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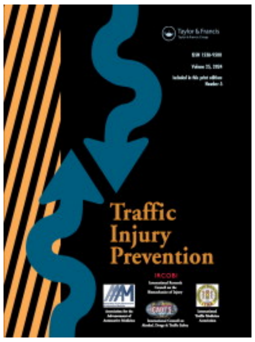

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The impact of indirect benefits (reduced travel time, fuel use and emissions) in cost benefit analysis of road safety countermeasures

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ABSTRACT

Objective: In cost benefit analysis of road safety countermeasures, all relevant effects on safety, travel time and environment have a substantial impact during economic appraisal. However, in the most widely used road safety appraisal tools such as SafetyAnalyst and International Road Assessment Programme (iRAP), indirect effects related to travel time and environment are not considered. Most economic appraisal studies conducted for road safety countermeasures consider only the safety benefits and ignore the indirect benefits due to lack of models to evaluate them. This study attempts to document the quantitative impact of indirect benefits during economic appraisal of road safety infrastructure investments particularly from the angle of reduced crashes.

Methods: To this effect, data from 9 European countries and the 20-year infrastructure improvement programme developed for the Netherlands are applied to demonstrate the impact of these indirect benefits through a quantitative study.

Results: The results show that indirect benefits increase the value of benefits by 7%, which improves the cost effectiveness of countermeasures. Consequently, the number of countermeasures selected for implementation are increased due to addition of these benefits. Travel time benefits constitute the largest share of indirect benefits with a contribution of 6% to the overall benefits due to countermeasure implementation.

Conclusion: In conclusion, indirect benefits have a substantial impact on the computation of benefits and countermeasure selection process. In order to present improved business cases for road safety infrastructure investments, there is need to include these benefits during economic appraisal process. Travel time benefits have the highest portion of all indirect benefits compared to vehicle operating costs (VOCs) and emission benefits. The study recommends conducting more research related to travel time benefits due to countermeasure implementation.

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Introduction

In road safety, economic appraisal is one of the key components of a roadway safety management process where the value of economic costs and benefits of chosen countermeasures over the appraisal period is determined to ensure efficiency and effectiveness of road safety investment programmes. The most widely used evaluation approaches during economic appraisal are cost benefit analysis (CBA) and cost effectiveness (PIARC 2020). Specifically, CBA is a systematic process that compares benefits and costs during economic appraisal to determine the desirability of a given business or policy. As a standard approach and to provide a common basis for comparison, benefits and costs are expressed in monetary terms. In CBA, a benefit cost ratio (BCR) is computed as the economic criteria for ranking and comparing alternative policies or projects.

In CBA of road safety countermeasures, it is important that all relevant effects on safety, travel time, environment and operational conditions are taken into consideration as these have a substantial influence on the results of a CBA (Martensen and Lassarre 2017). However, some CBA studies conducted for safety countermeasures consider benefits as reduced number of crashes or injuries (Daniels et al. 2019) and appear to ignore the indirect benefits due to lack of models to evaluate them (Yannis et al. 2008). The economic analysis of safety countermeasures using CBA has largely received criticism due to the value of statistical life (VOSL) used that forms part of the crash cost which is considered ethically unacceptable and also due to other factors (Hauer 2011). However, road safety analysts prefer this tool and one of the arguments in its favor against cost effectiveness analysis has been its ability to provide a complete assessment of

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all possible objectives (safety, mobility and environment). In some cases, there are additional impacts of road safety measures on mobility and the environment that should be included in a CBA (SWOV 2011; OECD/ITF 2015; EC 2018).

It is estimated that annually 1.35 million people (WHO 2018) die due to road crashes which costs most countries 1–5% of their gross domestic product (GDP) (Gorea 2016; Wismans et al. 2016; Jadaan et al. 2018). In addition, there are other costs incurred by society that relate to increased travel time or delays, vehicle-operating costs (VOCs) and increased emissions due to these road crashes that might be substantial in any evaluation. In a competing world of resources coupled with the need to promote and increase road safety programs, public money expenditure may probably be justified if the indirect benefits of safety countermeasure implementation are included in economic appraisal models or software. It is understandable that the numerical evaluation of indirect benefits might be challenging, and very little information is available in the scholarly literature partly explaining their limited use in economic analysis of road safety countermeasures.

In fact, indirect benefits include operational and environmental benefits that maybe positive or negative and are often computed from two angles: either by considering the direct consequences of implementing a road safety countermeasure or as a residual benefit resulting from the reduction in the number of crashes. The quantitative and qualitative impacts of safety investments are important in an economic appraisal to improve the consistency and reliability of decisions when evaluating and ranking countermeasures (Lawrence et al. 2018). Nonetheless, the quantitative impact of these indirect benefits particularly from the angle of reduced crashes in the CBA of safety countermeasures appears to be undocumented. Therefore, this paper attempts to document the likely impact of reduced three indirect benefits (travel time, fuel use, and emissions) on the overall benefits and countermeasure selection during economic appraisal of road safety infrastructure investments.

Direct and indirect benefits of road safety countermeasures

In most cost benefit studies of countermeasures and road safety investment appraisal models, the direct safety benefits of countermeasure implementation considered are usually expressed in terms of reduced number of crashes or injuries (Harwood et al. 2010; iRAP 2015; Lawrence et al. 2018; Daniels et al. 2019). For example, the signalization of a junction as a countermeasure may be substantial in reducing conflicts and thus directly results in reduction of crashes. Therefore, the term direct benefits in this analysis refers to safety benefits only expressed in terms of reduced number of crashes.

The term indirect benefits in this study refers to those positive impacts of road safety countermeasure implementation that result from a change in safety performance (reduced number of crashes) such as reduced travel time, improved travel time reliability, reduced fuel use and reduced emissions (FHWA 2018). However, travel time reliability benefits are not included in this analysis simply because in “rural other” or “urban other” facility types where traffic volumes are low, travel time is predictable and thus these benefits might be minimal and can be excluded in a CBA (Lawrence et al. 2018). Therefore, indirect benefits of reduced travel time, fuel use and emissions due to fewer crashes are analyzed as explained below.

Travel time benefits

The time spent by vehicle occupants being stuck or detouring around an accident site may yield monetary benefits if dedicated to production, recreation and other activities (Blincoe et al. 2015). Thus, the National Highway Traffic and Safety Administration (NHTSA) report, The Economic and Societal Impact of Motor Vehicle Crashes (Blincoe et al. 2015) provides for a methodology to estimate the average hours of delay per crash per roadway facility type and estimates the value of time per person-hour for different roadway facility types. Therefore, the monetary travel time benefit is the product of the estimated reduction in crashes, the average hours of delay per crash and the value of time per person-hour.

Emission benefits

Motor vehicle crashes result in increased greenhouse gas production and criteria pollutant emissions such as Carbon dioxide (CO_2), Carbon monoxide (CO), Sulfur dioxide (SO_2), Particulate Matter (PM), Nitrous oxides (NO_X) and Volatile organic compounds (VOC) as engines idle when drivers are caught in slowdowns and traffic jams resulting from lane closures, police, fire and emergency services (Blincoe et al. 2015). Similarly, the NHTSA report provides monetized values for the above emissions per crash severity and roadway facility types (Lawrence et al. 2018). Therefore, the emission monetary benefit is the product of the estimated reduction in crashes and the value of emission per crash.

Vehicle operating costs (VOCs)

VOCs typically include fuel and non-fuel related costs such as vehicle maintenance, insurance and depreciation, which are not sensitive to changes in operating conditions created by accident scenes. However, drivers burn more fuel as they respond to a crash by slowing down, idling and seeking other alternative routes to detour around the accident scene (Blincoe et al. 2015). The NHTSA report also provides values of increased fuel use per crash per severity per roadway type, which can be used to monetize the fuel related benefits. Therefore, the fuel related benefit is the product of the estimated reduction in crashes, gallons of fuel per crash and the cost per gallon of fuel.

Existing CBA software

SafetyAnalyst, Economic Efficiency Evaluation (E^3), Benefit Cost Analysis (BCA) and International Road Assessment Program (iRAP) are some of the widely used software

(Byaruhanga and Evdorides 2021). SafetyAnalyst developed for the Federal Highway Administration (FHWA) is used in the United States (US) by state and local highway agencies to identify an optimal set of countermeasures to maximize benefits for a given budget (Harwood et al. 2010). Similarly, the BCA supports these state and local highway agencies to conduct economic appraisal of road safety investments (FHWA 2018). E^3 is a European Union (EU) software developed as part of the Safety CaUsation, Benefits and Efficiency (SafetyCube) project with funding from European Commission to perform economic evaluation of safety interventions related to vehicle, infrastructure and human behavior (Martensen et al. 2018). The iRAP software developed by iRAP is used globally to perform economic appraisal of road safety countermeasures during the preparation of safer roads investment plans (iRAP 2015). A comparison of all the above-mentioned software shows that direct safety benefits related to a reduction in crashes or casualties are only considered in SafetyAnalyst and iRAP ignoring the indirect benefits that relate to mobility (travel time and vehicle expenses) and environment (noise and pollution). However, BCA and E^3 appear exceptional as they provide for the inclusion of indirect benefits of road safety countermeasures if known by analysts.

Methodology

The impact of indirect benefits on the overall safety benefits is demonstrated using the 20-year infrastructure improvement programme (Online Appendix Table A1) taken from iRAP (2021) for Netherlands (Utrecht 2014 Provincial Roads), developed by European Road Assessment Programme (EuroRAP) using ViDA software. ViDA is the iRAP's online road safety software that creates and analyses road inspection data to produce safer roads investment plans. This original data (Online Appendix Table A1) was modified accordingly to compute the monetary benefits and BCR values. For instance, the iRAP casualty numbers (fatalities and serious injuries) in Table A1 (Online Appendix) were converted to crash numbers (Online Appendix Table A3) using the statistical relationships developed from the crash and casualty data for 9 countries (Online Appendix Table A2) taken from Wijnen et al. (2017). Arguably, a crash-based approach that considers the number of crashes instead of casualties appears more effective than a casualty-based approach during economic appraisal of infrastructure investments (Byaruhanga and Evdorides 2022). The number of fatalities, serious injuries and the number of crashes for all severity levels were estimated using the ratios (Tables 1 and 2) developed using data in Table A2 (Online Appendix). The ratios in Table 1 are comparable to those in other studies (De Brabander and Vereeck 2007; Wijnen et al. 2017; Wijnen 2020). The developed ratios may be useful in estimating crash and casualty data where insufficient data has been collected.

Firstly, the combined number of fatalities and serious injuries (FSI) as per iRAP's original data in Table A1 (Online Appendix) was split considering 7 serious injuries per fatality (Table 2). This may be comparable to the 10 serious injuries per fatality used in iRAP (2015). The splitting resulted in individual number of fatalities and serious injuries. Furthermore, using the obtained individual number of fatalities, the number of slight injuries were estimated. Secondary, the obtained casualty numbers for three severity levels (fatal, serious injuries and slight injuries) were used to compute the number of crashes for three severity levels (fatal, serious injury, slight injury) using the statistical relationships in Table 1. Thirdly, as per the data in Table A2 (Online Appendix), 88.7% of the total crashes are PDO, and this was the basis in determining the number of PDO crashes. This percentage is comparable to 88.3% established by Park et al. (2012) on Korean expressways. Alternatively, the number of PDO crashes maybe estimated considering approximately 6 PDO crashes per injury (serious and slight injuries) which is similar to that recommended by Luathep and Tanaboriboon (2005) for urban areas. As an example, applying the statistical relationships in Table 2, the 10 FSI for signalized crossing countermeasure in Table A1 (Online Appendix) are split into 1.25 fatalities, 8.75 serious injuries and 56.39 slight injuries considering 3 casualty severity levels. The above casualty numbers were converted to crash numbers using the statistical relationships in Table 1. This now results in 1.2 fatal, 7.7 serious injury, 41.9 slight injury and 397.5 PDO crashes (Online Appendix Table A3) considering 4 crash severity levels. For every fatal crash, there are 1.08 fatalities based on the developed statistical relationships (Table 1).

Thus, the direct benefits in Equation (1) were computed by multiplying the number of crashes for each severity level with the respective crash unit cost and added altogether.

$$Crash\ Benefits\,(\$) = \begin{pmatrix} Estimated\ Reduction \\ in\ Crashes \end{pmatrix} \times \begin{pmatrix} Comprehesive\ Crash \\ Unit\ Cost\,(\$) \end{pmatrix} \tag{1}$$

Table 3 shows the updated SafetyAnalyst's crash unit costs taken from Harmon et al. (2018) used to compute these direct monetary safety benefits. Similarly, indirect benefits in

Table 1. Relationship between crash and casualty severity levels.

	Casualties		
Crash	Fatalities	Serious injuries	Slight injuries
Fatal	1.08	–	–
Serious injury	–	1.14	–
Slight injury	–	–	1.35

Table 2. Relationship between casualty severity levels.

	Casualties	
Fatality	Serious injuries	Slight injuries
1	7	45

Table 3. AASHTOWare SafetyAnalyst crash unit costs (2015 dollars).

Crash severity	Comprehensive crash unit cost ($)
Fatal	5,722,300
Severe	302,900
Slight	110,700
PDO	10,100

Source: Harmon et al. (2018).

Equations (2–4) were computed using the number of crashes for each severity level, the delay and fuel factors, values of time, fuel and emissions.

$$Travel\ time\ Benefits\ (\$) = \begin{pmatrix} Estimated \\ Reduction \\ in\ Crashes \end{pmatrix} \times (Delay\ Factor) \times \begin{pmatrix} Unit\ Value \\ of\ Time(\$) \end{pmatrix} \quad (2)$$

$$VOCs\ Benefits\ (\$) = \begin{pmatrix} Estimated \\ Reduction \\ in\ Crashes \end{pmatrix} \times (Fuel\ Factor) \times \begin{pmatrix} Unit\ Value \\ of\ Fuel(\$) \end{pmatrix} \quad (3)$$

$$Emission\ Benefits(\$) = \begin{pmatrix} Estimated\ Reduction \\ in\ Crashes \end{pmatrix} \times (Value\ of\ Emission(\$)) \quad (4)$$

The NHTSA methodology and the established factors of delay, fuel and emissions (Table 4) taken from Lawrence et al. (2018) were used. The delay factors are used to compute the reduction in travel time delay based on the reduction in the number of crashes. These were estimated by NHTSA based on the total delay experienced in each crash type for all the road types. The vehicle delay factors represent the total person-hours of delay computed using the total number of vehicles delayed considering one person per vehicle. The fuel factors are based on the fuel burned by vehicles during idle time and slow movement through the distance affected by the crash followed by the higher speeds to compensate for the time lost in the crash site. Equally, emission factors were computed based on the resulting increased criteria pollutant emissions as engines idle due to traffic congestion and slow down due to road traffic crashes. Average values for all the roadway facility types (Urban Interstate/Expressways, Urban Arterials, Urban Other, Rural Interstate/Principal Arterials and Rural Other) are used in this case study. The values of time per hour (average for all road types) and fuel per gallon used in the analysis are $27.35 and $2.50, respectively, taken from Lawrence et al. (2018). The estimated implementation costs for countermeasures converted to 2015 dollars by multiplying each cost with 1.11 (Statista 2021) are used. The computations for direct and indirect benefits were made based on the reduced number of crashes as per equations above. BCR 1 was computed by dividing direct benefits ($) by the estimated cost ($). BCR 2 was computed by dividing total benefits (the sum of direct and indirect benefits) by the estimated cost ($).

Table 4. Average delay, fuel and emission NHTSA factors for all road types.

Severity level	NHTSA Delay Factor (Hours per crash)	NHTSA Fuel Factor (Gallons per crash)	NHTSA Value of Emissions (Dollars per crash)
Fatal	1699.79	376	380.36
Serious Injury	130.16	81	80.87
Minor Injury	130.16	81	80.87
Property damage only	86.37	64	65.67

Source: Lawrence et al. (2018).

Results and discussion

In an effort to improve the economic analysis of road safety countermeasures, it is prudent if the analysis includes all the policy objectives and impacts. These results are a case study with the defined unit rates, NHTSA's methodology and factors to illustrate the impact of indirect benefits on economic appraisal of road safety countermeasures. The study only considers the indirect benefits resulting from the reduction in the number of traffic crashes due to countermeasure implementation. The other principles usually applied in economic appraisal of countermeasures such as discounting are not applied.

The results show that the indirect benefits of travel time, VOCs and emissions increase the monetary benefits by 7% due to a reduction in the number of crashes considering 4 crash severity levels as seen in Table A3 (Online Appendix). For example, the monetary benefits due to the installation of a signalized crossing increase from $17.6 m (direct benefits) to $18.9 m with the addition of three indirect benefits (travel time, VOCs and emissions). The analysis further shows that reduced travel time benefits contribute the highest percentage of all indirect benefits (92%) followed by VOCs (6%) and lastly reduced emission benefits (2%). This perhaps supports the previous recommendation by Wesemann (2000) to prioritize research effort into the mobility effects of countermeasures since they constitute the majority of the indirect benefits. Therefore, travel time benefits for road safety infrastructure investments appear to be substantial in the same way being the greatest expected benefit and important for road transportation infrastructure improvements (USDOT 2006, 2021; VTPI 2017). There are well-developed techniques for mobility effects of road transport projects (Hakkert and Wesemann 2005) that could suffice for travel time benefits. Therefore, it is important that travel time benefits are included in the appraisal of safety countermeasures as previously recommended by Elvik (2014).

Furthermore, the results clearly illustrate that indirect benefits have a substantial impact on the value of benefits in an economic appraisal of road safety countermeasures which agrees and supports the recommendations by EC (2018), Martensen and Lassarre (2017), OECD/ITF (2015) and SWOV (2011) to include indirect benefits in CBA of road safety countermeasures.

In addition, the results show that indirect benefits have an impact on countermeasure selection by comparing the computed BCR for direct benefits only (BCR 1) and that for direct and indirect benefits (BCR 2). Assuming budget constraints and setting the BCR threshold value to be greater than 4 for a countermeasure to be selected for implementation, 39 countermeasures may be selected considering direct benefits only. However, with indirect benefits added, the number of countermeasures that satisfy this economic selection criteria increase from 39 to 41, which represents an increase of 5%. Street lighting (mid-block) for 10.3 km and 2 sites of street lighting (pedestrian crossing) are the two countermeasures added to the program with the addition of indirect benefits in the analysis. As an example, the increase in benefits for Street lighting (mid-block) from $7,051,489 to $7,561,467 due to addition of indirect benefits may explain the increase in countermeasure selection. These two measures combined have the potential to reduce 163 PDO crashes over the analysis period (20 years). In addition, the computed BCR of 80% of the analyzed countermeasures increase due to addition of indirect benefits in the analysis. There is a high possibility of excluding some of the countermeasures during economical appraisal considering direct benefits only as these may not be justified economically (with a BCR less than 1) but may be justified with the addition of the indirect benefits.

This equally applies considering budget constraints in road safety infrastructure investments where countermeasures may only be considered if their BCR exceeds a certain threshold value determined by the budget constraint. The results further demonstrate that safety benefits constitute 93% of the total benefits, followed by travel time benefits (6%). This agrees and supports the fact that the most common form of a countermeasure implementation effect is the reduction in the number of crashes (Yannis et al. 2008; PIARC 2020).

The indirect benefits of road safety countermeasures most especially with network level analysis is not always included in a CBA. Since the accuracy of a CBA depends highly on accurate estimation of costs and benefits (Ejaz 2010), it is important that analysts consider indirect benefits as these might have a substantial impact on the value of benefits and in the selection of countermeasures. This appears to be the future of road safety economics as public expenditure must be justified amongst competing alternatives and in a bid to present improved business cases for road safety investments. While the estimation of these indirect economic benefits of transport infrastructure is unresolved (Oosterhaven and Elhorst 2003), the available research needs to be utilized to support the growing need to reduce road traffic crashes despite the limited budgets with governments and road authorities.

Conclusion

This study has documented the likely impact of including indirect benefits in a CBA on the monetary value of benefits and countermeasure selection resulting from a change in safety performance (reduced number of crashes) during economic appraisal of road safety countermeasures. Indirect benefits may increase the value of benefits up to 7% considering 4 crash severity levels, which ultimately increases the number of countermeasures for implementation. Travel time benefits constitute the highest portion of all indirect benefits as compared to VOCs and emission benefits. The study recommends more research effort in travel time indirect benefits since they constitute a higher share compared to the other indirect benefits considered. Finally, it is prudent to include indirect benefits in the economic evaluation of countermeasures as these may have a substantial impact on the overall benefits and on countermeasure selection.

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CRediT author statement

Chris Bic Byaruhanga: Methodology, Formal analysis, Investigation, Writing—Original Draft, Visualization and funding acquisition. Harry Evdorides: Conceptualization, Writing—Review & Editing, Supervision and Project administration.

Disclosure statement

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