Technical Background Paper for the GRSF Road Safety Calculator

Equations and Parameters

July 2025

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The Road Safety Calculator was developed by the **Global Road Safety Facility** (GRSF), a multidonor partnership managed by the World Bank that supports efforts in low and middle-income countries to halve road traffic fatalities and serious injuries by 2030.

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1 Introduction

The World Bank's Global Road Safety Facility (GRSF) recognizes the challenging situation faced by policymakers, engineers, planners, public health practitioners, and road safety advocates in low and middle-income countries (LMICs).

These challenges include the following:

- In many countries, population growth and economic expansion are fueling rapid increases in the demand for travel, but the development of roadway infrastructure has not been able to keep pace.
- Highways originally built to serve high-speed rural traffic are often the path of least resistance for new urban development. Incompatibilities between road design and user needs can result in major conflicts between motorized traffic and non-motorized users such as pedestrians, bicyclists, and bicycle rickshaw users.
- Many countries have rapidly growing fleets of vehicles that fall far short of global safety standards. Assuring these fleets are kept in a state of good repair is often challenging.
- Roadside vendors and businesses, while providing employment opportunities, can contribute to disorganized use of the road space. In more extreme cases, entrepreneurs illegally operate businesses on roadway right-of-way, putting themselves and their customers at risk of being struck by passing vehicles.
- Driver training and licensing programs frequently need to be strengthened, traffic law enforcement resources are often scarce, and in many cases emergency medical services are yet not deployed at a scale sufficient to respond promptly to road casualties.

Thus, in spite of a sincere desire to save lives and prevent injuries, it can be difficult to determine which aspects of road safety to prioritize. To address this situation, GRSF commissioned the development of the Road Safety Calculator, a web-based analysis tool designed to support the selection of situationally appropriate road safety strategies.

What does the road safety calculator do?

The GRSF Road Safety Calculator is a tool designed to help road safety policymakers make informed decisions on planning road safety investments. Currently, the calculator incorporates interventions covering all pillars of road safety (except for vehicle safety) and helps decisionmakers select the most effective road safety strategies for the road safety issues faced by their countries. For this purpose, road crash deaths and injury profiles are used along with Casualty Modification Factors (CMFs) derived through systematic reviews.

The GRSF Road Safety Calculator allows users to input basic information on current road safety status, road use, behavior status, etc. The output from this tool provides estimates of potential benefits in terms of reductions in deaths and serious injuries in selected road safety strategic priorities.

The Road Safety Calculator is designed to help answer questions like these:

- As technical lead for the Transport Ministry, you have been allocated the equivalent of $1 million US dollars to spend on road safety. What will yield the best return?
- Motorized two-wheeler drivers say helmets are too uncomfortable in the country's hot climate. What will be the likely effect of repealing the achievement of the targeted helmet use rate?
- National highways pass through many small communities. The National Association of Village Mayors is asking for money to install speed humps and other traffic calming measures at all village entrances nationwide. Would this be an effective way to prevent casualties?

In high-income countries (HICs), such questions are typically answered through geospatial (GIS) analysis based on data from police crash reports. This is possible because HIC law enforcement agencies devote substantial resources to collecting and maintaining records of nearly all roadway crashes—even those that only involve relatively minor property damage. In addition, most HICs have transportation ministry personnel who are tasked with gathering the crash records from every local police station, electronically mapping the location of each and every crash, and digitizing crash attributes such as contributing circumstances, severity, and the number of people affected. The scale of this effort is considerable: in the United States, a country of about 325 million people, there are more than 6 million police-reported crashes each year.

Such intensive recordkeeping is rare in LMICs, so the Road Safety Calculator takes a different analytical approach:

- The Calculator will ask for basic data inputs such as the targeted area-level (national or city, etc.) road casualty estimates, user behavior (helmet use rate, etc.), and infrastructure (proportion of low-speed roads with traffic calming, etc.). The user can enter the numbers directly. The Calculator provides links to suggested data sources: WHO GRSInfo: An app for road safety data (see country-specific data) WHO Global Health Observatory, and IHME Global Burden of Disease.
- Based on user input, the calculator determines what proportion of the existing crashes is amenable to a specific road safety strategic priority. For example, a motorized two-wheeler helmet use increase only affects motorized two-wheeler casualties and is assumed to have no effect on crashes involving motor vehicle occupants, pedestrians, or bicyclists.
- After the attributable fraction of casualties has been determined, casualty modification factors (CMFs) or calculation parameters are applied to estimate how many casualties will remain after the target of the strategic priority is achieved.
- The change in casualties is then reported to the user as the number of expected changes in casualties and the percent change in the existing casualties.

The Road Safety Calculator has two main modules: the Generate Optimal Road Safety Plan and the Analysis by Strategic Priorities.

Generate Optimal Road Safety Plan

This module enables users to estimate road safety outcomes (annual changes in fatalities and serious injuries) in all ten strategic priorities with optimal targets (e.g., achieving 95 percent of helmet use, achieving 95 percent of seatbelt use, etc.) all together. In the result, the user can see the baseline and the potential reduction in road crash casualties by strategic priority with optimal targets. Some strategic priorities can be related to each other and might double-count some of the benefits.

Analysis by Strategic Priorities

This module enables users to set their own target and estimate road safety outcomes by strategic priority (e.g., set the targeted percentage of helmet use, etc.).

2 Selection and Inclusion of Road Safety Strategic Priorities

Road safety is a multi-sectoral issue with various strategies for improvement. Hundreds of methods for improving roadway safety have been proposed, and many ineffective interventions have often been adopted and are still being applied due to mistaken belief, ease of application, political acceptance, low cost, and popularity. In some cases, there is poor research evidence that provides misleading results. It is of profound importance that resources are not wasted on these ineffective interventions on behalf of road safety but rather that strictly evidence-based road safety interventions are used in World Bank and other projects and the choice of actions in any road safety program. Thus, the selection of interventions for the Road Safety Calculator should rely on effective interventions with sound research evidence. Effective interventions are defined as those that reduce fatal and serious injuries and the most effective interventions are those that substantially reduce or eliminate these injuries. Ineffective interventions are those interventions that do not reduce these injuries.

Since the Road Safety Calculator is a quantitative tool, it focuses on strategics priorities where the effects on crash outcomes have been measured, usually through empirical before-after studies or comparisons of crash rates for different types of roads. GRSF has published guidance on "Road Safety Interventions: Evidence of What Works and What Does Not Work", which summarizes highly effective interventions across all pillars of road safety. Additionally, the UN has also set twelve global voluntary targets and activities at the national level such that countries can work towards achieving the goals of the Second UN Decade of Action of Road Safety. It was thus expected that the included interventions are effective and aligned with United Nation's twelve global voluntary targets as much as possible. With this in mind, a total of twenty different road safety interventions were identified for systematic reviews and the consideration of their inclusion in the strategic priorities of the Road Safety Calculator.

Although there are several ways to categorize safety interventions, for the purposes of the Road Safety Calculator they are organized into ten strategic priorities:

1. Helmet use
2. Seatbelt use
3. Alcohol use
4. Sidewalks
5. Intersections
6. Divided highways
7. Roadside barriers
8. High-speed roads
9. Traffic calming
10. Post-crash care

Subsequent sections of this document describe the analytical approach used in each of these modules. Where possible, CMFs used the Calculator include information from high-quality studies performed in LMICs. Nevertheless, it must be recognized that some promising interventions have never been applied in LMICs, or no quantitative studies from LMICs are available. For example, the conversion of two-lane rural highways to the "2 + 1" configuration (two lanes in one direction and one lane in the other direction, separated by a median cable barrier) has only been quantitatively evaluated for highways in Sweden.

3 Strategic Priorities

3.1 Helmet Use

Powered two-wheeler crashes frequently result in traumatic injury and mortality when the driver or passenger's head hits the ground, a vehicle, or a roadside object. Consistent use of high-quality helmets has been shown to reduce fatalities for riders of powered two-wheelers such as mopeds, powered scooters, and full-size motorized two-wheelers.

This module enables users to compute the reduction percentage of fatalities or serious injuries among motorized two-wheelers who wear helmets. The efficacy of this module relies on the baseline motorized two-wheeler helmet usage rate, as well as the target rate to be achieved. It is crucial that the helmet use rates input in the Road Safety Calculator represent proper helmet use that conform to technical standards such as those published by the United Nations Economic Commission for Europe (UNECE). Riders and passengers who wear substandard or unfastened helmets should be deducted from the helmet use rates.

Casualty Modification Factors/Parameters

Table 1 summarizes CMFs for changes in helmet use rates at the individual level. The most comprehensive analysis of the effects of motorized two-wheeler helmets is the Cochrane review by Liu et al. (2008) which reviewed 61 studies on the effects of helmet use, of which 4 were determined to be suitable for inclusion in statistical meta-analysis of helmet effects on fatalities. The primary studies appear to be based mainly on hospital admissions data, comparing the probability of death for a motorcyclist transported to hospital who was wearing a helmet at the time of the crash with those who were not wearing helmets when they crashed.

The Liu review also prepared a meta-analysis of helmet effects on non-fatal head trauma, but these CMFs are unsuitable for use the Calculator. In the Calculator, "Serious Injury" includes all injuries that require at least one night of hospitalization. Injuries to the arms, shoulders, spine, legs, and abdomen frequently occur in motorized two-wheeler crashes, and helmets provide little or no benefit for these injuries. A review by Elvik et al. (2009) appears to provide the best-available estimate of the overall effects of helmets on all types of non-fatal injuries.

Table 1. CMFs for motorized two-wheeler helmet use

Review	Income level of area(s) studied	No. of included primary studies	Fatality CMF (95% CI)	Injury CMF (95% CI)
Liu et al. (2008)	Mixed	4	0.58 (0.50, 0.68)	-
Elvik et al. (2009)	HICs	Not stated	-	0.75 (0.70, 0.80)

Equations

An increase in the helmet use rate will save motorcyclist's lives when the helmet meets safety standards, with no effects on casualties involving motor vehicle occupants, pedestrians, bicyclists, or other road users. The expected amount of casualty reduction (If increasing, this becomes a negative number) is calculated with the below equations:

$$F = F_{mc} \times (H_t - H_b) \times (SS_t - SS_b) \times \left(1 - CMF_f\right) \quad (1)$$

$$SI = SI_{mc} \times (H_t - H_b) \times (SS_t - SS_b) \times (1 - CMF_{si}) \qquad (2)$$

Where:

F = expected reduction or change in the number of fatalities (note: a positive number represents an expected reduction and a negative number represents an expected increase. See footnote for expanded explanation)[1]

SI = expected reduction or change in the number of serious injuries (note: a positive number represents an expected reduction and a negative number represents an expected increase. See footnote for expanded explanation)[2]

F_{mc}= number of fatalities of motorized two-wheelers (age 15 and above)

SI_{mc}= number of serious injuries of motorized two-wheelers (age 15 and above)

H_t= target rate of motorized two-wheeler helmet use (percent)

H_b= baseline rate of motorized two-wheeler helmet use (percent)

SS_t= target rate of helmets meeting safety standards (percent)

SS_b= baseline rate of helmets meeting safety standards (percent)

CMF_f= CMF for fatality

CMF_{si}= CMF for serious injury

[1] For values F and SI, an expected *reduction* in the number of fatalities or serious injuries is expressed as a positive number. Conversely, an expected *increase* in the number of fatalities or serious injuries is expressed as a negative number. Therefore, these equations are used to estimate the potential impact of both increases and decreases in fatalities and serious injuries.

[2] See above.

3.2 Seatbelt Use

This module relates to efforts to increase the rate of seatbelt wearing in personal motor vehicles such as cars, light trucks, vans, and sport-utility vehicles (SUVs). For example, it could be applied to a public information campaign that is expected to raise the rate of proper seat belt wearing from 80 to 85 percent. Note that the logic differs substantially from population-wide interventions such as legislation mandating seat belt use, where effectiveness is diluted by non-compliance with the law.

This module applies to a subset of the "motor vehicle occupant" crashes in the Road Safety Calculator. Mode shares are required to exclude crashes for occupants of other types of vehicles, namely powered three-wheelers (sometimes called auto rickshaws, CNGs, or tuk-tuks), buses, and heavy trucks.

Casualty Modification Factors/Parameters

Table 2 summarizes CMFs for changes in seatbelt use rates at the individual level. The most comprehensive available analysis of the effect of seatbelts on the risk of being killed or injured in an accident for those who wear or do not wear a seatbelt appears to be Høye and Elvik (2015), which summarized findings from 24 primary studies published since 2000. All studies included in their meta-analysis were from high-income countries (United States and Western Europe). The results show that seatbelt use reduces the risk of being killed or injured by 60 percent (c.i. -66; -53) in the front seats and by 44 percent (-58; -27) in the rear seats. No comparable data for LMICs has been found.

Table 2. CMFs for individual seatbelt use

Review	Income level of area(s) studied	No. of included primary studies	Fatality CMF (95% CI)		Serious Injury CMF (95% CI)	
			Front	Rear	Front	Rear
Høye and Elvik (2015)	HICs	24	0.40 (0.34, 0.47)	0.56 (0.42, 0.73)	0.40 (0.34, 0.47)	0.56 (0.42, 0.73)

Equations

An increase in the seatbelt use rate will save motor vehicle occupant's lives. The logic assumes the available CMFs apply equally to vehicle occupant, with no effects on casualties involving riders of motorized two-wheelers, pedestrians, bicyclists, or other road users. It is also assumed that the CMFs apply equally across all four vehicle types (cars; vans, SUVs and light trucks) but have no effects on other types of vehicles. The expected amount of casualty reduction (If increasing, this becomes a negative number) is calculated below equations:

$$F = F_{mv} \times (SB_t - SB_b) \times \left(1 - CMF_f\right) \tag{3}$$

$$SI = SI_{mv} \times (SB_t - SB_b) \times (1 - CMF_{si}) \tag{4}$$

Where:

F = expected reduction or change in the number of fatalities (note: a positive number represents an expected reduction and vice-versa. See footnote on page 5 for expanded explanation)

SI = expected reduction or change in the number of serious injuries (note: a positive number represents an expected reduction and vice-versa. See footnote on page 5 for expanded explanation)

F_{mv}= number of fatalities of motorized vehicle occupants (Cars, Vans, SUVs and Light Trucks only)

SI_{mv}= number of serious injuries of motorized vehicle occupants (Cars, Vans, SUVs and Light Trucks only)

SB_t= target rate of seatbelt use weighted by seating position (percent)

SB_b= baseline rate of seatbelt use weighted by seating position (percent)

CMF_f= CMF for fatality

CMF_{si}= CMF for serious injury

3.3 Alcohol Use

According to the WHO Global Status Report on Alcohol 2018, the percentage of road fatalities attributable to alcohol impairment ranges from 0.7 percent among Syrian women to 58.6 percent among Equatorial Guinean men. The victims are often pedestrians or passengers – not necessarily the person who was drinking.

Strategies for reducing alcohol-impaired driving include lowering *per se* limits on blood alcohol concentration (BAC), zero tolerance laws for young drivers, intensive enforcement of laws prohibiting impaired driving, ignition interlocks for vehicles driven by persons previously convicted of impaired driving, and alcohol use disorder assessment and treatment programs (CDC 2022). More broadly, impaired driving can be reduced by decreasing alcohol consumption through excise taxes, prohibiting alcohol advertising, imposing stricter age limits for alcohol purchases, restricting the hours and locations where alcohol is sold, improving enforcement to prevent illegal alcohol sales and over-serving of intoxicated customers.

Casualty Modification Factors/Parameters

The alcohol use module for the Executive Overview module and the Strategic Priority module simply computes the existing number of impaired-driving casualties and multiplies the result by the targeted percentage of reduction.

Equations

The logic assumes that a reduction in casualties is equally distributed across all road users. The expected amount of casualty reduction (If increasing, this becomes a negative number) is calculated below equations:

$$F = F_{all} \times ALC \times (1 - T) \tag{5}$$
$$SI = SI_{all} \times ALC \times (1 - T) \tag{6}$$

Where:

F = expected reduction or change in the number of fatalities (note: a positive number represents an expected reduction and vice-versa. See footnote on page 5 for expanded explanation)
SI = expected reduction or change in the number of serious injuries (note: a positive number represents an expected reduction and vice-versa. See footnote on page 5 for expanded explanation)
F_{all}= number of fatalities of all road users
SI_{all}= number of serious injuries of all road users
ALC= proportion of casualties in alcohol-related crashes (percent)
T= target percent reduction of alcohol-related casualties (percent)

3.4 Sidewalks

Historically, many countries (at all income levels) have underinvested in pedestrian infrastructure such as pedestrian crossings, pedestrian signals, and sidewalks (also called footpaths, footways, pedestrian pavements, or walkways). When no sidewalk is provided, pedestrians often walk on the side slope, road shoulder, or in the roadway (Figure 1). Pedestrian path choice is also influenced by factors such as commercial activities that encroach the roadway right-of-way, crowding, pathway blockage by parked vehicles or rubbish, lack of shade, uneven or damaged pavement, steep slopes, and obstacles such as electrical poles (Debnath et al. 2021).

This intervention applies to the stand-alone retrofitting of sidewalks along the existing roadway. This can be contrasted with more comprehensive projects that rebuild the entire roadway to an urban (curb-and-gutter) cross-section.

Figure 1. The absence of sidewalks puts pedestrians in conflict with motorized traffic., Highway P208, Abidjan, Côte d'Ivoire (Image: Google StreetView)

Casualty Modification Factors/Parameters

A systematic review of sidewalk safety studies found wide-ranging CMFs (0.12 to 2.71), but most of the studies did not contain enough information to support meta-analysis. A Peruvian case-control study of the effect of providing sidewalks on child pedestrian personal injury crashes (Donroe et al. 2008) was determined to be the result most relevant to the purposes of the Road Safety Calculator. The study found that the odds of child pedestrian injury were lower if the child lived in an area with sidewalks (CMF 0.63, c.i. 0.28 to 1.42). Results in a comparable range were obtained in Ethiopia (Berhanu 2004). Since the Donroe study focused only on child casualties and did not fully control for other design features that are likely to be highly correlated with sidewalk provision, the adjusted CMFs shown in Table 3 have been implemented in the Road Safety Calculator.

Table 3. Recommended CMF and confidence intervals

Review	Income level of area(s) studied	Treatment	Crash type and severity	Fatality CMF (95% CI)	Injury CMF (95% CI)
Donroe et al. (2008); Berhanu (2004)	LMICs	Retrofit sidewalk along existing roadway	Pedestrian-involved fatal & serious injury crashes	0.75 (0.50, 1.00)	0.75 (0.50, 1.00)

Equations

The installation of sidewalks is expected to significantly improve pedestrian safety. The logic assumes that the available CMFs apply to pedestrians only. The expected amount of casualty reduction (If increasing, this becomes a negative number) is calculated below equations:

$$F = F_p \times (SW_t - SW_b) \times \left(1 - CMF_f\right) \tag{7}$$

$$SI = SI_p \times (SW_t - SW_b) \times (1 - CMF_{si}) \tag{8}$$

Where:

F= expected reduction or change in the number of fatalities (note: a positive number represents an expected reduction and vice-versa. See footnote on page 5 for expanded explanation)

SI= expected reduction or change in the number of serious injuries (note: a positive number represents an expected reduction and vice-versa. See footnote on page 5 for expanded explanation)

F_p= number of pedestrian fatalities on roads with operating speed equal to or less than 50 Km/h

SI_p= number of pedestrian serious injuries on roads with operating speed equal to or less than 50 Km/h

SW_t= target proportion of roads with speeds less than or equal to 50 Km/h with sidewalks (percent)

SW_b= baseline proportion of roads with speeds less than or equal to 50 Km/h with sidewalks (percent)

CMF_f= CMF for fatality

CMF_{si}= CMF for serious injury

3.5 Intersections

At-grade intersections (junctions) are locations with path overlaps between conflicting traffic streams. Traffic control devices such as stop signs, traffic signals, mini-roundabouts, and roundabouts address these conflicts by guiding users to share the overlapping road space.

Engineering standards establish a hierarchy of intersection treatments. Typically, the lowest level of the hierarchy is the use of yield (give way) signs or two-way stop control (stop signs). Both designate preferred movements, usually resulting in disruptions for minor (low-volume) movement(s) while giving priority to major (high-volume) movements. If the traffic volume is similar on all legs (arms) of an intersection, all-way stop control or a mini-roundabout is typically installed. When the traffic volume is too large to be handled with signage alone, a traffic signal or full-size roundabout is typically required.

In high-income countries, these upgrades are often implemented sequentially as the traffic volume increases over time. In LIMCs, traffic growth frequently outpaces roadway system upgrades, leading to the possibility that an uncontrolled junction may need to be transformed directly into a signalized junction or roundabout.

Casualty Modification Factors/Parameters

CMFs are available for several types of intersection upgrades (

Table 4). For the Generate Optimal Plan module, a blended CMF (0.7 for both fatalities and serious injuries) is used. For the Strategic Priority module, users will select a specific treatment type from a drop-down menu. CMFs for upgrading directly from uncontrolled intersections to treatments (e.g., traffic signals, all-way stops, mini-roundabouts etc.) will be established by multiplying the stop control and signal-control CMFs. CMFs that are unavailable for fatalities or serious injuries are replaced with CMFs that cover other casualty severity levels.

Table 4. CMFs for Intersection Traffic Control

Review	Income level of area(s) studied	Treatment	Fatality CMF (95% CI)	Injury CMF (95% CI)
Elvik et al. (2009)	HICs	Add yield or give way signs	-	0.97 (0.91, 1.03)
Elvik et al. (2009)	HICs	One-way stop for 3-leg intersection	-	0.81 (0.62, 1.07)
Elvik et al. (2009)	HICs	Two-way stop for 4 leg intersection	-	0.65 (0.56, 1.25)
Elvik et al. (2009)	HICs	All-way stop	Unspecific: 0.55 (0.51, 0.60)	
Zhang 2022	USA	Mini-roundabout	0.50 (-, -)	-
Elvik et al. (2009)	HICs	New signal at 3-leg intersection*	-	0.85 (0.75, 0.95)
Elvik et al. (2009)	HICs	New signal at 4-leg intersection*	-	0.70 (0.65, 0.75)

** Presumably upgrading from stop control*

Equations

Upgrading intersections from uncontrolled to controlled is expected to improve safety at the intersections. The logic assumes that the available CMFs equally apply to all road users. The expected amount of casualty reduction (If increasing, this becomes a negative number) is calculated below equations:

$$F = F_i \times I_t \times \left(1 - CMF_f\right) \tag{9}$$

$$SI = SI_i \times I_t \times (1 - CMF_{si}) \tag{10}$$

Where:

F = expected reduction or change in the number of fatalities (note: a positive number represents an expected reduction and vice-versa. See footnote on page 5 for expanded explanation)

SI = expected reduction or change in the number of serious injuries (note: a positive number represents an expected reduction and vice-versa. See footnote on page 5 for expanded explanation)

F_i= number of fatalities of all road users at uncontrolled intersections

SI_i= number of serious injuries of all road users at uncontrolled intersections

I_t= target extent of intervention (percentage of uncontrolled intersections—starting with the worst performing in terms of casualties—to be converted into controlled intersections)

CMF_f= CMF for fatality

CMF_{si}= CMF for serious injury

3.6 Divided Highways

Some of the most severe crashes involve road users who cross the centerline on undivided highways, resulting in head-on crashes or opposite-direction sideswipes. Several methods for reducing such crashes have been devised, including centerline rumble strips, flexible delineator posts installed on the centerline, painted (flush) medians, grass medians, and median barriers.

The feasibility of each option depends on site-specific conditions such as the available right-of-way width and the adjacent land use. For example, conventional centerline rumble strips can be troublesome at sharp curves near residential areas due to noise from trucks overtracking the rumble strip. Similarly, adding a median barrier is only feasible where adequate width is available and there are few at-grade intersections/driveways.

Figure 2. Centerline rumble strips provide tactile feedback to deter unintentional crossing of the centerline (Massachusetts, USA). Photo: SayCheeeeeese/Wikimedia Commons

Figure 3. Flexible plastic delineator posts provide visual and tactile separation of traffic streams (Taiwan). Photo: Z7504/Wikimedia Commons

Figure 4. Painted (flush) median (New Zealand). Photo: Ingolfson/Wikimedia Commons

Figure 5. Cable median barrier (Czech Republic). Photo: Aktron/Wikimedia Commons

Unpaved (unsurfaced) rural roads are not included in this estimate because all of the treatments (except possibly medians) require the existence of a paved surface.

Casualty Modification Factors/Parameters

CMFs are available for several types of centreline crossover crash prevention treatments. For the Generate Optimal Plan module, a blended CMF (0.5 for both fatalities and serious injuries) is used. For the Strategic Priority module, users will select a specific treatment type from a drop-down menu. CMFs that are unavailable for fatalities or serious injuries are replaced with CMFs that cover other casualty severity levels.

Table 5. CMFs for centerline crossover crash prevention treatments

Review	Income level of area(s) studied	Treatment	Fatality CMF (95% CI)	Injury CMF (95% CI)
Chattergee (2023)	MIC (India)	Add flexible delineator posts to discourage overtaking in curves	0.65 (-, -)	-
Whittaker (2012)	Australia	Add median barrier	0.4 (-, -)	0.4 (-, -)
Elvik et al. (2009)	HICs	Add painted median on undivided two-lane road	0.72 (0.37, 1.24)	-
Elvik et al. (2009)	HICs	Add two travel lanes and median to existing urban arterial	0.49 (0.35, 0.67)	0.49 (0.35, 0.67)
Meta-analysis John et al. (2021a)	Sweden	Convert existing undivided two-lane road to 2+1 road	0.50 (0.21, 0.79)	0.50 (0.21, 0.79)
iRAP toolkit	Mixed	Install center line rumble strips	0.825 (0.75, 0.90)	0.825 (0.75, 0.90)

Equations

The installation of physical divisions on high-speed roads is expected to reduce the risk of head-on casualties. The logic assumes that the available CMFs equally apply to head-on casualties of all motor vehicle types on high-speed roads. The expected amount of casualty reduction (If increasing, this becomes a negative number) is calculated below equations:

$$F = F_h \times M_t \times (1 - CMF_f) \tag{11}$$
$$SI = SI_h \times M_t \times (1 - CMF_{si}) \tag{12}$$

Where:

F = expected reduction or change in the number of fatalities (note: a positive number represents an expected reduction and vice-versa. See footnote on page 5 for expanded explanation)

SI = expected reduction or change in the number of serious injuries (note: a positive number represents an expected reduction and vice-versa. See footnote on page 5 for expanded explanation)

F_h = number of head-on fatalities on roads with operating speeds of 80 km/h and above

SI_h = number of head-on serious injuries on roads with operating speeds of 80 km/h and above

M_t = target extent of intervention (percentage of undivided roads with operating speeds of 80 km/h and above - starting with the worst performing in terms of casualties - to undergo safety treatment)

CMF_f = CMF for fatality

CMF_{si} = CMF for serious injury

3.7 Roadside Barriers

Steering errors, falling asleep while driving, loss of traction on slippery road surfaces, excessive speed, driver intoxication, and vehicle equipment failures are among the many situations that can result in vehicles leaving the travelled way (carriageway). The resulting run-off-road (ROR) crashes can be very severe if non-crashworthy objects, steep slopes, or water crossings are present within about 10 meters of the outside edge of the roadway. Typical problems in LMICs include non-frangible trees or poles in the clear zone (**Figure 6**), steep side slopes, unprotected edge drops (**Figure 7**), missing/damaged guard rails or barriers (Figure 8), and non-crashworthy guard rail or barrier end treatments (Figure 9). This intervention encompasses various efforts to bring clear zones, side slopes, roadway edges, and barrier ends into conformance with engineering standards and good design practices.

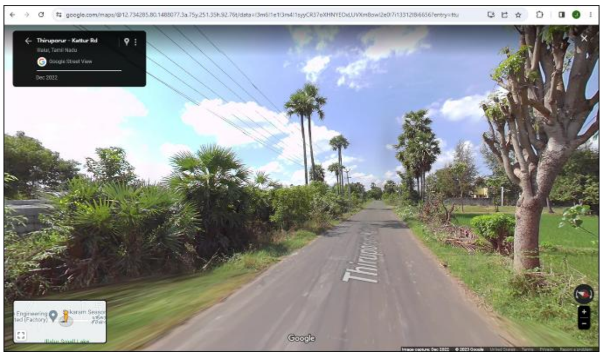

Figure 6. Non-frangible trees in the clear zone (Tamil Nadu 2022). Source: Google StreetView.

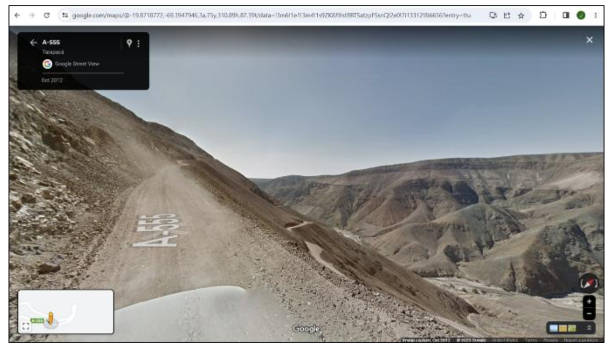

Figure 7. Steep edge drop without guard rail (northern Chile 2012) Source: Google StreetView.

Figure 8. Damaged guard rail (northern Ghana 2016) Source: Google StreetView.

Figure 9. Improper barrier end treatment (Tamil Nadu, India, 2022). Source: Google StreetView.

Casualty Modification Factors/Parameters

CMFs are available for several types of clear zone and edge-of-road barrier improvements (Jurewicz and Troutbeck 2012). For the Generate Optimal Plan module, CMFs of installing new barriers are used. For the Strategic Priority module, users will select a specific treatment type from a drop-down menu.

Table 6. CMFs for roadside barriers

Review	Income level of area(s) studied	Treatment	Fatality CMF (95% CI)	Injury CMF (95% CI)
Elvik et al. (2009)	HICs	Conversion to softer barrier	0.59 (0.34, 1.02)	0.68 (0.58, 0.80)
iRAP Toolkit	Mixed	Hazard removal	0.675 (0.60, 0.75)	0.675 (0.60, 0.75)
Elvik et al. (2009)	HICs	New barrier	0.56 (0.46, 0.68)	0.53 (0.48, 0.59)

Equations

The installation of roadside barriers is expected to reduce run-off causalities on high-speed roads. The logic assumes that the available CMFs equally apply to run-off casulaties of all motor vehicle types on high-speed roads. The expected amount of casualty reduction (If increasing, this becomes a negative number) is calculated below equations:

$$F = F_r \times B_t \times (1 - CMF_f) \tag{13}$$
$$SI = SI_r \times B_t \times (1 - CMF_{si}) \tag{14}$$

Where:

F = expected reduction or change in the number of fatalities (note: a positive number represents an expected reduction and vice-versa. See footnote on page 5 for expanded explanation)
SI = expected reduction or change in the number of serious injuries (note: a positive number represents an expected reduction and vice-versa. See footnote on page 5 for expanded explanation)
F_r= number of run-off-road fatalities on roads with operating speeds of 80 km/h and above
SI_r= number of run-off-road serious injuries on roads with operating speeds of 80 km/h and above
B_t= target extent of intervention (percentage of roads with operating speeds of 80 km/h and above with no roadside barriers - starting with the worst performing in terms of casualties - to undergo safety treatment)
CMF_f= CMF for fatality
CMF_{si}= CMF for serious injury

3.8 High-Speed Roads

Speed plays a central role in road safety outcomes in terms of the number of crashes and their severity level. Around 30 percent of fatalities in high-income countries are from speed-related cases (TRB, 1998; OECD, 2006). Estimates of speed involvement in crashes in LMICs vary, with figures ranging from less than 20 percent to almost 80 percent of injury and/or death. Peden (2004) reports a figure of approximately 50 percent of deaths in LMICs.

Both excess speed (exceeding the posted speed limit) and inappropriate speed (driving faster than the prevailing road or weather conditions allow) are important crash causation factors. It is also crucial to note that speed affects risk through both likelihood of crash occurrence and crash consequence. The rate of increase in crash risk varies with the change in speed. Knowledge regarding the impact of a change in speed on safety outcomes is critically important for good decision making.

Calculation Logics

There has been a large number of research studies to establish the relationship between speed and crash outcomes. These studies quantify safety outcomes of speed changes through "before-after" type evaluations of interventions, comparing safety outcomes before and after speed changes are made, usually taking account of other factors that might impact this change through use of "control" locations where no interventions have been used. Early examples of this research were analyzed and presented through Nilsson (2004)'s "Power Model" which identified that a 1 percent increase in average speed results in approximately a 2 percent increase in injury crash frequency, a 3 percent increase in severe crash frequency, and a 4 percent increase in fatal crash frequency.

These relationships are identified by combining the results of many different studies for which data are available on the change in speed and the change in crash outcomes. The research was conducted in many countries and involved a range of different speed-related interventions.

More recent research based on an even larger sample of studies suggests that the relationship between crash risk and speed is exponential, and not a power law (Elvik, 2013; Elvik et al., 2019). The practical implication of this research is that the effect of speed is even higher for high- speed roads than for lower speed roads and that even very small changes in speed can have a substantial impact on safety outcomes, i.e., a positive impact from a reduction in speed, and a negative one from an increase in speed. The Exponential Model also demonstrates that the more severe crash outcomes (fatal and serious crashes) are more sensitive to this change.

Equations

Reducing operating speeds is expected to reduce causalities on high-speed roads. The logic assumes that the available CMFs equally apply to casualties of all motor vehicle types on high-speed roads. The expected amount of casualty reduction (If increasing, this becomes a negative number) is calculated below equations:

$$F = F_s(1 - e^{\left[\left(S_{t'} - S_t\right) \times C_f\right]}) \tag{15}$$

$$SI = SI_s(e^{\left[\left(S_{t'} - S_t\right) \times C_s\right]}) \tag{16}$$

Where:

F = expected reduction or change in the number of fatalities (note: a positive number represents an expected reduction and vice-versa. See footnote on page 5 for expanded explanation)

SI = expected reduction or change in the number of serious injuries (note: a positive number represents an expected reduction and vice-versa. See footnote on page 5 for expanded explanation)

F_s= number of motorized fatalities on roads with operating speeds of 80 km/h and above

SI_s= number of motorized fatalities on roads with operating speeds of 80 km/h and above

$S_{t'}$= operating speed after intervention

S_t= operating speed before intervention

C_f= coefficient for fatality 0.08

C_s= coefficient for serious injury 0.06

The speed coefficients of 0.08 for fatal injury and 0.06 for serious injury summarize the relationship between speed and the number of fatal or serious injuries with standard errors of, in general, less than 0.005.

It should be noted that the coefficients are based on research that is mostly from high- income countries and that the tool has mainly been validated for homogenous free-flow traffic environments. It is uncertain how applicable the coefficients are in other countries, as the model has not been validated in these environments. Therefore, information should be treated as guidance only.

3.9 Traffic Calming

Traffic calming is an umbrella term for a variety of treatments intended to reduce crashes and improve urban livability by reducing traffic speeds and encouraging drivers to be more aware of non-motorized road users. Traffic calming treatments can broadly be categorized as those that reduce speeds through horizontal deflection of the vehicle path (such as chicanes and installing circular islands inside intersections), treatments that rely on vertical deflection (such as speed humps and raised pedestrian crossings) and perceptual treatments that give the illusion of a more constrained driving environment (such as gateways, landscaping, curb bulbouts, chokers, and paint markings that make traffic lanes look narrower).

The range of traffic calming treatment designs, treatment levels, and application environments is extraordinarily diverse. As a result, the safety outcomes identified in traffic calming studies are very broad, with some studies showing very good results, some showing little or effect, and a few showing increases in crashes. This heterogeneity is amplified by the wide range of performance measures and study designs that have been applied to assess the safety effectiveness of traffic calming projects. Most notably, some studies look only at the calmed area itself, while others consider the effects on traffic diverted from the calmed area to nearby noncalmed streets, where increased traffic volume can lead to more crashes.

Crash Modification Factors/Parameters

The evidence (Table 7) suggests that area-wide (neighborhood) traffic calming typically achieves overall crash reductions in the range of 16 to 17 percent for severe crashes, and around 20 percent for minor crashes. These results incorporate findings from projects marketed as 30 km/h or 20 mph zones, i.e., incorporating physical speed restraint measures (crash reductions are much more modest for signage-only 30 km/h or 20 mph limits). The value of greatest importance to the Road Safety Calculator is the CMF for fatal and serious injury crashes; based on the meta-analysis this is 0.83 (c.i. 0.68 to 1.01). Although this result is based on only 3 sources, it is consistent with the findings for related severity levels with much larger collections of studies. The crash reductions achieved in LMICs appear to be likely to be at the favorable end of this range, perhaps approaching 0.70.

Findings for pedestrian-involved crashes are mixed. The combined results of three studies (from Japan, Peru, and the United Kingdom) suggest a dramatic 51 percent reduction in pedestrian injuries (CMF 0.49). Nevertheless, research (mainly from HICs) shows a slight increase in the total number of pedestrian-involved crashes. These two results are not necessarily contradictory: it seems likely that pedestrian activity increases in traffic-calmed areas in part because pedestrians perceive that they are less likely to be injured if a crash occurs.

Table 7. CMFs for traffic calming on roads with speeds less than or equal to 50 km/h

Review	Income level of area(s) studied	No. of included primary studies	Road users	Fatality CMF (95% CI)	Injury CMF (95% CI)
Meta-analysis[3] John et al. (2021b)	Mixed	3	Motor vehicle occupants and riders of motorized two-wheelers	0.83 (0.68, 1.01)	0.83 (0.68, 1.01)
Meta-analysis[4] John et al. (2021b)	Mixed	2	Pedestrians	0.49 (0.23, 1.04)	0.49 (0.23, 1.04)

[3] Xu (2002), Chen (2013), and Li and Graham (2016)

[4] Donroe (2008), Li and Graham (2016), and Inada (2020)

Equations

The installation of traffic calming is expected to improve safety for both motorized vehicles and pedestrians. The logic assumes that the available CMFs for motor vehicle occupants and riders of motorized two-wheelers equally apply to casualties of all motor vehicle occupants and riders of motorized two-wheelers on roads with speeds less than or equal to 50 Km/h. Similarly, the available CMFs for pedestrians apply for pedestrian casualties on roads with speeds less than or equal to 50 Km/h. The expected amount of casualty reduction (If increasing, this becomes a negative number) is calculated below equations:

$$F = F_{mt} \times (TC_t - TC_b) \times \left(1 - CMF_f\right) + F_p \times (TC_t - TC_b) \times \left(1 - CMF_f\right) \tag{17}$$

$$SI = SI_{mt} \times (TC_t - TC_b) \times (1 - CMF_{si}) + SI_p \times (TC_t - TC_b) \times (1 - CMF_{si}) \tag{18}$$

Where:

F = expected reduction or change in the number of fatalities (note: a positive number represents an expected reduction and vice-versa. See footnote on page 5 for expanded explanation)

SI = expected reduction or change in the number of serious injuries (note: a positive number represents an expected reduction and vice-versa. See footnote on page 5 for expanded explanation)

F_{mt}= number of fatalities of motor vehicle occupants and riders of motorized two-wheelers on roads with speeds less than or equal to 50 Km/h

F_p= number of pedestrian fatalities on roads with speeds less than or equal to 50 Km/h

SI_{mt}= number of serious injuries of motor vehicle occupants and riders of motorized two-wheelers on roads with speeds less than or equal to 50 Km/h

SI_p= number of pedestrian serious injuries on roads with speeds less than or equal to 50 Km/h

TC_t= target proportion of roads with speeds less than or equal to 50 Km/h equipped with traffic calming measures (percent)

TC_b= baseline proportion of roads with speeds less than or equal to 50 Km/h equipped with traffic calming measures (percent)

CMF_f= CMF for fatality

CMF_{si}= CMF for serious injury

3.10 Post-Crash Care

The high road traffic death rates in LMICs are the result of a multitude of inter-related road safety factors, one of which is their lack of well-developed trauma systems. Research has shown that a significant contributor to trauma deaths in LMICs is prehospital deaths which occur following a crash but before the patient can be admitted to hospital. It is estimated that the proportion of trauma patients who die before reaching hospital in LICs is more than twice as high as in HICs (WHO, 2018). For example, a study by Mock et al. (1998) compared trauma mortality patterns across regions in three different countries (USA, Mexico, and Ghana) and found that in Kumasi, Ghana, prehospital deaths occurred in 51 percent of all seriously injured patients, whereas in Seattle, USA, 21 percent of patients died before reaching hospital.

Various technical approaches for analyzing the effects of improving the availability and quality of post-crash medical services have been discussed. For the Road Safety Calculator, logic for estimating road fatality reductions was developed based on expanding the geographical coverage of ambulance service availability.

Casualty Modification Factors/Parameters

The alcohol use module for the Executive Overview module simply computes the existing number of impaired-driving casualties and multiplies the result by the targeted percentage of reduction. Road Safety Calculator outputs for the safety effects of ambulance service are sensitive to assumptions about the proportion fatalities where the victim dies at the crash site or while being transported to a medical facility. CMF of 0.85 is adopted based on 2016-2020 data from NHTSA in the United States.

As shown in Figure 10, the tool logic assumes that people who die immediately as a result of the crash receive no benefit from the availability of ambulance service (dark grey cylinder). Among those who are transported to hospital, a portion still die as a result of their injuries (light grey cylinder). Those who are transported to hospital and survive (orange cylinder) are added to the existing number of serious injury cases. Due to lack of data, it is not currently possible to estimate the number of serious injury cases that are "downgraded" to minor injuries, so the tool currently assumes there is no effect on minor injuries.

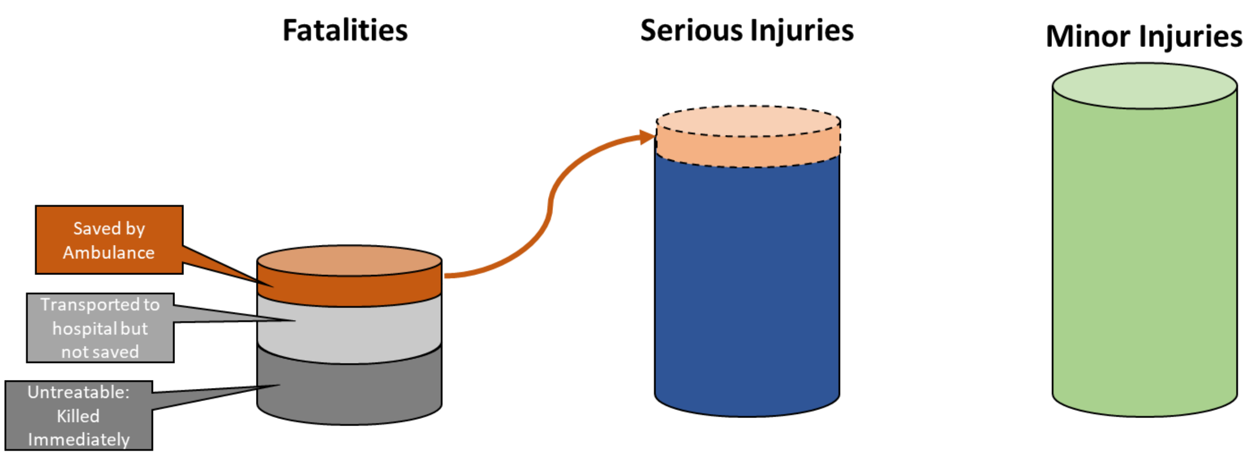

Figure 10. Tool logic: With ambulance service, a portion of fatalities become serious injuries

Equations

The logic assumes that a reduction in fatalities is equally distributed across all road users. The expected amount of fatality reduction (If increasing, this becomes a negative number) is calculated below equations:

$$F = F_{all} \times P_f \times CMF_f \tag{19}$$

Where:

F= expected reduction or change in the number of fatalities (note: a positive number represents an expected reduction and vice-versa. See footnote on page 5 for expanded explanation)
F_{all}= number of fatalities of all road users
P_f= proportion of fatalities that occurred instantly at the scene of the crash (percent)
CMF_f= CMF for fatality

References

Berhanu, Girma. 2004. "Models relating traffic safety with road environment and traffic flows on arterial roads in Addis Ababa." *Accident Analysis & Prevention* 36 (5):697-704. doi: 10.1016/j.aap.2003.05.002.

Chatterjee, S., Mitra, S., & Maitra, B. (2023). Approach for quantifying roadside hazard risk on two-lane highways in low-and middle-income countries. *Transportation research record*, *2677*(3), 113-127.

Chen, Li, Cynthia Chen, Reid Ewing, Claire E. McKnight, Raghavan Srinivasan, and Matthew Roe. 2013. "Safety countermeasures and crash reduction in New York City—Experience and lessons learned." *Accident Analysis & Prevention* 50:312-322. doi: https://doi.org/10.1016/j.aap.2012.05.009.

Donroe, Joseph, Monica Tincopa, Robert H. Gilman, Doug Brugge, and David A. J. Moore. 2008. "Pedestrian road traffic injuries in urban Peruvian children and adolescents: case control analyses of personal and environmental risk factors." *PLoS One* 3 (9):e3166.

Elvik, Rune, Alena Høye, Truls Vaa, and Michael Sørensen. 2009. *Handbook of Road Safety Measures - Second Edition*, *Emerald Group Publishing Limited*.

Elvik, R. (2013). A re-parameterisation of the Power Model of the relationship between the speed of traffic and the number of accidents and accident victims, Accident Analysis & Prevention, 50: 854-860.

Elvik, R., Vadeby, A., Hels, T., Schagen, I. (2019). Updated estimates of the relationship between speed and road safety at the aggregate and individual levels. Accident Analysis & Prevention, 123: 114-122.

Inada, Haruhiko, Jun Tomio, Shinji Nakahara, and Masao Ichikawa. 2020. "Area-Wide Traffic-Calming Zone 30 Policy of Japan and Incidence of Road Traffic Injuries Among Cyclists and Pedestrians." *AMERICAN JOURNAL OF PUBLIC HEALTH* 110 (2):237-243. doi: 10.2105/AJPH.2019.305404.

iRAP. n.d. iRAP Toolkit. Available at: https://toolkit.irap.org/ (Accessed: November 9, 2024)

John, S., Dorcas O., Guillermo B.E., Anna B., and Shauna H. 2021a. *Technical Memorandum Road Safety Calculator – Phase I Systematic Reviews: Barrier-Separated (2+1) Rural Highways.*

John, S., Dorcas O., Guillermo B.E., Anna B., and Shauna H. 2021b. *Technical Memorandum Road Safety Calculator – Phase I Systematic Reviews: Traffic Calming at High-Speed to Low-Speed Transitions.*

Høye, Alena, and R Elvik. 2015. Bilbelter, beltepåminnere og beltelås i lette kjøretøy (Seat belts, seat belt reminders and seat belt buckles in light vehicles). In *Trafikksikkerhets-håndboken (Handbook of Road Safety Measures)*. Oslo, Norway: Norwegian Institute of Transport Economics (Transportøkonomisk Institutt).

Li, Haojie, and Daniel J. Graham. 2016. "Quantifying the causal effects of 20 mph zones on road casualties in London via doubly robust estimation." *Accident Analysis & Prevention* 93: pp 65-74.

Liu, B. C., R. Ivers, R. Norton, S. Boufous, S. Blows, and S. K. Lo. 2008. "Helmets for preventing injury in motorcycle riders." *Cochrane Database of Systematic Reviews* (1). doi: 10.1002/14651858.CD004333.pub3.

Mock, C.N., et al., *Trauma mortality patterns in three nations at different economic levels: implications for global trauma system development.* The Journal of trauma, 1998. **44**(5): p. 804.

Nilsson, G. (2004). Traffic safety dimensions and the power model to describe the effect of speed on safety. Bulletin 221, Lund Institute of Technology, Lund.

OECD/ECMT Transport Research Centre. (2006). Speed management. OECD Publishing.

Peden, M. M. (2004). *World report on road traffic injury prevention*. World Health Organization.

Transportation Research Board (TRB). Committee for Guidance on Setting & Enforcing Speed Limits. (1998). Managing Speed: Review of Current Practice for Setting and Enforcing Speed Limits.

Wei Zhang. 2022. Developing Crash Modification Factors for Mini-Roundabouts. FHWA Publication No.: FHWA-HRT-22-109.

Whittaker, A. (2012). The safety benefit of continuous narrow painted median strips.

World Health Organization, *Global status report on road safety 2018*. 2018, World Health Organization: Geneva.

Xu, Meng, and W. L. Yue. 2002. "The comparison of two local area traffic management schemes for accident reductions." International Conference on Traffic and Transportation Studies (ICTTS) 2002, Guilin, Guangxi, China, 2002.

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