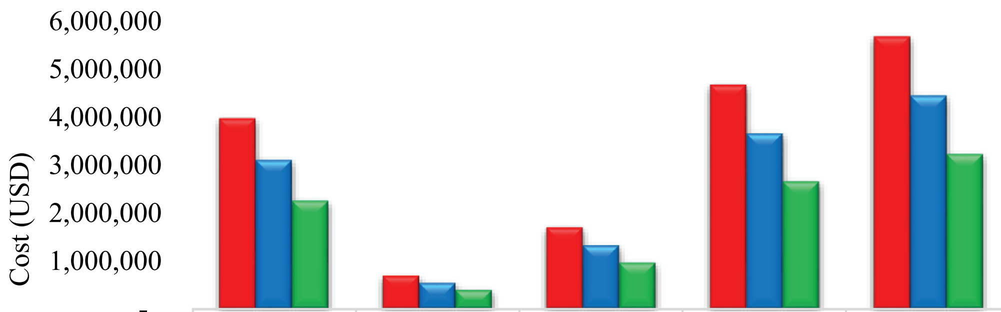
The review of the 4 models demonstrated that there are differences in the costing methods and components used (Figure 3). Accordingly, costs are generally sub-divided into human and economic or injury and crash-related costs. In addition, the terms direct and indirect costs are also used. In this review, the terms human and economic costs distinguish between these cost components.

Figure 5. Comparison between economic and human costs used in the models.



	E3 (2015) Human Costs	E3 (2015) Economic costs	SafetyAnalyst (2015) Human Costs	SafetyAnalyst (2015) Economic costs	BCA (2016) Human Costs	BCA (2016) Economic costs
Fatal	70%	30%	71%	29%	85%	15%
Severe	75%	25%	51%	49%	80%	20%
Minor/Slight	57%	43%	49%	51%	73%	27%

Figure 6. Computed fatal crash unit costs using VOSL and percentages of economic costs.



	VOSL	Economic costs Lower (15%)	Economic costs Upper (30%)	Comprehensive costs Lower Limit	Comprehensive costs Upper Limit
US	3,976,245	701,690	1,704,105	4,677,935	5,680,350
UK	3,114,650	549,644	1,334,850	3,664,294	4,449,500
EU	2,262,362	399,240	969,584	2,661,602	3,231,945

3.4.2. Cost valuation methods

3.4.2.1. Cost of fatalities. In SafetyAnalyst, BCA and E^3 models, the willingness to pay (WTP) approach is the basis in estimating human cost of fatalities. A WTP approach is an attempt to estimate how much money an individual (Individual WTP) or the society as a whole (Social WTP) is willing to pay for a crash risk reduction (Schoeters et al., 2017). In determining individual WTP, the revealed preference (RP) and the stated preference (SP) methods are used to trade-off between money and the risk reduction. The RP methods, commonly used in the US, value risk based on actual behaviour, while the SP methods, preferred in Europe, use questionnaires to ask respondents how much they are willing to pay for more safety. However, in other studies, the gross output, net output, life insurance, court award and implicit public sector valuation approaches have been used (Jacobs, 1995).

3.4.2.2. Cost of non-fatalities. Information regarding the cost of non-fatalities is relatively poor, as many studies have focused on the VOSL, which leads to the estimation of human costs of fatalities (Schoeters et al., 2017). The cost of a serious injury as a percentage of VOSL is 10–16% by Wijnen et al. (2017) and 20–30% by McMahon and Dahdah (2008). Generally, the E^3 model recommends the WTP approach to determine the cost of non-fatalities relative to VOSL. However, in the US, where the BCA model is used, QALYs approach values non-fatal injuries by the duration and severity of the health problem. The costs for the non-fatal injured victims are in terms of the maximum abbreviated injury scale (MAIS), body part and type of fracture or dislocation (Zaloshnja et al., 2004).

3.4.2.3. Crash and casualty costs. Figure 4 presents unit costs for iRAP (computed for UK), SafetyAnalyst (Harmon et al., 2018) and BCA (Harmon et al., 2018) and E^3 (Wijnen et al., 2017) models. In order to compare the differences in the costs considered by each of the four models, the iRAP values were computed for UK based on the formula that the value of a fatality is 70 times the GDP per capita and that of a serious injury is equal to 25% of the value of a fatality (McMahon & Dahdah, 2008). The GDP per capita for UK (US$44,495) for 2015 (Statista, 2019) was used. Furthermore, Figure 5 shows the percentages of economic and human costs computed using data by Harmon et al. (2018) and Wijnen et al. (2017). The comprehensive crash unit cost for a fatality (Figure 6) was computed for UK, EU and US based on the iRAP methodology using the 2015 GDP per capita for the US ($56,804), EU ($32,319) and UK ($44,495). Based on the computed VOSL and using the iRAP methodology, the value of a serious injury is US$ 994,061 for US and US$565,590 for EU.

4. Discussion

This systematic review sought to capture the global practice in the utilisation of road safety economic models as part of road management systems. The review might not have identified all the relevant studies due to limitations in the search strategy; for example, some scholarly literature may not be in English or included in the databases considered. However, there are reasons to believe that the review discovered the main knowledge currently available. Subsequently, the simple demonstration based on the review showed that the methods used worldwide in determining the cost and performance of road safety countermeasures during their life cycle are not many and not fully consistent and harmonized.

The SafetyAnalyst and iRAP are comprehensive decision support tools used for the implementation of safety management plans. Conversely, BCA and E^3 appear to be mere economic analysis models. In addition, the systemic approach (based on existing road attributes) in iRAP appears to be more practical than the SafetyAnalyst's crash-based and may result in improved network safety in the long run as compared to the crash-based approach.

E^3 analyses a single countermeasure, the BCA model may consider up to two measures and both SafetyAnalyst and iRAP models can consider multiple countermeasures. This limits the applicability of the first two models because in practice, a combination of countermeasures may be implemented at a section and junction and in a road network. However, the iRAP model may also be considered as limited because it takes into account only 2 severity levels (fatal and serious injuries) compared to at least 4 severity levels in BCA, SafetyAnalyst and E^3 models. Furthermore, to determine the combined effect of multiple countermeasures, the multiplicative approach using CMFs is common although it tends to overestimate safety benefits in some studies ([PIARC] Permanent International Association of Road Congresses, 2019).

There is no uniformity in all models regarding their economic analyses. The SafetyAnalyst and BCA models utilise crash unit costs, whereas iRAP uses casualty unit costs. The E^3 model conducts analysis for either crashes or casualties. Crash and casualty unit costs used in all the models are not directly comparable. For example, the cost of serious injuries as a percentage of VOSL varies between 10 and 30%. Furthermore, computed unit cost for serious injuries for EU and US is higher than all the serious injury crash unit costs used in the models, implying that the iRAP methodology may be overestimating the unit cost of a serious injury. The BCA crash costs appear to be unrealistic since fatal crash costs computed for the US and the EU using the iRAP methodology are on average comparable with those used by SafetyAnalyst and E^3 models unlike those by the BCA model. All the models consider the human and economic costs in their cost components except iRAP that considers only human costs. Further analysis shows that human costs have a major share over the total crash cost and on average up to 70% compared to 30% of other economic costs.

The computation of countermeasure costs during appraisal differs in all methods and the end-of-life costs are not considered. Ideally, a life cycle approach should consider all the costs incurred during planning, design, building/construction, operation, maintenance and disposal in road project appraisal. SafetyAnalyst's cost computation approach offers the strength of an annualised cost method, which may be applicable to multiple treatments with unequal service lives. Finally, the indirect benefits related to reduced travel delays, VOC and emissions appear only in the BCA tool, making it unique compared to other models.

5. Conclusions

The main findings of this systematic review and subsequent analysis are as follows:

(1) SafetyAnalyst, BCA, E^3 and iRAP are the most widely used road safety investment appraisal models.

(2) SafetyAnalyst and iRAP are comprehensive decision support tools unlike BCA and E^3 that appear to be economic analysis models.

(3) The BCA and E^3 models have limited application because they consider a single or up to two countermeasures, whereas the SafetyAnalyst and iRAP models can analyze multiple countermeasures.

(4) It appears that there is neither uniformity nor universally accepted standards to compute the crash or casualty unit costs as well as the cost and performance of road safety countermeasures during their life cycle.

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Appendix A Electronic bibliographic databases

Web of Science, Ovid (Medline and EMBASE), EBSCOhost, ProQuest, SCOPUS, Cochrane, Barbour Environment Health and Safety, CIS (Construction Information service), Taylor and Francis, Concrete vault, Engineering Handbooks Online, Espacenet, GEOBASE & Compendex (Ei Village 2), Intellectual Property Office, Knovel, TRIS (Transport Research Information services), ITRD (International Transport Research Documentation), SafetyLit, ICE Virtual Library, OECD iLibrary, Business and Intellectual Property Centre—the British Library, and United States Patent and Trade Mark Office.

Organisation websites

World Road Association/PIARC, iRAP—the International Road Assessment Programme, World Bank/IDA, World Health Organization (WHO), DFID—UK Department for International Development, TRL Limited—Transport Research Laboratory, UK, AfDB—African Development Bank Group, EuropeAid—European Commission Cooperation Office, SWOV—Institute for Road Safety Research, the Netherlands, VTI—Swedish National Road and Transport Research Institute, TOI—Norway Institute of Transport Economics, AAA Foundation for Traffic Safety, ARRB—Australian Road Research Board, ITE—Institute of Transportation Engineers, ICE—Institute of Civil Engineers, US Department of Transport—Federal Highway Administration (USA) and NHTSA—National Highway Traffic Safety Administration, USA.

Appendix B Search terms

WEB OF SCIENCE (02/12/2019)

Road safety near/3 (measure* OR countermeasure* OR intervention* OR infrastructure* or engineering), Road* investment near/3 (appraisal OR economic* OR model OR tool, Road safety near/4 (appraisal OR economic* OR investment* OR tool OR model), “Road safety” OR “Traffic safety” OR “Accident prevention” OR “Road transport safety” OR “Highway safety” OR “Road user safety.” (Appraisal investment) OR (Socio economic*) OR (Cost-Benefit Analysis*) OR (Cost-Effectiveness*) OR (Investment assessment*) OR (Investment evaluation).

OVID—MEDLINE AND EMBASE (02/12/2019)

(“Road* safety countermeasure*” or “Road* safety intervention*” or “Road* safety infrastructure*”), (“Accident* measure*” or “Accident* countermeasure*” or “Accident* intervention*”). (Traffic safety adj3 (measure* or countermeasure* or intervention* or infrastructure*)). (“Investment appraisal” or “Socio economic*” or “Cost-Benefit Analysis*” or “Cost-Effectiveness” or “Investment assessment*” or “Investment evaluation*”). (Road safety adj4 (appraisal or economic* or investment* or tool or model)).

EBSCOhost (02/12/2019)

(Road safety countermeasure*) OR (Road safety measure*) OR (Traffic safety measure*) OR (Road safety Intervention*) OR (Road traffic safety measure*) OR (Accident prevention measure*) OR (Road safety engineering infrastructure*) OR (Road safety infrastructure*) OR (Safety engineering measure*). (“Investment appraisal”) OR (“Socio economic*”) OR (“Cost-Benefit Analysis*”) OR (“Cost—Effectiveness”) OR (“Investment assessment*”) OR (“Investment evaluation*”). (Road safety investment model*) OR (Appraisal investment model*) OR (Socio-economic model*) OR (Cost-Benefit model*) OR (Cost-Benefit Analysis model*) OR (Cost—Effectiveness model*) OR (Investment assessment model*) OR (Investment evaluation model*).

PROQUEST (02/12/2019)

(("Road* safety countermeasure*") OR ("Road* safety intervention*") OR ("Road* safety infrastructure*") OR ("Road* traffic countermeasure*") OR ("Road* traffic intervention*") OR ("Road* traffic infrastructure") OR ("Accident* measure*") OR ("Accident* countermeasure*") OR ("Accident* intervention*") AND (("Investment appraisal") OR ("socio economic") OR ("socio economical") OR ("socio economically") OR ("socio economics") OR ("Cost-Benefit Analysis*") OR ("Cost Effectiveness") OR ("Investment assessment*") OR ("Investment evaluation*")).

SCOPUS (03/12/2019)

((("Road* safety countermeasure*" OR "Road* safety intervention*" OR "Road* safety infrastructure*")) OR (("Road* traffic countermeasure*" OR "Road* traffic intervention*" OR "Road* traffic infrastructure")) OR (("Accident* measure*" OR "Accident* countermeasure*" OR "Accident* intervention*"))) AND (("Investment appraisal" OR "Socio economic*" OR "Cost-Benefit Analysis*" OR "Cost—Effectiveness" OR "Investment assessment*" OR "Investment evaluation*")) ("Investment appraisal" OR" Socio economic*" OR" Cost-Benefit Analysis*" OR" Cost-effectiveness" OR" Investment assessment*" OR" Investment evaluation*").

TAYLOR AND FRANCIS (04/12/2019)

[road] AND [safety] AND [model] OR [appraisal] AND [measures], [road] AND [safety] AND [[appraisal] OR [tool]], [road] AND [[appraisal] OR [tool]]

GEOBASE & COMPENDEX (Ei VILLAGE 2) (04/12/2019)

(((($ROAD $SAFETY $INVESTMENT $MODEL) AND ((($Road $safety OR $appraisal OR economic* OR investment* OR $tool OR $model))). (((($Road $safety $investment $appraisal OR $Road $safety $tool OR $Road $safety $model) OR (((({Investment appraisal} OR {Socio economic*} OR {Cost Benefit Analysis*} OR {Cost—Effectiveness} OR {Investment assessment*} OR {Investment evaluation*}))). (("Road* safety countermeasure*" OR "Road* safety intervention*" OR "Road* safety infrastructure*" OR "Road* traffic countermeasure*" OR "Road* traffic intervention*" OR "Road* traffic infrastructure" OR "Accident* measure*" OR "Accident* countermeasure*" OR "Accident* intervention*")). ((Road safety investment appraisal OR Road safety tool OR Road safety model)), (((($Road $safety OR $appraisal OR economic* OR investment* OR $tool OR $model) AND ((((((($Road $safety $investment $appraisal OR $Road $safety $tool OR $Road $safety $model) OR (((({Investment appraisal} OR {Socio economic*} OR {Cost-Benefit Analysis*} OR {Cost—Effectiveness} OR {Investment assessment*} OR {Investment evaluation*}) AND ((((({Road safety} OR {Traffic safety} OR {Accident prevention} OR {Road transport safety} OR {Highway safety} OR {Road user safety}) OR (((({Road* safety countermeasure*} OR {Road* safety intervention*} OR {Road* safety infrastructure*} OR {Road* traffic countermeasure*} OR {Road* traffic intervention*} OR {Road* traffic infrastructure} OR {Accident* measure*} OR {Accident* countermeasure*} OR {Accident* intervention*})

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