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A COMPARISON BETWEEN CRASH AND CASUALTY ECONOMIC ANALYSIS APPROACHES OF ROAD SAFETY INFRASTRUCTURE COUNTERMEASURES

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Abstract: The economic analysis of safety measures is one of the core elements of a road safety program aimed at determining accurately the economic benefits. However, there is still a mix of approaches in some of the most widely used road safety investment appraisal models. For example, SafetyAnalyst is a crash-based evaluation model while the International Road Assessment Programme (iRAP) is a casualty-based model. The objective of this study was to compare crash with casualty based economic analysis approaches of infrastructure related safety countermeasures to inform economists and road safety analysts on the most appropriate approach. The study utilises data from 9 countries and the 20-year infrastructure improvement program for Netherlands developed using EuroRAP and ViDA software. The results of this study demonstrated that a crash-based approach is more comprehensive and results in a wider range of countermeasures selected for implementation. In addition, compared to a casualty-based approach the value of safety benefits and the number of countermeasures selected increased by 26% and 10% respectively using a crash-based approach. This paper suggests that any road safety appraisal model may perform better by considering crashes instead of casualties and more so if the property damage only crashes are included in the analysis.

Keywords: road safety, economic analysis, infrastructure countermeasures, crash unit cost, casualty unit cost, model.

1. Introduction

The economic analysis of road safety countermeasures is one of the core elements of a road safety program aimed at determining accurately the economic benefits (Welle *et al.*, 2018). However, as evidenced in the most widely used road safety investment appraisal models, SafetyAnalyst (Harwood *et al.*, 2010) and Benefit Cost Analysis (BCA) by FHWA (2018) are crash-based models while the International Road Assessment Programme (iRAP, 2015) is a casualty-based model. Moreover, Economic Efficiency Evaluation (E^3) model conducts economic analysis for both crashes and casualties (Martensen and Lassare, 2017); in this case, the choice depends on whether the countermeasure is to prevent crashes thus using a crash-based approach or mitigating the consequences of a crash such as seatbelts thus using a casualty-based approach. To this end, the focus of this paper is to examine the selection of infrastructure measures

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to prevent crashes versus a casualty-based approach that may underestimate benefits within a comprehensive safe road system.

Harmon *et al*. (2018) recommends analysts to work with crashes and crash unit costs during economic appraisal of safety countermeasures. Similarly, in a report by OECD/ITF (2015), the efficiency assessment of a safety related measure requires the number of road crashes or accidents affected by a measure. In PIARC (2020), the key measure to assess effectiveness of any safety infrastructure intervention is the expected reduction in crashes expressed as a crash modification factor (CMF). However, Martensen *et al.* (2016) considers the effectiveness of a measure as a reduction in either the number of crashes or the number of casualties. Similarly, the most common ways of measuring progress in road safety is by the number of road crashes, the number of road casualties and the associated negative consequences (Wegman, 2017). In practice, crash and casualty-based approaches are used in economic analysis of road safety infrastructure measures most probably without due consideration of the impact of either approach on the calculated economic benefits and ultimately the selection of countermeasures. The economic implications might be substantial if for instance instead of analysing crashes, casualties are analysed and a significant proportion of crashes not involving casualties are not considered. For instance, in Germany and Finland, the property damage only (PDO) crashes have a share of up to 50% in total costs for road crashes. Furthermore, in the analysis conducted for countries that include all severity levels, PDO crashes accounted for 2% to 55% share in the total cost of crashes, which is higher than that of slight injuries ranging between 1.9% and 34% (Wijnen *et al.*, 2017). Therefore, this study aims to clarify the economic benefits of these two approaches and their impact in the selection of infrastructure countermeasures.

1.1. Economic Analysis of Road Safety Countermeasures

Economic analysis is a process that allows organisations to identify, quantify and determine the value of economic costs and benefits of chosen countermeasures over the appraisal period to ensure efficiency and effectiveness of safety programs (U.S. DOT, 2003). Cost effectiveness, cost utility and cost benefit analyses tools identify how to use scarce resources to obtain the greatest possible benefit or the highest return on investments in road safety (Martensen *et al*., 2018).

The concept of economic analysis for safety measures is quite challenging due to the complex nature of determining the life cycle costs and benefits of countermeasures as well as crash or casualty unit costs. Consequently, this has led to arguments by Hauer (2011) describing the cost benefit analysis (CBA) tool as deficient due to uncertainties in defining the value of statistical life (VOSL) used. However, PIARC (2020) and Safety CaUsation, Benefits and Efficiency (SafetyCube) Decision Support System (Martensen *et al*., 2018) typically accept and use CBA as an economic evaluation tool. There is more substance to this tool subject to parameter estimation enhancement. For instance, this tool can underestimate safety benefits depending on the approach used; thus the need for sound economic analysis. The tool commonly used in road safety research determines the policy priorities and resource allocation typically through safety benefits expressed in terms of reduced number of crashes or casualties.

A crash-based approach refers to an economic analysis in which the safety benefits of implementing a countermeasure are the number of crashes reduced. A road crash or accident refers to unplanned or uncontrolled event involving at least one vehicle, cyclist or motorcyclist and in which at least one person is killed, injured or property is damaged. Therefore, a crash can be fatal (at least one person is killed), serious (at least one person is seriously injured and no person killed), slight (at least one person is slightly injured but no person is killed or seriously injured) and finally a PDO crash in which no person is killed nor injured. In a casualty-based approach, the safety benefits of implementing a countermeasure are the number of casualties reduced. A casualty refers to a person killed or injured in a crash, subdivided into killed, seriously injured and slightly injured. In terms of severity levels, a crash-based approach has more severity levels than a casualty due to the property damage level added that might have a significant effect on the analysis results. In order to perform a CBA all relevant effects of the measure relating to safety, mobility (travel and vehicle expenses) and environment are paramount. However, the effects on mobility and environment appear complex to estimate and are scarce in the scholarly literature. Consequently, most of the appraisal models like SafetyAnalyst and iRAP ignore such effects in their economic analysis except the BCA model that estimates these effects based on reduced number of crashes. Therefore, in the advancement of economic analysis of safety measures, in order to utilise the available research with regard to mobility and environment, it is imperative that analysts develop or modify their models to analyse crash numbers instead of casualties.

2. Methodology and Data

To demonstrate the above approaches, the total cost of crashes and casualties was computed first using the number of crashes/casualties (Table 1) for 9 European countries with the respective European Union (EU) standard crash and casualty unit costs for 2015 (Table 2 and Table 3) for each severity level and adding them together for each country.

Table 1
Crash and Casualty Data

Country	Crashes				Casualties		
	Fatal	Serious Injury	Slight Injury	PDO	Fatalities	Serious Injuries	Slight Injuries
Austria	429	9,262	26,917	646,553	523	10,502	34,522
Estonia	61	433	1,345	29,218	67	467	1,756
Finland	208	475	4,641	478,863	229	519	6,186
Germany	3,187	58,744	240,504	2,104,250	3,377	67,732	321,803
Iceland	16	155	741	5,500	16	178	1,130
Ireland	179	398	4,399	21,734	188	508	6,252
Norway	148	597	4,380	403,719	160	693	5,670
Slovenia	112	868	5,605	11,358	120	932	7,778
UK	1,658	20,676	123,988	2,232,305	1,775	22,807	169,895

Source: (Wijnen et al., 2017)

These unit costs developed by the European SafetyCube project aim to support stakeholders in conducting economic efficiency evaluation of measures. Secondly, the study computed a simple benefit cost ratio (BCR) to demonstrate the effect of these approaches on countermeasure selection considering only countermeasures with a BCR greater than 3. The monetary safety benefits are the number of crashes/casualties reduced multiplied with the respective unit costs (Table 2 and Table 3) and added together for all the severity levels. The 20-year infrastructure improvement program (Table A1) for Netherlands (Utrecht 2014 Provincial Roads) taken from iRAP (2021), developed using EuroRAP and ViDA software is used and modified accordingly to compute BCR.

Table 2

Crash Unit Cost and Components

Severity Level	Medical Costs	Production Loss	Human Costs	Property Damage	Administrative Costs	Other Costs	Total Unit Costs (€)
Fatal	11,757	727,616	1,809,467	17,542	8,891	3,817	2,579,090
Serious Injury	19,158	50,285	263,945	11,143	5,557	709	350,797
Slight injury	1,957	3,629	21,212	7,231	2,677	634	37,340
PDO	0	0	0	2795	764	400	3,959

Source: (Wijnen et al., 2017)

Table 3

Casualty Unit Cost and Components

Severity Level	Medical Costs	Production Loss	Human Costs	Property Damage	Administrative Costs	Other Costs	Total Unit Costs (€)
Fatalities	5,430	655,376	1,587,001	11,555	6,346	3,638	2,269,346
Serious Injuries	16,719	43,627	230,385	7,622	4,364	413	303,130
Slight Injuries	1,439	2,669	15,597	5,317	1,876	519	27,417

Source: (Wijnen et al., 2017)

In iRAP, the number of casualties reduced due to countermeasure implementation depend on the risk factors that change the star rating score for the 100m road segments. This data was the basis in estimating the number of fatalities and injuries and the number of crashes for all severity levels using the ratios (Table 4 and Table 5) developed from real crash and casualty data (Table 1).

Table 4

Relationship between Crash and Casualty Severity Levels

Crash	Casualties		
	Fatalities	Serious Injuries	Slight Injuries
Fatal	1.08	-	-
Serious Injury	-	1.14	-
Slight Injury	-	-	1.35

Source: (Author's own computation)

Table 5
Relationship between Casualty Severity Levels

Casualties		
Fatality	Serious Injuries	Slight Injuries
1	7	45

Source: (Author's own computation)

The ratios in Table 4 are comparable to the number of casualties per crash by severity level in Greece and Norway (Wijnen *et al.*, 2017) and those used in other countries and studies to estimate the number of crashes (De Brabander and Veereck, 2007; Wijnen, 2020). The total number of fatalities and serious injuries (FSI) as per iRAP was split considering 7 serious injuries per fatality (Table 5) which is slightly lower than the 10 serious injuries per fatality used in iRAP (iRAP, 2015). The PDO crashes are 88.7% of the total crashes using data in Table 1 and this determined the number of PDO crashes in the crash-based approach. Therefore, in this study for every injury, there are approximately 6 PDO crashes, which is comparable to the recommended 6 PDO crashes in urban areas and 5.3 PDO crashes established in South Africa (Luathep and Tanaboriboon, 2005).

3. Results and Discussion

The study has compared crash and casualty economic analysis approaches and their impact on countermeasure selection during economic appraisal of safety related infrastructure countermeasures. It is limited to the crash and casualty data, crash-to-casualty ratios, crash/casualty unit costs and the cost of countermeasures presented. In addition, other principles involved in cost estimation such as discounting are not considered.

3.1. Comparing the total cost of crashes and casualties

Table A2 presents the cost of crashes and casualties computed using crash/casualty numbers with their respective unit costs. Considering all the severity levels in both cases, on average, the total cost of crashes is higher by over 70% compared to the total cost of casualties. In countries like Finland and Norway, the total cost of crashes is much higher since 99% of the total crashes are PDO crashes. On average, the PDO crashes are approximately 90% of the total number of crashes and these account for over 30% of the total cost of crashes which agrees with the previous findings by Wijnen *et al.* (2017) where in Germany and Finland the PDO crashes had a share of up to 50% of the total cost of road crashes. Similarly, in a study conducted in Singapore, the PDO crashes were 50% of the total cost of crashes (Chin, 2003). In addition, in Netherlands, about 24% of the total cost of crashes is attributable to PDO crashes (SWOV, 2020). This implies that PDO crashes generally have a significant impact on the total cost of crashes and thus on the results of an economic analysis of countermeasures. Therefore, in an economic appraisal of road safety countermeasures, considering the number of crashes prevented gives a more realistic representation of the actual benefits that might accrue with countermeasure implementation than the casualty approach. In addition, the safety benefits are higher in a crash-based approach as the crash unit cost is usually higher than a casualty unit cost since crashes include one or more vehicles and persons (Wijnen *et al*., 2017; De Brabander and Vereeck, 2007).

3.2. The Impact of Crash and Casualty Approaches on Countermeasure Selection

Table A3 presents the recomputed BCR values using the iRAP approach, which have changed significantly largely due to the unit costs and ratios used presented in Table 3 and Table 5 respectively that perhaps differ from those used to compute the BCR values in Table A1. The iRAP model performs economic analysis of single or multiple countermeasures during the preparation of the safer roads investment plans (iRAP, 2015). Although iRAP does not consider all the injury severity levels, it is typically a casualty-based model. In this approach, the number of fatalities and serious injuries saved are considered and this results into the selection of 26 countermeasures (Table A3).

Including the number of slight injuries saved in the casualty-based approach results in the selection of 30 countermeasures presented in Table A4. This represents an increase of 15% in the number of countermeasures selected compared to the iRAP approach. In addition, the value of safety benefits increases by 28% for each of the countermeasures in the casualty-based approach. For example, the safety benefits of implementing signalised crossings increase from €5.5 million in the iRAP approach to €7.0 million in the casualty-based approach.

Generally, the change in the number of countermeasures selected and safety benefits is significant because slight injuries on average are 85% of the total number of casualties and account for over 20% of the total cost of casualties (Table A2) which is between 1.9% and 34% previously established by Wijnen *at al*. (2017). In Great Britain (DfT, 2020), the slight injuries were 79% of the total number of casualties in 2019. This gives an implication, that even in a casualty-based model like iRAP, it is important to consider slight injuries during economic appraisal of countermeasures as they have a significant impact on countermeasure selection.

In the crash-based approach, there are 33 countermeasures selected for implementation as presented in Table A5. This accounts for a 10% increase in the number of countermeasures selected compared to the casualty-based approach shown in Table A4. In addition, the safety benefits increase by 26% for each of the countermeasures being analysed. For instance, the safety benefits of implementing signalised crossings increase from €7.0 million in casualty-based approach to €8.8 million in crash-based approach. Generally, the results show that a crash-based approach is more effective compared to a casualty-based approach as the BCR threshold values are increased. This explains why road safety economists should ideally work with crashes and not casualties as previously recommended by Harmon *et al.* (2018). The increase is justified partly by the large number of PDO crashes, which on average are 90% of the total crashes (c.f. Table A2) which is comparable to 88.3% established on the network of Korean expressways in 2008 by Park *et al.* (2012). Therefore, in a casualty-based approach, there is a likelihood of a good number of crashes not considered that may not result in any casualty as seen above.

The difference in unit costs together with the number of PDO crashes have a much higher impact on the economic analysis results. This supports the previous argument by Wijnen *et al.* (2017) where the PDO crashes are major cost components in most countries and their exclusion might result in underestimation of total cost of crashes. This impact is cumulative with more severity levels considered and becomes substantial with the addition of PDO crashes, which are usually more than the other severity levels. The implementation of a particular measure may have differing effects depending on the severity level, which is important in any evaluation. It is important at this stage to remember that most infrastructure measures are designed based on an analysis of crash data and accident causation and not on casualties' causation thus leading to countermeasure effectiveness often expressed in terms of a crash reduction and not a casualty reduction, hence the common term CMF. In addition, to facilitate international comparison and standardise accident data collection, economic analysis of countermeasures must also be standardised and streamlined with regard to the crash-based approach.

The analysis above is a specific case study used as a demonstrator of the need to consider crash-based costs instead of casualty-based costs and without examining whether there are constraints in the road safety budget. In addition, the overall countermeasures prioritisation procedure requires examination with regard to the existing road conditions together with the selection and prioritisation mechanism. For example, it is important to group the countermeasures with regard to their frequency of implementation and the budget source. In other words, distinction is required of the above countermeasures as routine, periodic or rehabilitation works. This can have a significant impact on the final selection of countermeasures together with any budget constraints of the agency responsible for implementing the above countermeasures programme (Azmi and Evdorides, 2019).

4. Conclusion

Based on the above analysis, the following conclusions may be drawn:

1. The total cost of road crashes is higher than that of casualties;
2. A crash-based approach is superior to a casualty-based approach that underestimates safety benefits;
3. A crash-based approach results in a wider range of countermeasures selected for implementation due to enhanced economic justification;
4. A crash-based approach does not change the priority of the countermeasures;
5. A more comprehensive countermeasure selection and prioritisation process is required to take into account budget constraints, road safety implementation works, discounting and full life cycle analysis.

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Appendices

Table A1

Infrastructure Improvement Program (Utrecht)

S/N	Countermeasure	Length / Sites	Fatalities & serious injuries saved	Present value of safety benefit (€)	Estimated Cost (€)	Program BCR
1	Signalised crossing	1 sites	10	3,233,649	45,000	72
2	Improve curve delineation	0.40 km	0.5	148,419	7,460	20
3	Sight distance (obstruction removal)	1.40 km	2	678,298	35,280	19
4	Pedestrian fencing	27.20 km	9	2,976,955	179,606	17
5	Street lighting (intersection)	14 sites	21	6,599,575	504,000	13
6	Refuge Island	14 sites	14	4,606,949	416,422	11
7	Shoulder rumble strips	199.30 km	84	27,156,276	2,382,592	11
8	Protected turn lane (unsignalised 4 leg)	3 sites	14	4,375,323	535,399	8
9	Unsignalised crossing	5 sites	4	1,230,100	217,465	6
10	Centreline rumble strip / flexi-post	1.80 km	0.3	108,423	19,512	6
11	Central hatching	5.70 km	0.6	184,481	34,173	5
12	Parking improvements	1.50 km	0.3	99,666	18,900	5
13	Improve Delineation	45.70 km	13	4,190,892	847,446	5
14	Traffic calming	2.90 km	1	370,148	87,581	4
15	Central median barrier (no duplication)	0.70 km	1	365,701	95,182	4
16	Protected turn lane (unsignalised 3 leg)	54 sites	74	23,918,473	7,210,571	3
17	Footpath provision driver side (adjacent to road)	27.90 km	35	11,319,681	4,388,280	3
18	Footpath provision passenger side (>3m from road)	26.80 km	29	9,267,974	3,085,368	3
19	Footpath provision driver side (>3m from road)	25.40 km	28	9,060,036	2,922,040	3
20	Bicycle Lane (off-road)	3.50 km	3	1,122,681	392,156	3
21	Footpath provision passenger side (informal path >1m)	5.80 km	1	406,768	141,451	3
22	Footpath provision driver side (informal path >1m)	4.70 km	1	307,139	114,747	3
23	Roadside barriers - driver side	206.20 km	199	64,041,774	27,898,500	2
24	Roadside barriers - passenger side	159.20 km	111	35,791,424	21,558,000	2
25	Footpath provision passenger side (adjacent to road)	44.10 km	52	16,843,531	6,939,120	2
26	Central median barrier (1+1)	34.80 km	41	13,286,137	6,288,200	2
27	Wide centreline	12.50 km	0.6	181,898	75,710	2
28	Delineation and signing (intersection)	8 sites	0.5	149,378	88,582	2
29	Road surface rehabilitation	0.80 km	0.4	115,173	70,435	2
30	Clear roadside hazards - driver side	0.10 km	0.1	34,232	20,000	2
31	Additional lane (2 + 1 road with barrier)	15.10 km	80	25,660,031	20,655,000	1
32	Shoulder sealing driver side (>1m)	103.50 km	40	12,712,184	9,156,140	1
33	Shoulder sealing passenger side (>1m)	71.50 km	29	9,428,574	6,334,720	1
34	Duplication with median barrier	1.20 km	26	8,323,159	6,480,000	1
35	Street lighting (mid-block)	10.30 km	4	1,352,702	1,483,200	1
36	Upgrade pedestrian facility quality	43 sites	3	826,756	767,405	1
37	Lane widening (up to 0.5m)	1.00 km	2	684,333	656,756	1
38	Overtaking lane	0.30 km	1	339,394	405,000	1
39	Shoulder sealing passenger side (<1m)	6.60 km	0.9	292,349	294,490	1
40	Protected turn provision at existing signalised site (4-leg)	1 sites	0.6	204,497	237,955	1
41	Lane widening (>0.5m)	0.10 km	0.6	186,272	152,529	1
42	Clear roadside hazards (bike lane)	1.20 km	0.5	160,633	216,000	1
43	Shoulder sealing driver side (<1m)	1.50 km	0.2	68,926	66,640	1
44	Side road signalised pedestrian crossing	1 sites	0.1	28,480	45,000	1
45	Street lighting (ped crossing)	2 sites	0.1	26,839	36,000	1

Source: (IRAP, 2021)

Table A2

Comparing the Cost of Crashes and Casualties

Country	Crashes					Casualties				Cost of crashes/Cost of casualties
	Fatal	Serious	Slight	PDO	Total cost of crashes (€)	Fatal	Serious	Slight	Total cost of casualties (€)	
Austria	429	9,262	26,917	646,553	7,920,295,531	523	10,502	34,522	5,316,828,892	1.49
Estonia	61	433	1,345	29,218	475,115,953	67	467	1,756	341,752,144	1.39
Finland	208	475	4,641	478,863	2,772,192,852	229	519	6,186	846,606,266	3.27
Germany	3,187	58,744	240,504	2,104,250	46,137,923,908	3,377	67,732	321,803	37,018,055,453	1.25
Iceland	16	155	741	5,500	145,082,415	16	178	1,130	121,247,886	1.20
Ireland	179	398	4,399	21,734	851,577,882	188	508	6,252	752,038,172	1.13
Norway	148	597	4,380	403,719	2,353,003,850	160	693	5,670	728,618,840	3.23
Slovenia	112	868	5,605	11,358	847,606,898	120	932	7,778	768,088,106	1.10
UK	1,658	20,676	123,988	2,232,305	24,996,617,407	1,775	22,807	169,895	15,599,586,275	1.60

Source: (Author's own computation)

Table A3

Countermeasures Selected using the iRAP Approach

S/N	Countermeasure	Length / Sites	Fatalities	Serious injuries	Safety benefit (€)	Estimated Cost (€)	Program BCR
1	Signalised crossing	1 sites	1.3	8.8	5,489,070	45,000	122
2	Improve curve delineation	0.40 km	0.1	0.4	274,454	7,460	37
3	Sight distance (obstruction removal)	1.40 km	0.3	1.8	1,097,814	35,280	31
4	Pedestrian fencing	27.20 km	1.1	7.9	4,940,163	179,606	28
5	Street lighting (intersection)	14 sites	2.6	18.4	11,527,047	504,000	23
6	Shoulder rumble strips	199.30 km	10.5	73.5	46,108,188	2,382,592	19
7	Refuge Island	14 sites	1.8	12.3	7,684,698	416,422	18
8	Protected turn lane (unsignalised 4 leg)	3 sites	1.8	12.3	7,684,698	535,399	14
9	Unsignalised crossing	5 sites	0.5	3.5	2,195,628	217,465	10
10	Central hatching	5.70 km	0.1	0.5	329,344	34,173	10
11	Parking improvements	1.50 km	0.0	0.3	164,672	18,900	9
12	Centreline rumble strip / flexi-post	1.80 km	0.0	0.3	164,672	19,512	8
13	Improve Delineation	45.70 km	1.6	11.4	7,135,791	847,446	8
14	Traffic calming	2.90 km	0.1	0.9	548,907	87,581	6
15	Central median barrier (no duplication)	0.70 km	0.1	0.9	548,907	95,182	6
16	Protected turn lane (unsignalised 3 leg)	54 sites	9.3	64.8	40,619,118	7,210,571	6
17	Footpath provision driver side (>3m from road)	25.40 km	3.5	24.5	15,369,396	2,922,040	5
18	Footpath provision passenger side (>3m from road)	26.80 km	3.6	25.4	15,918,303	3,085,368	5
19	Footpath provision driver side (informal path >1m)	4.70 km	0.1	0.9	548,907	114,747	5
20	Footpath provision driver side (adjacent to road)	27.90 km	4.4	30.6	19,211,745	4,388,280	4
21	Wide centreline	12.50 km	0.1	0.5	329,344	75,710	4
22	Bicycle Lane (off-road)	3.50 km	0.4	2.6	1,646,721	392,156	4
23	Footpath provision passenger side (adjacent to road)	44.10 km	6.5	45.5	28,543,164	6,939,120	4
24	Roadside barriers - driver side	206.20 km	24.9	174.1	109,232,493	27,898,500	4
25	Footpath provision passenger side (informal path >1m)	5.80 km	0.1	0.9	548,907	141,451	4
26	Central median barrier (1+1)	34.80 km	5.1	35.9	22,505,187	6,288,200	4

Source: (Author's own computation)

Table A4

Countermeasures Selected using the Casualty-based Approach (all Severity Levels)

S/N	Countermeasure	Length / Sites	Fatalities	Serious injuries	Slight injuries	Safety benefit (€)	Estimated Cost (€)	Program BCR
1	Signalised crossing	1 sites	1.3	8.8	56.4	7,035,172	45,000	156
2	Improve curve delineation	0.40 km	0.1	0.4	2.8	351,759	7,460	47
3	Sight distance (obstruction removal)	1.40 km	0.3	1.8	11.3	1,407,034	35,280	40
4	Pedestrian fencing	27.20 km	1.1	7.9	50.8	6,331,655	179,606	35
5	Street lighting (intersection)	14 sites	2.6	18.4	118.4	14,773,861	504,000	29
6	Shoulder rumble strips	199.30 km	10.5	73.5	473.7	59,095,445	2,382,592	25
7	Refuge Island	14 sites	1.8	12.3	78.9	9,849,241	416,422	24
8	Protected turn lane (unsignalised 4 leg)	3 sites	1.8	12.3	78.9	9,849,241	535,399	18
9	Unsignalised crossing	5 sites	0.5	3.5	22.6	2,814,069	217,465	13
10	Central hatching	5.70 km	0.1	0.5	3.4	422,110	34,173	12
11	Parking improvements	1.50 km	0.0	0.3	1.7	211,055	18,900	11
12	Centreline rumble strip / flexi-post	1.80 km	0.0	0.3	1.7	211,055	19,512	11
13	Improve Delineation	45.70 km	1.6	11.4	73.3	9,145,724	847,446	11
14	Traffic calming	2.90 km	0.1	0.9	5.6	703,517	87,581	8
15	Central median barrier (no duplication)	0.70 km	0.1	0.9	5.6	703,517	95,182	7
16	Protected turn lane (unsignalised 3 leg)	54 sites	9.3	64.8	417.3	52,060,273	7,210,571	7
17	Footpath provision driver side (>3m from road)	25.40 km	3.5	24.5	157.9	19,698,482	2,922,040	7
18	Footpath provision passenger side (>3m from road)	26.80 km	3.6	25.4	163.5	20,401,999	3,085,368	7
19	Footpath provision driver side (informal path >1m)	4.70 km	0.1	0.9	5.6	703,517	114,747	6
20	Footpath provision driver side (adjacent to road)	27.90 km	4.4	30.6	197.4	24,623,102	4,388,280	6
21	Wide centreline	12.50 km	0.1	0.5	3.4	422,110	75,710	6
22	Bicycle Lane (off-road)	3.50 km	0.4	2.6	16.9	2,110,552	392,156	5
23	Footpath provision passenger side (adjacent to road)	44.10 km	6.5	45.5	293.2	36,582,894	6,939,120	5
24	Roadside barriers - driver side	206.20 km	24.9	174.1	1122.2	139,999,922	27,898,500	5
25	Footpath provision passenger side (informal path >1m)	5.80 km	0.1	0.9	5.6	703,517	141,451	5
26	Central median barrier (1+1)	34.80 km	5.1	35.9	231.2	28,844,205	6,288,200	5
27	Road surface rehabilitation	0.80 km	0.1	0.4	2.3	281,407	70,435	4
28	Delineation and signing (intersection)	8 sites	0.1	0.4	2.8	351,759	88,582	4
29	Roadside barriers - passenger side	159.20 km	13.9	97.1	626.0	78,090,409	21,558,000	4
30	Clear roadside hazards - driver side	0.10 km	0.0	0.1	0.6	70,352	20,000	4

Source: (Author's own computation)

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Table A5

Countermeasures Selected using the Crash-based Approach

S/N	Countermeasure	Length / Sites	Fatal	Serious injury	Slight injury	PDO	Safety benefit (€)	Estimated Cost (€)	Program BCR
1	Signalised crossing	1 sites	1.2	7.7	41.9	397.5	8,829,598	45,000	196
2	Improve curve delineation	0.40 km	0.1	0.4	2.1	19.9	441,480	7,460	59
3	Sight distance (obstruction removal)	1.40 km	0.2	1.5	8.4	79.5	1,765,920	35,280	50
4	Pedestrian fencing	27.20 km	1.0	6.9	37.7	357.8	7,946,638	179,606	44
5	Street lighting (intersection)	14 sites	2.4	16.1	88.0	834.8	18,542,156	504,000	37
6	Shoulder rumble strips	199.30 km	9.8	64.5	352.1	3339.4	74,168,624	2,382,592	31
7	Refuge Island	14 sites	1.6	10.8	58.7	556.6	12,361,437	416,422	30
8	Protected turn lane (unsignalised 4 leg)	3 sites	1.6	10.8	58.7	556.6	12,361,437	535,399	23
9	Unsignalised crossing	5 sites	0.5	3.1	16.8	159.0	3,531,839	217,465	16
10	Central hatching	5.70 km	0.1	0.5	2.5	23.9	529,776	34,173	16
11	Parking improvements	1.50 km	0.0	0.2	1.3	11.9	264,888	18,900	14
12	Centreline rumble strip / flexi-post	1.80 km	0.0	0.2	1.3	11.9	264,888	19,512	14
13	Improve Delineation	45.70 km	1.5	10.0	54.5	516.8	11,478,478	847,446	14
14	Traffic calming	2.90 km	0.1	0.8	4.2	39.8	882,960	87,581	10
15	Central median barrier (no duplication)	0.70 km	0.1	0.8	4.2	39.8	882,960	95,182	9
16	Protected turn lane (unsignalised 3 leg)	54 sites	8.6	56.9	310.2	2941.8	65,339,026	7,210,571	9
17	Footpath provision driver side (>3m from road)	25.40 km	3.3	21.5	117.4	1113.1	24,722,875	2,922,040	8
18	Footpath provision passenger side (>3m from road)	26.80 km	3.4	22.3	121.6	1152.9	25,605,835	3,085,368	8
19	Footpath provision driver side (informal path >1m)	4.70 km	0.1	0.8	4.2	39.8	882,960	114,747	8
20	Footpath provision driver side (adjacent to road)	27.90 km	4.1	26.9	146.7	1391.4	30,903,593	4,388,280	7
21	Wide centreline	12.50 km	0.1	0.5	2.5	23.9	529,776	75,710	7
22	Bicycle Lane (off-road)	3.50 km	0.3	2.3	12.6	119.3	2,648,879	392,156	7
23	Footpath provision passenger side (adjacent to road)	44.10 km	6.0	39.9	218.0	2067.2	45,913,910	6,939,120	7
24	Roadside barriers - driver side	206.20 km	23.1	152.9	834.1	7911.1	175,709,003	27,898,500	6
25	Footpath provision passenger side (informal path >1m)	5.80 km	0.1	0.8	4.2	39.8	882,960	141,451	6
26	Central median barrier (1+1)	34.80 km	4.8	31.5	171.9	1629.9	36,201,352	6,288,200	6
27	Road surface rehabilitation	0.80 km	0.0	0.3	1.7	15.9	353,184	70,435	5
28	Delineation and signing (intersection)	8 sites	0.1	0.4	2.1	19.9	441,480	88,582	5
29	Roadside barriers - passenger side	159.20 km	12.9	85.3	465.3	4412.7	98,008,539	21,558,000	5
30	Clear roadside hazards - driver side	0.10 km	0.0	0.1	0.4	4.0	88,296	20,000	4
31	Shoulder sealing passenger side (>1m)	71.50 km	3.4	22.3	121.6	1152.9	25,605,835	6,334,720	4
32	Shoulder sealing driver side (>1m)	103.50 km	4.6	30.7	167.7	1590.2	35,318,393	9,156,140	4
33	Duplication with median barrier	1.20 km	3.0	20.0	109.0	1033.6	22,956,955	6,480,000	4

Source: (Author's own computation)

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