Development of the Investment Case to Reduce Road Traffic Injuries among Adolescents

Final Report

A project funded by FIA Foundation

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Table of Contents

List of Tables

List of Figures

Introduction

In September 2020, Victoria University, in conjunction with the Centre for Research Excellence on Driving Global Investment in Adolescent Health, presented a proposal to FIA Foundation for support of a project for development of an investment case to reduce road traffic injuries among adolescents.

The project builds upon previous research by the Victoria Institute for Strategic Economic Studies (VISES) at Victoria University developing a model for understanding the impact of a range of interventions on deaths and injuries from road traffic accidents in a variety of settings in low- and middle-income (LMICs) (Sheehan et al. 2017, Symons et al. 2019).

Most of the evidence for the effectiveness of interventions to reduce road traffic injuries derives from studies done in high-income countries. This is one significant limitation on the development of investment cases for optimal transport in LMICs, where there is less evidence on the appropriateness, feasibility and effectiveness of these interventions and where effectiveness is likely to depend on the state of infrastructure, the nature of health systems and the degree of governance.

This study aims to address this evidence gap by improving our understanding of the most appropriate interventions to reduce road traffic injuries among adolescents, particularly for those in LMICs and for underserved or marginalised groups.

The project has 4 phases.

Phase 1 Review of evidence on effective interventions

The first phase of the research program has involved conducting a comprehensive review of the evidence on the effectiveness of interventions to reduce road traffic injuries in LMICs, as the basis for establishing a methodology to design the most appropriate set of interventions in these circumstances.

Phase 2 Cost information

Investment cases require interventions to be costed. Current modelling has relied on a narrow base of evidence from high-income countries on the costs of public health programs, infrastructure, enforcement and compliance. Some of these are unsatisfactory as they rely on proxy measures.

The second part of the research program has identified sources of data on the cost of road traffic interventions in LMICs and incorporated this additional information into the model.

Phase 3 Model development

The third phase of the research program was the development of the Road Safety Intervention Model (RSIM) building on the VISES Road Safety Model (VRSM) by incorporating the evidence collected in phases 1 and 2 as structural quantitative relationships between interventions, and road safety outcomes and costs.

Phase 4 Economic analysis

The final phase of the project was to incorporate the outcomes from the Road Safety Intervention Model into an economic model expressing the health outcomes of reduced deaths and serious injury in economic terms, and enabling the development of return on investment analyses. This modelling enables the cost and benefits of different intervention scenarios to be calculated using an optimisation model, that can select a subset of interventions that is optimised subject to a budget constraint or specified reduction in fatalities or serious injuries.

Finally, to validate the modelling we report the application of the RSIM and economic modelling to a number of case study countries examined in more detail. These countries are Tanzania, Viet Nam and Colombia.

In conducting this project, we have been greatly assisted by the research and data provided by over 20 consultations with experts in a range of organisations. We would like to thank all these people for their great generosity and assistance. In particular, these consultations have been very useful in guiding the choice of case study countries. A description of these consultations was provided in the progress report to FIA Foundation in February 2021.

This report was prepared by Dr John Symons with assistance from Dr Kim Sweeny, both from the Victoria Institute of Strategic Economic Studies (VISES) at Victoria University.

VISES Road Safety Model

The Road Safety Intervention Model (RSIM) builds on the VISES Road Safety Model (VRSM) developed for a study on adolescent health and wellbeing funded by UNFPA (Sheehan et al., 2017), which itself drew upon the studies of Chisholm and Naci (2008, 2012), who undertook modelling for LMICs at a regional level. The VRSM started from the path of deaths and serious injuries from road accidents by age, gender, and vehicle type using data on deaths and prevalence from the Global Burden of Disease (GBD) database (IHME, 2019) to develop an unchanged policy base case. It compared this with one achieved through systematic implementation of a range of interventions.

After the identification of key interventions, the VRSM estimated the cost of these interventions and their effectiveness in reducing deaths and serious injuries for young people (aged 10 to 24) for 77 LMICs. The results of these estimates were then included in a modelling framework to calculate the reduction in deaths and serious injuries achieved in each of the 77 countries studied, relative to the base case.

The results from the VRSM were then included in an economic model to estimate the economic and social benefits arising from these reductions, and hence calculate benefit-cost ratios (BCRs). In the central case, the interventions, and hence the deaths and injuries avoided, run to 2050, although the economic and social benefits of fewer deaths and injuries continue beyond 2050. The various elements of this methodology are illustrated in Figure 1 and outlined below.

The RSIM extends the VRSM in numerous ways as illustrated in Figure 2 and detailed in the subsequent sections.

Figure 1: VRSM model

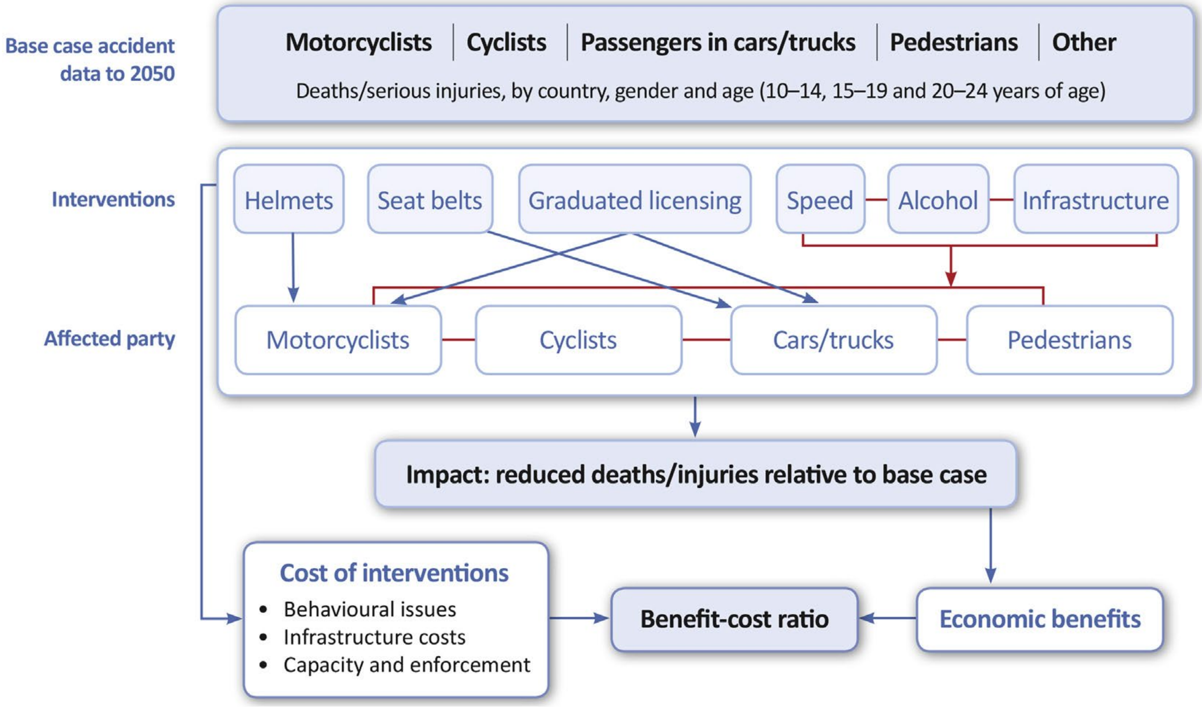
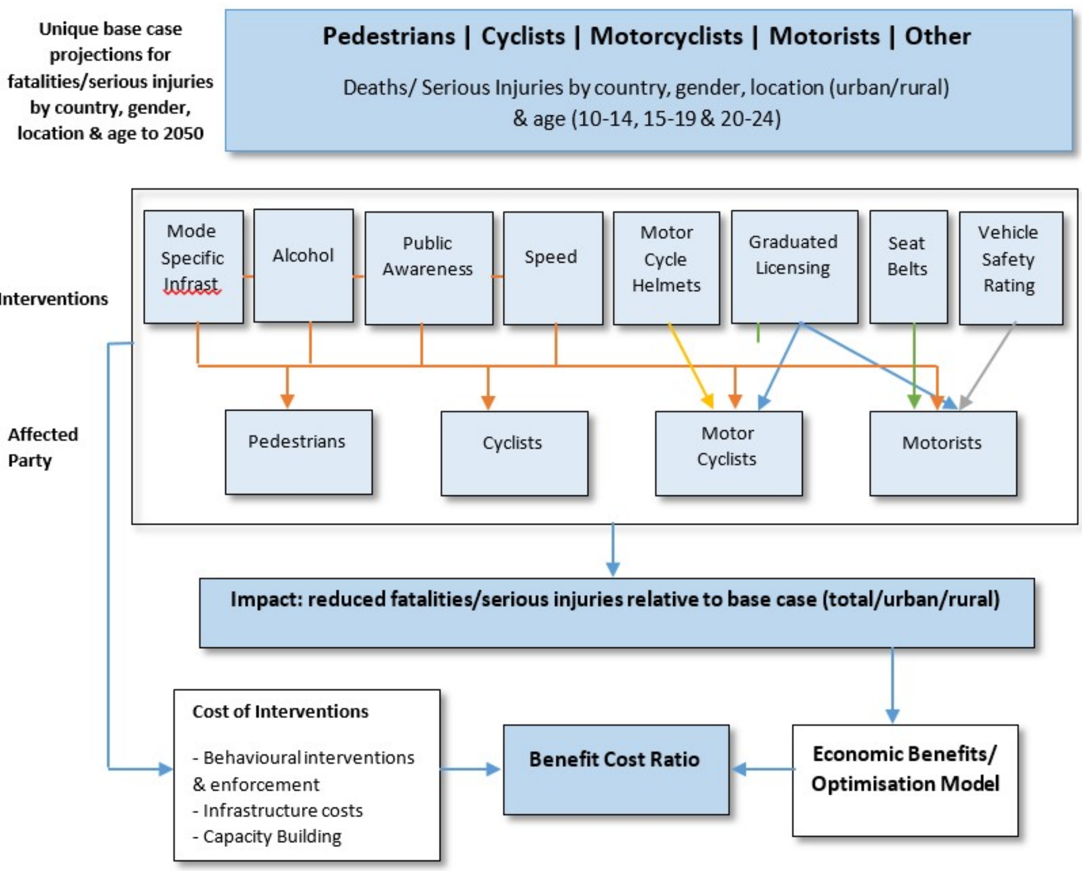


Figure 2: Updated and extended RSIM



Interventions and their Effectiveness

Over the period from 1970 to 2015, the median OECD road accident fatality rate fell by 70%, as a result of the development and implementation of many road safety interventions and an increase in share of travel in motor vehicles with their increase in safety particularly since 2000 (Figure 5). In recent years, more attention has been given to road safety in many LMICs. The high-income experience is represented extensively in the literature. However, as the focus of this study is on LMICs, it is important to draw on the recent developing country literature, but also to apply carefully the findings of the broader literature.

There is a broad consensus in this literature about the most effective interventions to reduce road accidents. As a result, the VRSM modelled the following interventions for all categories of road accidents:

- speed compliance;
- alcohol enforcement; and
- safer infrastructure.

Additional factors were included specifically for:

- motorcycle riders (helmets);
- occupants of motor vehicles (seat belts); and
- a graduated licensing scheme (for both motorcycle riders and motor vehicle drivers).

Table 1 summarizes the findings about the effectiveness of these various interventions from the 20 studies identified as having such information. Table 2 shows the effectiveness of measures actually used in the modelling, with a single figure used for both fatalities and injuries, together with the assumptions about the extent to which these measures are in place in the base case. Both tables are reproduced from Symons, Howard, Sweeny, Kumnick, and Sheehan (2019).

As can be seen in Table 1, the estimates of the effectiveness of the interventions vary widely in the literature, and these variations may reflect the intensity with which the interventions are applied. For example, drawing on many of the studies shown in Table 1, the Global Research Safety Partnership Seat Belt Manual (FAS, 2009) indicates the benefits of wearing a seat belt compared with not wearing one (in a motor vehicle) as follows: 50% fatality reduction for drivers, 45% reduction for front seat passengers, and 25% reduction for rear seat passengers. These figures have been summarised by a 40% average reduction in fatalities from seat belt use. Several studies have examined the benefit of motorcycle helmet wearing, with a strong and repeated finding of significant reductions in the risk of death and serious injury, as summarized in Table 1. The effectiveness of alcohol limit enforcement, speed compliance and graduated licensing schemes is shown in Table 2. The effects of each of these interventions are complex and vary due to cultural contexts, levels of enforcement, appropriate testing equipment and training, and initial speed, amongst other factors.

Table 1: Intervention effectiveness in the literature

Intervention	Measure of effectiveness	Effectiveness summary range (%)	Effectiveness (% reduction)
Seat belts	Wearing seatbelt	Fatalities 7–65%	65% (Peden, 2005), 7–9 (Dellinger, Sleet, & Shults, 2007), 11 (Chisholm & Naci, 2008), 11 (Chisholm & Naci, 2012), 11 (Elvik & Vaa, 2004)
		Injuries 18–77%	40 (Peden, 2005), 18 (Chisholm & Naci, 2008), 77 (Milder, Gupta, & Özkan, 2013), 18 (Chisholm & Naci, 2012), 18 (Elvik & Vaa, 2004)
Helmets	Wearing helmet	Fatalities 20–42%	36 (Chisholm & Naci, 2008), 20 (Bishai & Hyder, 2006), 42 (Liu, Ivers, & Norton, 2008), 29 (Olson, Staples, & Mock, 2016), 36 (Chisholm & Naci, 2012)
		Injuries 18–54%	18–29 (Chisholm & Naci, 2008), 41 (Bishai & Hyder, 2006), 69 (Liu et al., 2008), 54 (Olson et al., 2016), 18–29 (Chisholm & Naci, 2012)
Alcohol	Modern constraints on alcohol use on roads	Fatalities 3–48%	10 (Bishai, Asiimwe, & Abbas, 2008), 25 (Chisholm & Naci, 2008), 22 (IQR 14–35) (Elder, Shults, & Sleet, 2002), 20 (18–22) (WHO, 2006), 25 (Chisholm & Naci, 2012)
		Injuries 3–48%	3 (Bishai et al., 2008), 15 (Chisholm & Naci, 2008), 35–48 (Ditsuwan, Veerman, Bertram, & Vos, 2013), 15 (Chisholm & Naci, 2012)
Speed enforcement	Systematic speed limit enforcement	Fatalities 17–25%	17 (Bishai et al., 2008) , 25 (Bishai & Hyder, 2006)
	Injury severity reduction due to percentage speed reduction	Injuries 14–56%	56 (Ameratunga, Hijar, & Norton, 2006), 14 (Chisholm & Naci, 2008), 30–40 (Wilson, Willis, Hendrikz, & Bellamy, 2006), 14 (Chisholm & Naci, 2012), 14 (Elvik & Vaa, 2004), 15–24 (Cameron & Elvik, 2010)
	Injury severity reduction due to speed reduction	Injuries 6–50%	9 (Bishai et al., 2008), 6 (Chisholm & Naci, 2008), 8–50 (Wilson et al., 2006), 6 (Elvik & Vaa, 2004)
Graduated licensing scheme	Implementation of GLS scheme	Fatalities 31–57%	57 (Williams, Tefft, & Grabowski, 2012), 20 (VicRoads, 2017)
		Crash rates 4–43	28 (4–43) (Hartling, Wiebe, & Russell, 2004), 31 (26–41) (Dellinger et al., 2007), 20–40 (Shope, 2007)
Investment in safer roads		Injury accidents 7–20%	7% (urban roads), 20 (rural roads) (Elvik & Vaa, 2004)

Table 2: Intervention effectiveness used in the model

Intervention	Base case	Intervention effectiveness	Level of deaths/injuries after intervention
Seat belt usage	60% unless data available	40%	84% of base case (for 60% current usage)
Helmet usage	40% unless data available	36%	78% of base case (for 40% current usage)
Enforcement of alcohol limits	0%	25%	75% of base case
Enforcement of speed limits	0%	14%	86% of base case
Better preparation of novice drivers (e.g., GLS)	0%	20%	80% of base case
Building better infrastructure	0%	15%	85% of base case

The impact of better infrastructure in the VRSM is also shown in Table 1 and Table 2, and is a broad brush figure proposed to capture the impact of higher quality roads. In the VRSM, the estimates are supported by recent demonstration projects in India and other countries. In India, for example, a project in Karnataka state involved traffic calming, better delineation, pedestrian, bus and truck parking facilities, leading to nearly 60% reduction in road fatalities in the year following the completion of the project (van der Horst, Thierry, Vet, & Fazlur Rahman, 2017). Another demonstration project on the 139 km Renigunta-Kapada Road in Andhra Pradesh, India, led to a 43% reduction in injuries, and 22% reduction in fatalities (van der Horst et al., 2017).

These country-specific estimates were used in a VISES study on adolescent health and wellbeing in India in collaboration with the Public Health Foundation of India and funded by UNFPA India office.

In the VRSM, the interventions are assumed to be independent, but with multiplicative effects. However, the effectiveness value for particular interventions varies between countries, as different circumstances apply, for example in Islamic countries where the consumption of alcohol is restricted the effect of alcohol enforcement is reduced.

In terms of the existing level of these interventions, some data are available from the World Health Organization regarding estimated levels of helmet wearing and seat belt usage (for 14 and 20 countries, respectively). Where available, we use these data, but otherwise use a base case rate of 40% and 60%, respectively, for helmet wearing and seat belt usage. For other interventions, no data are available, and the base case assumption is no implementation.

The intervention path in the VRSM was modelled by applying the effectiveness values, by country, age, and accident mode, to the base case. The difference between deaths and serious injuries in the intervention and base cases is the measure of the impact of the interventions.

While the studies draw upon data in high-income countries, it should be noted the following points are relevant to the use of these estimates for studies in LMICs. First, the basic physics and human tolerance to injury of modern road accidents applies in all countries. To reduce such accidents requires safer vehicles moving at lower speeds on better roads, better drivers and riders in full control of their vehicles and with adequate protection, and vulnerable road users (pedestrians and cyclists) protected from rapidly moving, high-mass vehicles.

Despite this, the reliance on information from high-income countries is a limitation of the previous modelling and the primary motivation for the further development of the model in the RSIM.

Interventions research in low- and middle-income countries

Although the methods for implementing these interventions will differ across countries, some consistency in response is to be expected. There is also a growing body of literature, mainly pilot interventions in LMICs, which show substantial effects of these programs. These include studies for India (Srinivasan, 2017; Usha, Ravindran, Soumithran, & Nair, 2014), Bangladesh (van der Horst et al., 2017), Uganda (Bishai et al., 2008), Rwanda (WHO, 2007), Vietnam (Olson et al., 2016), China (Stevenson, Yu, & Lil, 2008; Zhao, Chen, & Qi, 2016), Iran (Azami-Aghdash, Sadeghi-Bazarghani, & Heydari, 2018), Chile (Nistal-Nuno, 2017), and Brazil (Andreuccetti, Carvalho, & Cherpitel, 2011). Staton, Vissoci, and Gong (2016) recently undertook a meta-analysis of 18 articles from 11 lower-income countries, finding substantial reduction in accidents and/or injuries in most cases, but comment on the limitations of many studies and the critical role of enforcement.

Vecino-Ortiz, Jafri, and Hyder (2018) studied the interventions that would best reduce unintentional injuries in the 84 countries where the world's poorest billion people live, finding that drink driving enforcement and speed limitation were by far the most important. Their statistical method assumes that the effect sizes reported for high-income countries can be transferred to low-income countries.

While these studies have indicated some of the most suitable approaches in LMICs, further investigations are required to substantiate the cost, suitability and effectiveness of previously modelled interventions, as well as identify new potential interventions.

RSIM Model Development

The major features of the development of the RSIM are a more sophisticated approach to the development of baseline trends, the inclusion of rural/urban and total splits, the extension of existing interventions, as well as the addition of further relevant interventions. In addition, finer granularity of infrastructure investments and types of infrastructure is enabled to include interventions that are most appropriate for LMICs. Modal share analysis, physical activity and air pollution elements were considered for the RSIM. However, data and compatibility issues prevented their inclusion in the current iteration, but this may be included in further iterations of the model. Two completely new components of Investment Optimisation have been developed to explore best returns on investment.

Baselines

VRSM base case fatalities

Establishing a valid base case projection of deaths and serious injuries from road accidents out to 2050 is essential to the calculation of the benefits of interventions, and is not a straightforward task. Different transport modes have different accident rates (e.g., motor vehicles generally have a lower fatality rates than motorcycles), and the same transport mode has different trends for different age cohorts and genders.

For example, the fatality rate for 20–24 year-old female motor vehicle occupants in Tanzania is shown in Figure 3 and compared with 10–14 year-old male pedestrian fatality rate (Figure 4) in the same country.

Figure 3: Tanzania 20–24 year-old female motor vehicle fatality rate

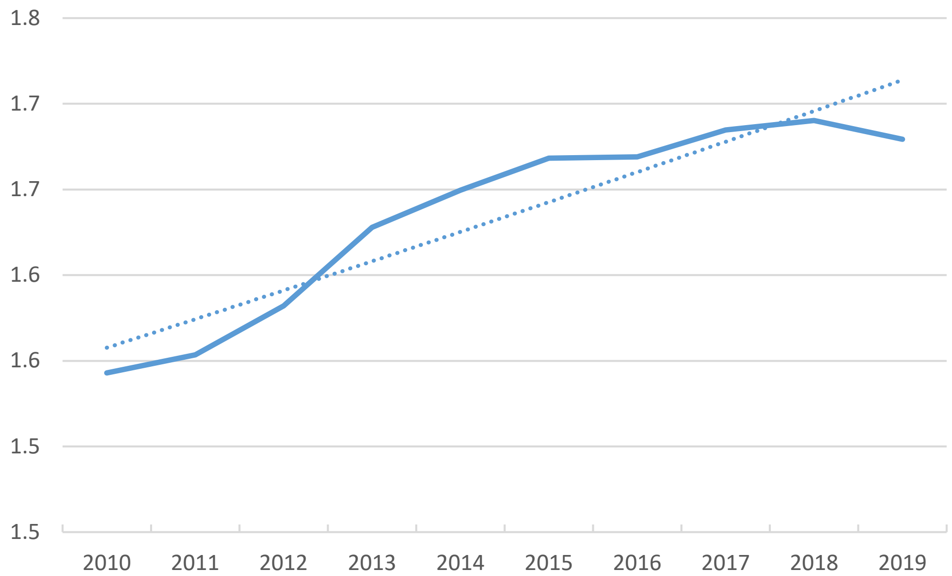
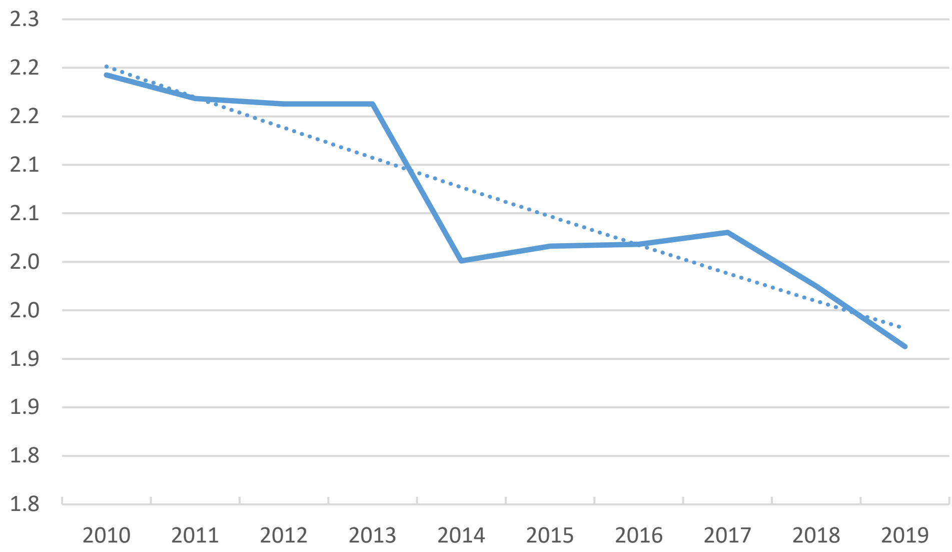


Figure 4: Tanzania male 10–14 year-old pedestrian fatality rate



In addition, the relative importance of transport modes varies over the development path and cultural context. Many external factors influence the extent of road accidents including the nature and pace of economic development. By analogy, with the work of Kuznets on inequality and economic development (Kuznets, 1955), some authors have argued that the incidence of road accidents follows a Kuznets curve (an inverted U curve, or negative 2nd order polynomial curve), rising rapidly as gross domestic product (GDP) per capita rises from low levels, but then falling after per capita income passes a threshold level (Kopits & Cropper, 2005; McManus, 2007). While this approach was considered, it was not pursued due to the uncertainties and inconsistencies regarding level of development and the complex interaction with cultural contexts for many LMICs. In addition, as shown in Figure 3 and Figure 4, it is not valid to generalise for all modes for all age groups, as the data shows they vary substantially in the same timeframe.

The approach taken with the VRSM followed McManus (2007), by utilising the starting point for the base case as that of fatality rates (deaths per 100,000 population) in 2019 by age, gender and mode type. The VRSM held this value fixed for each country out to 2050. In the VRSM, the population of each country modelled varied over time in line with the United Nations Population Division projections, but the fatality rates remained fixed for each age group, gender and mode within each country. The base case data of fatality rates by age, gender and vehicle or injury type are from the GBD 2019 database. Three age cohorts (10–14, 15–19 and 20–24 years of age) are used for the following types of injured persons: pedestrian, cyclist, motorcyclist, motor vehicle occupant, and other categories. This produces 30 baselines (age cohort x gender x transport mode) for fatalities and an additional 30 baselines for serious injuries for each of the 77 countries (4620 individual baselines).

VRSM base case serious injuries

For each death from road accidents, there are a large number of people injured, with the figure of 16 persons sent to hospital for every death often quoted. Many of these injuries are minor, or of limited duration, or with limited impact on long-term employment that is the primary economic impact considered in the economic analysis. Consequently, an estimate of serious injuries was required as opposed to the broader injuries. The GBD 2019 data provides estimates of the incidence of injuries from road accidents, in addition to estimates of mortality. These estimates again are by age, gender, and vehicle accident type for each country provide our starting point. In the model, we take account only of injuries causing severe and profound limitations, such as to preclude the person's ability to work at all in the future, assumed to be those with greater than 80% permanent impairment on standard impairment scales. There is very little data on the distribution of injuries by severity, but there are a number of country studies. We rely here on a detailed study (BITRE, 2009), which found that in Australia in 2006, 4.1% or about 1 in 24 of those hospitalized had severe or profound limitation (i.e., impairment of 80%). In the absence of any other data, we assume that 4.1% of injury incidences as measured in the GBD data lead to a disability with severe or profound limitation unless other data is available.

The estimates of injuries from GBD 2019 data provide insight into the incidence of deaths and serious injuries for young people in accidents involving different types of vehicle and across countries. They imply an average ratio of 2 serious injuries per death. The data for the 77 countries show that the death/serious injury ratio is highest for accidents involving cars and trucks. For cyclists, the ratio is considerably lower. While the cause of these differences has not been definitively established, it may relate significantly to speed, with many car/truck and motorcycle accidents involving vehicles travelling at high speed, often in non-urban areas. In addition, pedestrians are in grave danger of being killed if struck by a rapidly moving vehicle, and many accidents involving bicycles are single vehicle accidents or in urban areas where motor vehicles travel more slowly that may result in serious injury but are less likely to be fatal.

It is also notable that across all vehicle types, death/serious injury ratios are about twice as high in LMICs than in OECD countries. Presumably, this reflects the many differences between LMICs and the OECD countries in road conditions, vehicle technology, safety programs, quality of injury treatment, as well as timely access to injury treatment. It also suggests that the assumption drawn from the Australian study (that 4.1% of GBD injuries are serious) is likely to significantly underestimate the extent of serious injury in the 77 LMICs.

For base case projections of serious injuries for each year, as per the approach taken with fatalities, the VRSM held the serious injury rate per 100,000 constants for each age cohort, gender and country over the period being modelled out to 2050. This rate was applied to establish the projected number of death and serious injuries for each age cohort and gender.

Road Safety Intervention Model (RSIM) baselines

A significant difference between the VRSM and RSIM is the estimation of the baselines. The RSIM has adopted a new approach with a trend line used to forecast baseline deaths and serious injuries out to 2050 based on the trend from the previous 10 years of GBD fatality and serious injury data (2010 to 2019). Five types of trendlines were sampled to assess the most appropriate to determine which type of line produced the most reliable trend as follows.

- Exponential trendline: a curved line that is most useful when data values rise or fall at increasing rates.
- Linear trendline: a straight line that is used with simple linear data sets. Data is linear if the pattern in its data points resembles a line with data that increases or decreases at a steady rate.

- Logarithmic trendline: a curved line suitable for data when the rate of change in the data increases or decreases quickly and then levels out. A logarithmic trendline can use negative and/or positive values.
- Polynomial trendline: a curved line that is used when data fluctuates. It is useful, for example, for analysing gains and losses over a large data set. The order of the polynomial can be determined by the number of fluctuations in the data or by how many bends (hills and valleys) appear in the curve. A 2^{nd} order polynomial trendline generally has only one peak or trough.
- Power trendline: a curved line that is suitable for data sets that compare measurements that increase at a specific rate.

The difficulty for selecting an appropriate trendline is due to substantial variation in trends for the 4620 individual baselines across the 77 study countries. While each individual dataset of the 4620 datasets may have a type of trendline that is more suitable than others, given the number of baselines it is unwieldy and inconsistent to have separate types of trendlines for each dataset, and consequently one type of trendline is more appropriate. The trendline details are summarised below.

For the RSIM, the most appropriate trendline was determined through a number of factors including the R-squared statistic, and whether the trendline forecast rapidly increasing rates or negative rates. R-squared is a statistical measure of how close the data points are to the fitted regression line. It is also known as the coefficient of determination, or the coefficient of multiple determination for multiple regression. A figure of 1 indicates that the model explains all the variability of the response data around its mean. The closer to 1, the better the Goodness of Fit.

All 5 trendlines were applied to the age cohorts (3), genders (2), modes (5) and deaths/serious injuries (2) for three countries (300 data points), to determine which trendline provided the best goodness of fit through the coefficient of determination, R-squared. The average R-squared value for each type of trendline was calculated for each country and compared.

The results of the trendline estimates for three countries are shown in Table 3.

Table 3: Trendline R-squared values

Trendline	Pedestrian average	Bicycle average	Motorcycle average	Motor vehicle average	Other average	Overall average
Exponential	0.641	0.746	0.729	0.670	0.690	0.695
Linear	0.638	0.743	0.725	0.668	0.691	0.693
Logarithmic	0.557	0.672	0.635	0.642	0.611	0.624
2nd order polynomial	0.880	0.877	0.900	0.818	0.886	0.872
Power	0.568	0.674	0.637	0.645	0.610	0.627

While the 2^{nd} order polynomial generated the highest R-squared value over data from the last 10 years (i.e. the best Goodness of Fit), in numerous cases the forecast figures increased rapidly so that by 2050 they were 4 or 5 times higher than current figures or they generated rapidly increasing negative figures within a short time frame. Due to these features, the 2^{nd} order polynomial was not considered an appropriate trendline for the RSIM. The trendlines with the next highest R-squared values were the exponential and linear trendlines with almost identical R-squared values. Of these, the linear trendline also generated negative values when projected into the next decade in some circumstances, and was subsequently dismissed as unsuitable. This resulted in an exponential trendline being considered the most appropriate type of trendline to forecast fatalities and serious injuries out to 2050 for the base case.

When the exponential trendline was modelled for all age fatalities and serious injuries, genders, age groups and modes for the 77 countries, a small number of discrepancies were identified leading to some trendlines increasing substantially by 2050. The model was updated to automatically identify these discrepancies and replace the exponential trendline with a linear trendline.

Urban/rural disaggregation

The proportion of road traffic injuries that occur in rural as opposed to urban settings is of paramount importance due to the difference in relative death and serious injuries rates. In road accident research, a distinction is often made between urban and rural areas as two different environments with different accident outcomes and profiles. For example, rural areas are overrepresented in fatalities, however, the GBD data does not differentiate between rural and urban areas for fatalities or serious injuries. Disaggregating the urban and rural areas gives greater insight into where interventions can have a greater effect.

There are numerous explanations provided for the difference between urban and rural areas, including but limited to, the lack of availability of emergency services, higher travelling speeds, poor quality of road surfaces, and the greater prevalence of drink driving. In addition, less populated areas are sometimes characterized by a different age structure and social deprivation, leading to additional risk factors. Rural residents also tend to travel greater distances by road and are, thus, more likely to be involved in serious collisions (Eksler, Lassarre, & Thomas, 2008; Li, Doong, Chang, Lu, & Jeng, 2008).

Sherriff et al. (2015) found motor vehicle occupant death rates in rural as opposed to urban areas were higher by a factor of 1.45 (i.e. 66.57/100,000 versus 45.83/100,000). Muelleman, Wadman, Tran, Ullrich, and Anderson (2007) found that the risk of motor vehicle collision death is nearly twice as high in the most rural counties in Nebraska, whereas Zwerling et al. (2005) found the fatality rate in rural areas was 2.99 times higher than the urban rate corrected for vehicle kilometres travelled. For our purpose, the modelling a factor of 2 for rural over urban is used. A population-weighted factor will be used to determine the number of deaths in rural and urban areas, as illustrated in the example below.

Assuming the factor of 2 for the rural fatality rate compared to the urban rate, for a country with a total population of 1,000,000 and an overall fatality rate of 25 per 100,000, the total number of deaths would be 250. If this country had a population that was 40% urban and 60% rural, the relative populations would be 400,000 urban and 600,000 rural. The 40% weighted urban fatality rate would be 15.625 per 100,000 (62.5 fatalities) and the 60% rural fatality rate would be 31.25 per 100,000 (187.5 fatalities). The model assumes the fatality rates of all modes change according to this calculation (Table 4).

Table 4: Rural/urban disaggregation

Area	Fatality rate/100,000	Population	Fatalities
Total	25	1,000,000	250
Rural	31.25	600,000	187.5
Urban	15.625	400,000	62.5

The difference between urban and rural fatality rates is not the same for minor and serious injury rates. A study in England and Wales found that minor and serious accidents are more frequent in urban areas, whereas fatal accidents are more likely in rural areas (Cabrera-Arnau, Prieto Curiel, & Bishop, 2020). In this study, Cabrera-Arnau et al. (2020) define injuries where the victim needs to be detained in hospital as an 'inpatient' as being serious. This is a different definition to the one used in the modelling taken from the BITRE study previously used in the modelling. Consequently, it is considered that serious injuries would be lower than that reported by Cabrera-Arnau et al., who found on a per capita basis, that serious injuries were 2.6 times more likely in urban areas as opposed to rural areas. Given the lack of studies in this field, a conservative figure of 1.5 is used in the model consistent with the lower figure of Sherriff et al. (2015).

Infrastructure interventions

The updated infrastructure interventions in the RSIM draw upon the work undertaken by the International Road Assessment Program (iRAP) and their road star-rating system. The iRAP Star Ratings are based on an extensive sample of roads and road inspection data, and provide a relatively objective measure of the level of safety that is 'built-in' to the road for vehicle occupants, motorcyclists, bicyclists and pedestrians. The same section of road may have very different star ratings for vehicle occupants, motorcyclists, bicyclists and pedestrians.

iRAP have produced summary assessments for many countries in terms of how many of the roads of each country have a particular star rating for each mode of travel. These results are presented both in length of roads and vehicle kilometres travelled (VKT). The VKT is the preferred measure, as it more accurately reflects the usage of roads and where road traffic accidents can be expected to occur. An example is shown in Table 5 with the summary data for road star ratings for vehicle kilometres travelled in Tanzania for different modes. Table 5 shows that 42.6% of all pedestrian travel is on 1-star roads.

Table 5: Summary road star rating for modes in Tanzania

Mode	1-star	2-star	3-star	4-star	5-star
Motor vehicle	51.1%	26.8%	21.6%	0.5%	0.0%
Motor cycle	52.8%	37.0%	10.2%	0.0%	0.0%
Cyclist	71.6%	22.1%	6.2%	0.0%	0.0%
Pedestrian	42.6%	54.2%	3.1%	0.0%	0.0%

The relative safety of road star ratings has been established by the OECD (ITF, 2016), where for every increase in star rating, there is an approximate halving of the number of people who are killed and seriously injured (ITF, 2016). The combination of the relative risk for each star rating and relative proportion of roads will be used in conjunction with the GBD data to model how many deaths and serious injuries are expected on each of the star-rated roads for each mode.

While reductions for each incremental improvement in star rating vary between 43% and 75% in the literature, for the purpose of this analysis the more conservative estimate of a 50% reduction in fatal and serious injury outcomes for each incremental star rating improvement has been used.

For example, due to the relative safety characteristics, for a given mode, if 50% of travel is on 1-star roads and 50% is on 2-star roads, then approximately 66.7% of fatalities would be expected to occur on 1-star roads and 33.3% on 2-star roads, despite 50% of travel occurring on both. An example of fatality distribution and road star rating for Tanzania is shown in Table 6.

Table 6: Road star rating and % of fatalities in Tanzania

% travel by mode	1-star	2-star	3-star	4-star	5-star
Motor vehicle	51.1%	26.8%	21.6%	0.5%	0.0%
Expected % of fatalities	73.0%	19.1%	7.7%	0.1%	0.0%
Motor cycle	52.8%	37.0%	10.2%	0.0%	0.0%
Expected % of fatalities	71.5%	25.1%	3.4%	0.0%	0.0%
Cyclist	71.6%	22.1%	6.2%	0.0%	0.0%
Expected % of fatalities	85.0%	13.1%	1.8%	0.0%	0.0%
Pedestrian	42.6%	54.2%	3.1%	0.0%	0.0%
Expected % of fatalities	60.4%	38.5%	1.1%	0.0%	0.0%

This refinement of fatalities by road type and mode (in addition to rural/urban disaggregation) enables more detailed and accurate modelling of interventions, particularly with respect to the costs of particular infrastructure investments and optimal investments in different parts of a given country.

While iRAP provide broad categories of risk reduction for specific infrastructure for each mode, such as delineation of lanes, pedestrian crossings, lane widening or median barriers, modelling specific interventions on a national scale is not feasible. On a regional scale, such as a city or small region such an approach may be feasible in future iterations of the model.

Bicycle helmets and lights

Bicycle lights

The issue of conspicuity to improve the safety of bicycle riders has been the subject of a small amount of research, specifically examining the use of fluorescent clothing and bicycle lights used during daytime, as has now become standard practice for all new motor vehicles (EC, 2021). Their intended use is not to help the driver see the road, but to help other road users identify an active vehicle.

Edewaard, Szubski, Tyrrell, and Duchowski (2019) found daytime use of rear-facing bicycle lights increased the distance in which drivers of motor vehicles noticed the bicyclist by a factor of 2.7. However, few studies have found an increased risk of collisions among cyclists that who do not have one or more visibility aids (Hagel et al., 2014) and had low level of usage visibility aids in low light conditions (Lacherez, Wood, Marszalek, & King, 2013; Wood, Lachereza, Marszaleka, & King, 2009). One explanation is that the use of visibility aids is also associated with exposure, because frequent cyclists are more likely to wear highly visible clothing (Teschke et al., 2012). Furthermore, under poor visibility condition, the car driver may fail to detect the cyclist and react in time; research has also found how cyclists overestimate at what distance they would be visible (Wood et al., 2009). Although visibility aids have the potential to improve conspicuity and recognition, the effect of visibility aids on bicycle motor vehicle collisions remains unknown (Prati, Marín Puchades, De Angelis, Fraboni, & Pietrantoni, 2018). Given the lack of compelling evidence in the literature, this intervention has not been included.

Bicycle helmets

While numerous researchers advocate mandating the use of bicycle helmets, this is a complicated issue with contradictory conclusions drawn in the literature. Some studies have found the injury risk reduction benefits of helmets up to certain speeds are counter balanced by reductions in numbers of people cycling due to helmet use enforcement and consequent reduction in overall health benefits from reduced physical activity (Elvik, 2011; Rissel & Wen, 2011).

Some studies suggest wearing helmets is an effective intervention to reduce mortality and morbidity of cyclist trauma. While there is considerable evidence to suggest helmets can reduce the severity of an injury, in certain collisions generally above 30kmh (Sepulveda-Lopez, Antona-Makoshi, Rubio, & Rodríguez-Millán, 2020) cyclists have very poor survival rates regardless of whether they wear helmets or not (Bíl, Dobiáš, Andrášik, Bílová, & Hejna, 2018).

In their study, Bíl et al. (2018) found 37% of cyclists would have survived their collision had they been wearing a helmet. This is higher than the results found by Elvik (2011) who concluded helmets led to a 15% reduction in fatalities. However, Elvik also noted that a population-wide increase in helmet use, for example after legislation, is not generally matched by similar reductions in overall head injury rates. As this study focuses on LMICs, the access, affordability and cultural appropriateness of bicycle helmets is also questionable. For this reason, bicycle helmets have not been included in the model at present, however, this intervention may be included in future iterations of the model.

Car safety rating

The 2015 Global Status Report on Road Safety included a detailed section on vehicle safety. Using seven priority vehicle safety standards recommended by Global New Car Assessment Program (NCAP), the World Health Organisation carried out a survey on their level of application around the world. The seven standards are from the UN's World Forum for Harmonisation of Vehicle Regulations and include:

- seat belts;
- seat belt anchorages;
- front impact;
- side impact;
- electronic stability control;
- pedestrian protection; and
- child seats.

The combination of the seven standards contribute to a car's overall safety rating. The overall rating is included in the interventions that are to be included in the RSIM, however, the effectiveness has not been finalised.

Global NCAP has adopted a Road Map for Safer Vehicles 2020 that provides a recommended timetable for UN Member States to apply the most important UN vehicle safety regulations. Global NCAP's analysis indicates that these are being comprehensively applied by approximately 40 out of a total of 193 UN Member States and overwhelmingly by high-income countries. The WHO states that "there is an urgent need for these minimum vehicle standards to be implemented by every country", as these requirements are absent in many LMICs.

The NCAP tests new cars and gives them a safety rating from zero to five stars. A rating of zero stars means people in the car would have a higher chance of being injured or dying in a crash, and a rating of five stars means people in the car would have a much lower chance of being injured or dying in a crash. NCAP is focused on the effects of various types of crashes on the people in the vehicle. Tests are also conducted to see what happens to pedestrians if they are hit by the car.

An NCAP rating has been included in the RSIM, with the fatality and serious injury rate of motor vehicle occupants being reduced proportionate to the average star rating of particular nation's fleet of cars. The main data considerations are the average level of safety rating for the fleet of the vehicles in each country, the rate of increase in star rating per annum due to the change in the composition of the nationwide fleet and the percentage effectiveness of star ratings in terms of fatalities and serious injuries with respect to star ratings. Some studies have been undertaken comparing older vehicles with newer vehicles, for example an ANCAP study comparing a 2015 Toyota Corolla against a 1998 Toyota Corolla, with the former registering 5 stars and the latter 0 stars (ANCAP, 2017). This study found the pre-2000 built vehicles accounted for 20% of the fleet but were involved in 33% of the fatalities, whereas the newer vehicles (2011–2016) accounted for 31% of the fleet but only 13% of fatal crashes. The authors estimated the rate of fatal crashes for the older vehicles (pre-2000) were 4 times that of the 2011–2015 vehicles.

Research undertaken at the Monash University Accident Research Centre (MUARC) (Newstead, Watson, Keall, Cameron, & Rampollard, 2020) into the crashworthiness of vehicles gives an indication how the safety of motor vehicles has improved over time.

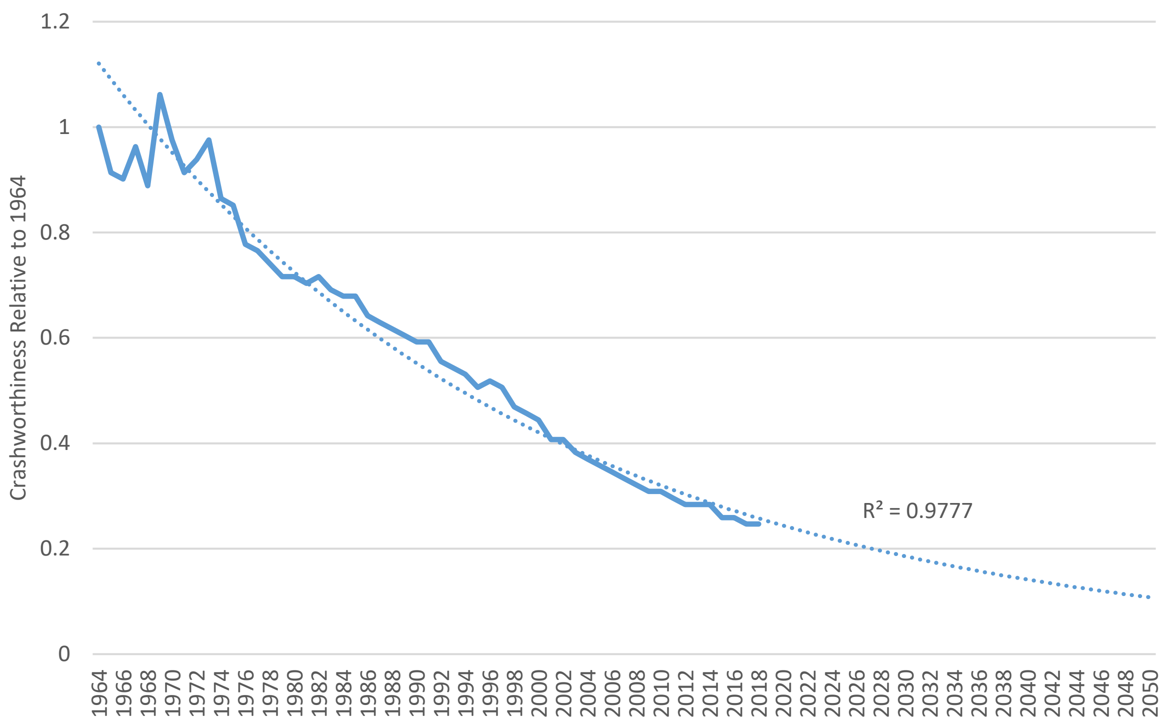
Crashworthiness ratings are the relative safety of vehicles in protecting their own occupants by examining injury outcomes to drivers in real-world crashes reported to police. MUARC calculate this as the measure of the risk of death or serious injury to a driver of that vehicle after a crash, and has two components:

1. Injury risk: rate of injury for drivers involved in crashes where a vehicle is towed away or someone is injured. This is affected by factors such as electronic stability control, anti-lock braking, etc.
2. Injury severity: rate of serious injury (death or hospital admission) for injured drivers. This is affected by such factors as seat belts, crumple zones, air bags, etc.

Multiplying these two components gives the crashworthiness rating. This is a measure of the risk of serious injury for drivers involved in crashes. The estimate for each car is expressed as a percentage, representing the number of drivers killed or admitted to hospital per 100 drivers involved in a tow-away crash, with a lower figure representing a safer car.

The crashworthiness estimates and their confidence limits are plotted relative to 1964 for each year of manufacture in Figure 5. While vehicles are those found in Australian and New Zealand, the general trend of safer vehicles through time applies in many, though by no means all countries. There are well known examples of safety features being removed from some cars for sale in LMICs, which is being addressed by a campaign called “Democratising Car Safety” (Global NCAP, 2015). It is possible the general trend for the study countries of decreasing fatality rates of motor vehicle occupants for all the study countries may in part reflect this general improvement in crashworthiness.

Figure 5: Crashworthiness versus year of manufacture (relative to 1964) (from Newstead et al., 2020 p59)



Implementing safer car policies in LMICs is complicated by the fact many cars are imported, and most countries have few restrictions on these imported cars. This issue has been addressed by a the project, Promoting Safer and Cleaner Used Vehicles, in Africa and examined in a report commissioned by the FIA Region I (AASA, 2020). That paper aimed to investigate the feasibility, social/financial/environmental impact, and challenges to policy reform. Safer vehicles will reduce the number of road-related deaths and injuries, reducing the fiscal burden associated with loss of life and recovery from serious injury. Amongst other recommendations including an age limit of 5 years, they recommend banning zero and one-star safety rated cars. The effectiveness of this policy is very difficult to ascertain due to the lack of data regarding the safety level, age and turnover of car fleets in different countries.

The Transport Research Laboratory has published reports on the importance of safer vehicles and found the three highest priority vehicle safety standards to be:

1. Minimum standards for crashworthiness, i.e. regulations that help to protect occupants in front and side impact crashes.
2. Electronic Stability Control (ESC) for crash avoidance.
3. Pedestrian protection measures to improve safety for Vulnerable Road Users (VRUs) including pedestrians and bicyclists. (Wallbank, McRae-McKee, & Durrell, 2016 p i)

Wallbank et al. (2016) estimated that crashworthiness regulations would prevent 11,000 car occupant fatalities up to 2030, and regulations for ESC, pedestrian protection and autonomous braking for vulnerable road users would prevent a further 14,000 fatalities between 2020 and 2030. Overall, they found if Argentina, Brazil, Chile, and Mexico adopted the full set of priority vehicle safety standards from 2020, more than 25,000 lives could be saved and over 170,000 serious injuries prevented by 2030.

The increase in safety of the vehicle fleet includes two factors, namely:

- voluntary uptake, where the inclusion of safety features is led by the willingness of manufacturers to fit them and willingness of consumers to pay for them; and
- mandatory uptake through regulatory intervention, where all vehicles or all vehicle types are be required to meet the regulatory requirements by a specific date.

The estimation of the effect of these combined factors is then dependent upon the number of newly registered vehicles, and then combined with how quickly these safety features are included through the car fleet based upon the rate of turnover. Wallbank et al. (2016) found the rate of turnover varies substantially, for example, only 3% of cars in the Mexico fleet are new each year, but this is much higher for Chile at 7%. With these factors considered, they estimated approximately 2–3% fewer cumulative fatalities by 2030. Given the additional challenges in implementing these regulations effectively in low-income countries, a conservative figure of 1% reduction has been included in the model.

The costs modelled with implementing this program are the estimated regulatory costs as opposed to the increased cost per vehicle. This includes setting up a testing centre. Wallbank et al. (2016) quote a testing centre in Brazil would be expected to cost in the order of 0.002% of GDP.

Public awareness programs

Public awareness campaigns have previously not been included in the VRSM. A brief literature review on public awareness campaigns for road safety found solid evidence of their effectiveness. Preliminary findings from the two-year Slow Zones, Safe Zones speed reduction program implemented in Gia Lai Province, Vietnam, by AIP Foundation indicate public awareness campaigns concerning speed compliance reduced the percentage of crashes near schools by 4.1%, whereas a study in Japan found a 2.5% reduction in deaths (Inada, Tomio, Nakahara, & Ichikawa, 2021). Other studies such as Phillips, Ulleberg, and Vaa (2011) find the average effect of road safety campaigns is a 9% reduction in accidents. Given the variability, a conservative value of 4.5% is used in the model.

The Health Economic Assessment Tool

Physical activity

The incorporation of the Health Economic Assessment Tool (HEAT) into the RSIM has been investigated for both physical activity and air pollution. Physical inactivity is a significant public health problem in most regions of the world. It is unlikely to be solved by classical health promotion approaches alone, such as organized forms of sport or exercise done in leisure time. Promoting cycling and walking is a promising route to getting more physical activity, since it can be more readily integrated into people's busy schedules, than, for example, leisure-time exercise. It is also a win-win approach: it not only promotes health but can also lead to positive environmental effects, especially if cycling and walking replace short car trips. These forms of physical activity are also more practical for population groups where sport is either not feasible because of physical limitations, or is not an accessible leisure activity for economic, social or cultural reasons.

The evidence base for the long-term health effects of physical activity on young people is not as large as that for adults. The advisory group for the Health Economic Assessment Tool concluded that the evidence for children and adolescents is insufficient and that economic appraisals should solely focus on adults for now. However, there is still a considerable amount of research into the benefits of physical activity for adolescents, and the WHO HEAT User Manual (WHO, 2017) does not rule out using the HEAT approach for adolescents. But it states that if the assessed population is considerably younger or older than average, the user can specify a lower or higher age range. The age groups to which the results are applied and for which mortality rates are used should be made explicit, and if the model is applied to children or older adults, any related assumptions should also be made explicit (WHO, 2017 p16).

This is a considerable issue as lack of physical activity among adolescents is not limited to high income countries, as can be seen in Figure 6 and Figure 7 which show the prevalence of insufficient physical activity among school going adolescents (11–17 year olds) (WHO, 2016). The implications of physical inactivity have been calculated as amounting to 5.3 million early deaths each year (Lee et al., 2012). In addition, millions of people acquire lifestyle related diseases such as Type 2 diabetes at increasingly earlier ages, as well as heart disease, high blood pressure and strokes, several forms of cancer, poor lung function, depression and anxiety, diminished cognitive function and poorer sleep (Lee et al., 2012).

Figure 6: Presence of insufficient physical activity (male) (WHO, 2016)

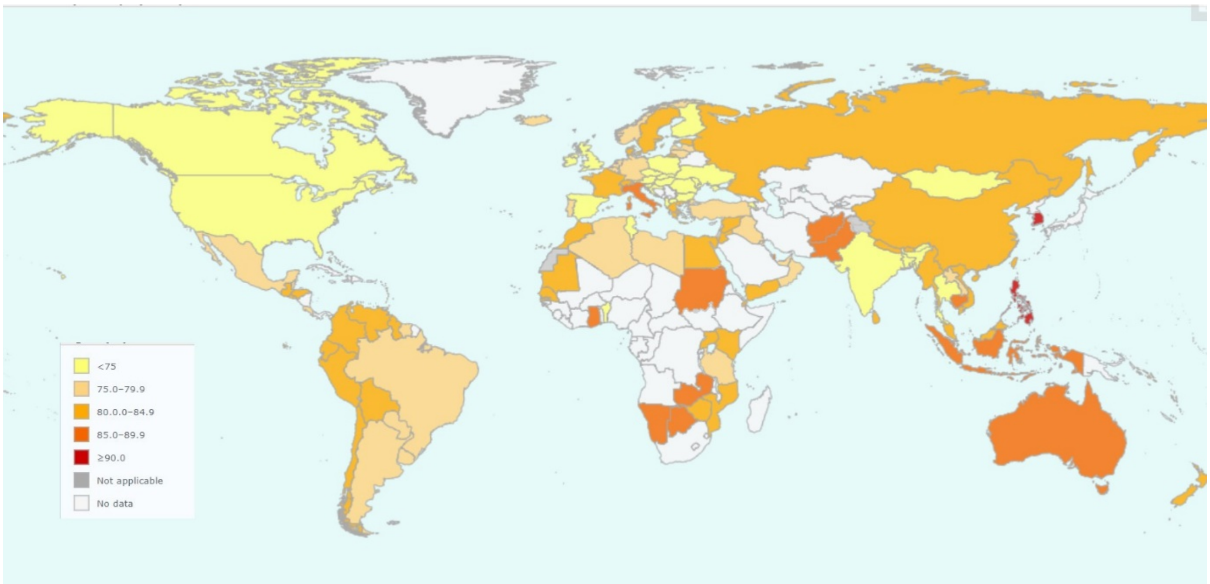
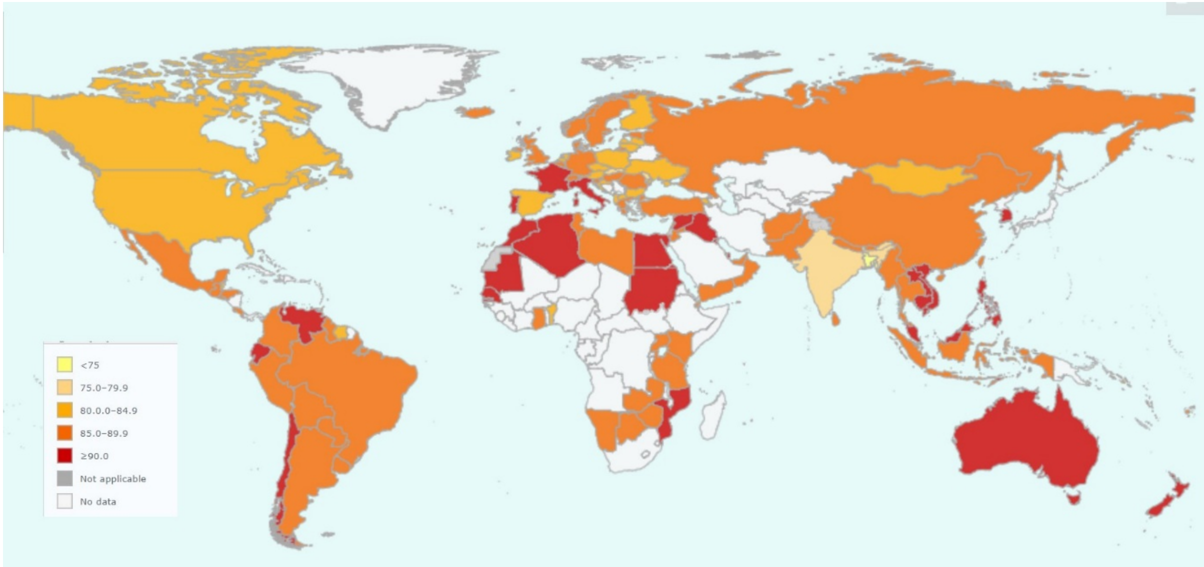


Figure 7: Presence of insufficient physical activity (female) (WHO, 2016)



Preliminary investigations were made into the ability of including physical activity and air pollution into the model using Seville, Spain as a case study, where a high quality bicycle network resulted in nearly 10% of trips shifting to cycling in an 18-month period. Data was obtained from the authors of Marqués, Hernández-Herrador, Calvo-Salazar, and García-Cebrián (2015) regarding mode share changes and vehicle kilometres travelled. However, data incompatibility issues around the construction of the RSIM highlighted the necessity to completely reconstruct the RSIM in order to accommodate modal shares. Currently the RSIM does not include modal share into its calculations, but rather only fatality and serious injury rates per 100,000. By default, the RSIM assumes an unchanged modal share between the different modes. For any benefits to be calculated from increased cycling or walking, this would assume a certain percentage of trips by motorised transport would be replaced by active transport (i.e. walking and cycling). This would also affect the projected fatality rates of both motorised transport, as well as active transport. Despite this, it is expected that shifts in modal proportions will occur. However, for significant increases in the modal share of active transport, infrastructure improvements are expected to be 5-star quality roads.

While a model combining elements of the RSIM with modal shares is considered feasible and desirable, it is beyond the scope of this project due to its complexity and time constraints.

Air pollution

According to the WHO, ambient air pollution kills approximately 4.2 million people worldwide every year due to stroke, heart disease, lung cancer, and acute and chronic respiratory diseases. Around 91% of the world's population lives in places where air quality levels exceed WHO limits. While ambient air pollution affects developed and developing countries alike, LMICs experience the highest-burden, with the greatest toll in the Western Pacific and Southeast Asia regions (WHO, 2021a).

Calculating the exposure of cyclists or pedestrians to air pollution requires defining the air pollution in the study area. As with physical activity, the HEAT assumes that a certain proportion of the population changes its transport mode from motorised transport to walking or cycling. As also assumed in epidemiological studies on the health effects of air pollution, the HEAT results are based on the assumption that this average transport behaviour corresponds with the urban background air pollution levels. Conversion factors between background air pollution levels and exposure while walking or cycling were determined through numerous studies that estimated the concentrations of particulate matter with an aerodynamic diameter of 2.5 µm or less (PM2.5) while cycling or walking, and background concentrations were assessed for the construction of the HEAT.

While data is available, the same issues with respect to physical activity are present for air pollution with respect to the RSIM. While younger age groups can be modelled with any assumptions made explicit, a significant reconstruction of the model would be required to include modal shares, and extensive data issues are also present with respect to the modal shares. However, data with respect to average PM2.5 pollution are available through the WHO (2021b).

Costs of Interventions

For this study, the costs involved with implementing the proposed interventions are in three categories:

- implementing behavioural measures (helmets, seat belts, alcohol control, speed limits, and GLS);
- developing road safety management capacity; and
- infrastructure improvements.

Each of these elements is critical to the effective implementation of road safety interventions.

In terms of costs, only five studies have been identified that provide specific estimates of the annual costs of full implementation of the four behavioural measures (helmets, seat belts, alcohol control, and speed enforcement) (Bishai & Hyder, 2006; Chisholm & Naci, 2008, 2012; Ditsuwan et al., 2013). The estimates are summarized in Table 7.

Table 7: intervention costs, USD

Cost range, $ per capita	Cost range, share of GDP	Source
Seat belts		
$0.09–$1.45 (per capita 2016 $)	0.003%–0.011% of GDP (2005)	(Chisholm & Naci, 2008)
$0.09–$0.30 (per capita 2016 $)		(Chisholm & Naci, 2012)
Helmets		
$0.14 and $0.49 (per capita 2016 $)	0.001%–0.007% of GDP (2005)	(Chisholm & Naci, 2008)
$0.13–$0.17 (per capita 2016 $)		(Chisholm & Naci, 2012)
0.011–$0.304 (per capita 2016 US$)		(Bishai & Hyder, 2006)
Alcohol		
$0.15–$0.33 (per capita 2016 $)		(Chisholm & Naci, 2012)
$0.15–$2.24 (per capita 2016 $)	0.004%–0.012% of GDP (2005)	(Chisholm & Naci, 2008)
0.251 (per capita 2016 US$)	0.0079% of GDP	(Ditsuwan et al., 2013)
Speed enforcement		
$0.17–$0.36 (per capita 2016 $)		(Chisholm & Naci, 2012)
$0.011–$0.304 (per capita 2016 US$)		(Bishai & Hyder, 2006)
$0.17–$2.37 (per capita 2016 $)	0.005%–0.013% of GDP (2005)	(Chisholm & Naci, 2008)
0.0032 (per capita 2016 US$)		(Chisholm & Naci, 2008)
	0.00091% of GDP	(Bishai et al., 2008)
Total all four		
Sum of above	0.013%–0.043% of GDP (2005)	(Chisholm & Naci, 2008)
		(Chisholm & Naci, 2012)
Integrated implementation	0.007%–0.024% of GDP (2005)	(Chisholm & Naci, 2008)
		(Chisholm & Naci, 2012)

VRSM costs

The question of the costs of a coordinated implementation of the four measures, as opposed to the sum of the costs of implementing the four measures individually, was initially addressed by Chisholm and Naci (Chisholm & Naci, 2008, 2012). They estimated a cost for coordinated implementation varying between 0.007% and 0.024% of GDP, depending on the region of implementation. This percentage figure is lower than the sum of the individual intervention costs, which vary between 0.013% and 0.043% of GDP, due to cost savings from coordinated implementation.

As the model assumes a high level of enforcement, the figure used for coordinated implementation is at the upper end of the range (0.024% of GDP) from Chisholm and Naci (2008) across all countries.

The only data regarding costs associated with implementing a graduated licensing scheme are those provided by VicRoads (2017) and are estimated to be 0.006% of GDP when fully implemented. Consequently, this figure is added to the 0.024%, producing a total for behavioural measures of 0.03% of GDP.

A report by the World Bank estimated the costs of developing management capacity based on two US$20 million demonstration projects being implemented in each "GDP equivalent entity of $50 billion" over a 5-year period (say 2016–2021) to build capacity and systems (Bliss & Breen, 2009). In percentage terms, this equates to expenditure of 0.08% of GDP per annum to build the required capacity.

In addition to capacity building, funding for ongoing adequate maintenance and governance of legislative processes, enforcement systems, data assembly and management (crash, offence, licensing, and vehicle registration), infringement management, and court systems, would be needed. The operation and maintenance of these capacities would require further, although reduced funds, for each of years from 2022 to 2030. The VRSM includes values that are two thirds of that in the capacity building stage or 0.055% of GDP.

Consequently, the VRSM estimated the total cost of implementing the various interventions to develop and maintain management capacity, and to build better infrastructure, corresponds to 0.165% of GDP (0.03 + 0.08 + 0.055) in the first 5 years, and 0.14% of GDP for subsequent years.

Updated costs in RSIM

The RSIM uses the same behavioural and management capacity costs and adds the costs of the additional interventions – improved car safety standards and public awareness campaigns – as well as greater granularity of infrastructure costs.

Infrastructure costs

For infrastructure costs, the RSIM utilised an average figure from the modelling undertaken by iRAP. The iRAP analysis assumed targeting the highest volume 10% of roads for each road user group with major infrastructure upgrades, where required, would address safety levels for greater than 50% of travel (e.g. CBD areas and major shopping and education areas for pedestrians and cyclists; motorcycle routes and high-volume national highways, motorways and urban arterials for vehicles). The analysis includes an average investment of $250,000 per km in upper-middle income countries, $150,000 in lower-middle income countries and $100,000 in low-income countries. This analysis assumes some road sections will require more than these levels of investment and some may not require any investment at all. Lower cost maintenance upgrades and speed management initiatives (assumed to be equivalent to 10% of the major upgrade costs) are all assumed for the lower travel volume parts of the network. These costs are converted into a percentage of GDP that is used to estimate the costs for each country.

iRAP have also undertaken studies to determine the cost of a campaign for many countries, including the cost in improving roads to achieve 75% of all travel being on 3-star or better roads.

While the VRSM used average costs from the iRAP, assumptions targeting the highest volume 10% of roads for each road user group would address safety levels for greater than 50% of travel; costs for the RSIM are calculated in more detail. The iRAP analysis assumed an average investment of $400,000 per km in high-income countries, $250,000 in upper-middle income countries, $150,000 in lower-middle income countries, and $100,000 in low-income countries. In using these estimates, it is noted that some road sections will require more than these levels of investment and some may not require any investment at all. The iRAP analysis included lower cost maintenance upgrades, and speed management initiatives (assumed to be equivalent to 10% of the major upgrade costs) have been assumed across the lower volume parts of the network.

While it is possible to model the inclusion of specific interventions, e.g. delineation, speed humps, dependent upon efficacy rates suggested by iRAP in their Toolkit suite, this is only applicable in small, clearly defined areas or regions. Determining, for example the number of speed humps, separated footpaths or delineated intersections, for a nationwide study is not feasible.

While specific interventions have not been modelled, the proportional cost of infrastructure (in % of GDP) according to mode type has been based upon the road user groups (WHO, 2018) leading to the following estimations for modelling purposes:

- vehicle occupants 70%;
- pedestrians 20%;
- motorcycles 5%; and
- cyclists 5%.

While this is an indication only, it enables highly tailored infrastructure interventions suitable to the local setting, e.g. Vietnam has a very high level of motorcycles, while in Tanzania the majority of fatalities are pedestrians. Separating out infrastructure mode types, enables the optimisation model to select the most appropriate infrastructure interventions.

Car safety standards costs

The FIA Region I report (AASA, 2020) identified financial implications for the participating countries' economy on both, governmental and individual level. These includes the requirement that a regulating agency be established to regulate the car safety standards. These can conceivably be incorporated into the capacity building costs. However, an additional 0.01% of GDP per annum is assumed to build capacity and establish a new agency.

Optimisation

The purpose of the optimisation component within the RSIM is to determine the best value mix of interventions for each country that can reduce either road traffic fatalities or serious injuries. The optimisation component has two modules, with an additional objective function being the lowest number of fatalities or serious injuries for a given investment figure or percentage of GDP.

Optimisation structure

All potential interventions (with infrastructure separated into modes) are included in the analysis. Interventions are built into the model by acting upon the pre-existing fatality rate at a certain percentage effectiveness for each intervention. The optimisation model has two separate modules with two different objective functions and set of constraints.

The first module calculates the optimal solution for each country scenario to achieve the goal of reducing the fatality or serious injury rate to, for example, 50% by 2030 at minimal cost. The second module calculates the greatest reduction in fatalities or serious injuries for a given expenditure as expressed as a percentage of GDP, for example 0.15% GDP per annum.

The optimisation model consists of a linear programming optimisation model constructed within the Microsoft Excel software programme. Given the multiplicative nature of the interventions, the GRG (Generalized Reduced Gradient) nonlinear solver is used. This solver method looks at the gradient or slope of the objective function as the input values (or decision variables) change, and determines that it has reached an optimum solution when the partial derivatives equal zero.

Economic Modelling

The RSIM estimates the number of deaths and cases of serious disability averted from the intervention scenario compared to the base scenario of no change. The scale of these health outcomes for a particular country depends on the prevalence of road traffic injuries by age and sex, the composition of the intervention program and other country-specific parameters within the model. The cost of the intervention program will also vary depending on which interventions are chosen for the intervention program.

The estimates of deaths and disability averted and the cost of the program are inputs used in the economic model.

The method for expressing health outcomes in economic terms follows closely that used in previous road safety studies (Rasmussen, Maharaj, Sheehan, & Friedman, 2019; Sheehan et al., 2017; Symons et al., 2019).

The economic benefits are calculated by following the cohort of people over their lifetimes whose deaths or serious disability are averted for each year of the intervention program. As the period of the intervention is from 2022 to 2050 there are 29 such cohorts.

The people in each cohort age are subject to death rates for their country, age and sex using estimates from the most recent UN World Population Prospects (UN 2019) projections to the year 2100.

The number of these people that are in the labour force is calculated by using the most recent labour force participation rate projections from the ILO (2019) for the period to 2030. For each year and age and sex cohort, the number of people in the labor force is calculated by applying the labor force participation rate estimate appropriate for each estimate of the number of people in that year by age and sex.

The economic contribution from these people in the labor force is calculated by multiplying the number by an estimate in that year of the GDP per person in the labor force, and a factor estimating the productivity of their age compared to average productivity. GDP estimates are obtained from the World Bank for the most recent year (World Bank 2020) and labor force estimates from the ILO.

Average productivity is obtained by dividing GDP by the labor force and this is allowed to increase each year by a rate depending on the country World Bank income status.

The results for each cohort are their contribution to GDP each year in which they are in the labor force. Summing across all the cohorts gives a measure of the GDP resulting from the deaths and serious disability averted by the intervention program.

Because the cost of the components of the intervention program are expressed as a percentage of GDP, estimates of the overall GDP for the particular country in each year are required and can be calculated by multiplying the estimated average productivity in that year by the estimate of the overall labor force in that year.

In order to compare the economic benefits and costs associated with the intervention program, both are expressed as net present values (NPV) using the standard World Bank discount rate of 3%. A common investment metric is the benefit-cost ratio, and this is calculated by dividing the economic benefits by the cost both in NPV.

Results

To illustrate how the RSIM and the investment case can be used, we compared a base scenario with a common intervention scenario to calculate the number of deaths and serious injuries averted and the benefits and costs of the intervention program from 2022 to 2050 for the 77 countries currently included within the RSIM.

Table 8 shows the number of road traffic deaths averted by the intervention program for each of the age groups 10–14, 15–19 and 20–24 years old for each sex. Table 9 shows the number of serious injuries averted.

The benefits and costs of the intervention program and the resulting benefit-cost ratios are given in Table 10. While there is considerable variation among countries in the size of the BCRs ranging from 4.6 to 66, all results show benefits exceeding costs by a significant margin indicating high returns on investment.

Table 8: Road traffic deaths averted

	Male				Female				Persons			
	10 to 14	15 to 19	20 to 24	Total	10 to 14	15 to 19	20 to 24	Total	10 to 14	15 to 19	20 to 24	Total
Afghanistan	2,835	9,734	14,869	27,438	1,010	1,724	2,050	4,783	3,845	11,457	16,919	32,221
Angola	3,480	14,611	23,078	41,169	2,269	4,871	5,210	12,351	5,750	19,482	28,288	53,520
Azerbaijan	143	433	1,085	1,661	59	86	89	235	203	519	1,174	1,896
Bangladesh	4,009	9,319	11,526	24,854	662	1,262	1,249	3,173	4,671	10,581	12,775	28,027
Benin	926	1,862	2,452	5,240	674	704	712	2,090	1,600	2,565	3,164	7,329
Bolivia	307	1,179	1,430	2,915	140	220	241	601	447	1,399	1,671	3,517
Botswana	299	508	597	1,404	146	232	250	628	445	739	848	2,032
Brazil	2,571	21,329	36,962	60,862	1,619	4,274	6,302	12,195	4,190	25,603	43,264	73,057
Burkina Faso	3,495	8,804	11,232	23,531	2,611	3,025	2,814	8,449	6,105	11,830	14,046	31,981
Burundi	959	2,680	3,866	7,505	630	799	629	2,058	1,588	3,479	4,495	9,562
Cambodia	566	4,087	4,881	9,533	204	673	597	1,474	770	4,760	5,478	11,008
Cameroon	2,861	6,743	10,045	19,648	1,138	1,377	1,521	4,035	3,998	8,120	11,565	23,684
Central African Republic	1,412	4,706	6,199	12,316	602	1,250	1,136	2,988	2,014	5,955	7,335	15,304
Chad	1,671	2,762	3,614	8,046	1,140	786	714	2,641	2,811	3,548	4,328	10,687
Chile	117	1,058	1,423	2,598	131	261	279	671	248	1,319	1,701	3,269
China	7,399	42,532	90,036	139,967	3,421	9,357	12,219	24,997	10,821	51,889	102,255	164,964
Colombia	588	4,306	10,073	14,966	434	1,293	1,587	3,314	1,022	5,599	11,659	18,280
Comoros	166	480	575	1,221	101	187	150	437	267	667	725	1,658
Congo	488	2,237	2,906	5,631	248	670	664	1,582	736	2,907	3,570	7,213
Cote d'Ivoire	1,537	3,256	4,380	9,173	1,120	1,310	1,224	3,655	2,657	4,567	5,604	12,828
Democratic Republic of the Congo	14,084	47,285	75,195	136,564	8,943	16,320	15,742	41,005	23,027	63,605	90,938	177,570
Djibouti	26	67	102	196	15	12	13	40	41	80	115	236
Egypt	5,147	17,463	22,883	45,493	2,703	4,816	5,349	12,868	7,850	22,279	28,232	58,361
Equatorial Guinea	81	543	750	1,375	30	88	94	212	112	631	845	1,587
Eritrea	180	640	915	1,735	118	153	131	402	298	793	1,046	2,137
Ethiopia	2,642	8,694	10,989	22,326	1,408	1,769	1,618	4,795	4,050	10,463	12,608	27,120
Gabon	150	915	1,166	2,232	60	173	149	382	210	1,088	1,315	2,614
Ghana	2,580	8,547	12,358	23,485	849	1,435	1,425	3,709	3,429	9,982	13,783	27,193
Guatemala	529	2,652	7,821	11,002	230	716	761	1,707	759	3,368	8,582	12,709
Guinea	1,264	2,463	3,195	6,922	983	887	903	2,773	2,247	3,349	4,098	9,695
Guinea-Bissau	175	537	758	1,470	104	178	213	494	278	715	971	1,964
Haiti	672	1,424	2,105	4,201	337	614	540	1,491	1,009	2,039	2,644	5,692

India	11,684	42,790	111,378	165,852	9,888	11,629	18,714	40,231	21,572	54,418	130,092	206,082
Indonesia	12,379	59,738	45,385	117,502	2,617	7,045	4,591	14,253	14,996	66,782	49,976	131,754
Iraq	961	5,288	6,315	12,564	442	943	1,226	2,611	1,402	6,231	7,542	15,175
Kenya	993	4,613	5,552	11,158	636	1,183	1,145	2,963	1,629	5,795	6,697	14,121
Kyrgyzstan	252	464	923	1,639	109	192	134	435	362	656	1,056	2,074
Laos	216	1,273	1,925	3,414	94	282	304	679	310	1,555	2,229	4,093
Lesotho	200	660	1,196	2,056	86	229	258	573	286	889	1,455	2,630
Liberia	220	527	815	1,562	150	185	196	531	370	713	1,010	2,093
Madagascar	1,094	3,565	5,159	9,818	848	1,256	1,091	3,195	1,942	4,821	6,251	13,013
Malawi	650	2,645	3,612	6,907	312	584	450	1,347	963	3,229	4,063	8,254
Mali	1,642	3,195	4,105	8,943	1,127	1,000	879	3,006	2,769	4,196	4,984	11,949
Mauritania	382	685	988	2,055	366	361	435	1,162	749	1,046	1,423	3,217
Mexico	2,594	14,150	31,718	48,462	1,324	2,512	4,849	8,685	3,918	16,662	36,568	57,147
Morocco	934	9,195	6,426	16,555	374	876	810	2,059	1,308	10,071	7,236	18,615
Mozambique	1,378	8,412	12,321	22,111	392	1,343	1,249	2,984	1,770	9,755	13,570	25,095
Myanmar	402	7,062	8,539	16,003	221	1,225	932	2,378	623	8,287	9,471	18,381
Nepal	289	3,532	5,556	9,377	131	297	367	795	420	3,830	5,922	10,172
Niger	2,914	6,101	7,153	16,168	1,801	1,692	1,454	4,947	4,714	7,793	8,608	21,115
Nigeria	8,145	14,683	18,130	40,958	3,801	3,811	3,797	11,409	11,947	18,494	21,926	52,367
North Korea	417	3,890	7,171	11,478	217	900	1,185	2,302	633	4,790	8,356	13,780
Pakistan	5,364	18,287	31,727	55,378	7,690	8,921	12,060	28,671	13,054	27,208	43,786	84,049
Papua New Guinea	1,123	2,912	3,979	8,014	156	635	791	1,582	1,280	3,546	4,770	9,595
Peru	291	979	2,344	3,613	269	495	620	1,385	560	1,474	2,964	4,998
Philippines	2,917	9,342	17,996	30,255	1,546	2,294	3,123	6,964	4,464	11,636	21,119	37,219
Rwanda	884	2,876	3,623	7,383	567	696	679	1,942	1,451	3,572	4,302	9,325
Sao Tome and Principe	6	61	54	121	2	10	7	19	8	71	62	140
Senegal	658	2,220	3,255	6,133	435	496	459	1,391	1,094	2,716	3,714	7,524
Sierra Leone	589	1,280	1,870	3,739	489	455	460	1,404	1,079	1,735	2,330	5,143
Solomon Islands	38	194	515	747	15	116	168	299	53	310	683	1,046
Somalia	1,625	4,117	5,441	11,183	911	963	792	2,666	2,537	5,080	6,233	13,849
South Africa	68	3,384	30,292	33,744	22	1,289	2,140	3,450	90	4,673	32,431	37,195
South Sudan	766	1,427	1,558	3,751	499	407	305	1,211	1,265	1,834	1,863	4,962
Sudan	2,337	7,568	9,223	19,128	1,008	1,057	1,389	3,453	3,346	8,624	10,611	22,581
Swaziland	109	282	451	842	47	80	74	201	156	363	525	1,044
Tajikistan	359	529	1,965	2,852	90	138	143	371	449	667	2,108	3,223
Tanzania	3,016	7,662	9,513	20,191	2,055	2,758	2,453	7,265	5,071	10,420	11,966	27,457

The Gambia	104	601	774	1,479	47	81	75	203	151	683	849	1,683
Togo	758	1,849	2,698	5,304	615	829	934	2,378	1,373	2,678	3,632	7,682
Turkmenistan	37	147	340	524	21	55	57	132	57	202	397	656
Uganda	4,236	10,803	14,530	29,568	1,945	2,860	2,438	7,244	6,181	13,663	16,968	36,812
Uzbekistan	1,024	2,351	4,914	8,289	436	476	828	1,739	1,460	2,827	5,742	10,028
Vietnam	1,833	15,769	19,912	37,515	798	2,977	3,514	7,289	2,632	18,746	23,426	44,804
Yemen	4,350	11,721	16,746	32,816	2,353	2,729	4,020	9,103	6,703	14,450	20,766	41,920
Zambia	797	4,417	6,277	11,491	321	786	685	1,792	1,119	5,203	6,962	13,283
Zimbabwe	1,262	2,889	3,486	7,637	437	606	573	1,615	1,699	3,495	4,058	9,252
Total	145,656	539,991	857,316	1,542,958	81,849	131,276	149,428	362,549	227,513	671,266	1,006,743	1,905,512

Table 9: Cases of serious road traffic injury averted

	Male				Female				Persons			
	10 to 14	15 to 19	20 to 24	Total	10 to 14	15 to 19	20 to 24	Total	10 to 14	15 to 19	20 to 24	Total
Afghanistan	9,188	16,228	19,803	45,219	5,049	6,803	6,518	18,369	14,236	23,031	26,321	63,588
Angola	16,589	31,546	36,464	84,599	13,975	15,188	13,419	42,582	30,564	46,734	49,884	127,181
Azerbaijan	1,908	4,167	5,400	11,475	1,107	1,631	1,654	4,392	3,015	5,797	7,055	15,867
Bangladesh	164,312	226,511	234,540	625,362	39,010	67,995	83,792	190,796	203,321	294,505	318,331	816,158
Benin	6,452	10,319	13,949	30,720	4,859	5,352	5,417	15,628	11,312	15,671	19,365	46,348
Bolivia	1,359	2,154	2,479	5,991	777	687	680	2,144	2,136	2,840	3,159	8,135
Botswana	756	929	994	2,678	803	781	829	2,414	1,560	1,710	1,823	5,092
Brazil	34,093	88,026	123,708	245,827	11,941	20,093	27,030	59,064	46,033	108,119	150,738	304,891
Burkina Faso	17,343	27,502	35,775	80,620	11,110	12,153	12,166	35,428	28,453	39,656	47,940	116,049
Burundi	8,069	12,945	15,713	36,728	5,393	4,908	3,994	14,295	13,463	17,853	19,707	51,023
Cambodia	3,046	9,637	12,602	25,285	1,749	3,266	3,611	8,626	4,795	12,903	16,213	33,911
Cameroon	17,372	30,873	40,595	88,840	9,442	10,614	10,463	30,519	26,813	41,487	51,059	119,359
Central African Republic	1,957	3,328	3,696	8,981	1,382	1,448	1,354	4,183	3,339	4,776	5,050	13,164
Chad	10,599	15,614	19,589	45,803	6,467	6,057	5,587	18,111	17,066	21,672	25,176	63,914
Chile	2,415	4,676	5,191	12,282	1,915	2,838	2,956	7,709	4,330	7,514	8,147	19,991
China	192,416	278,009	386,583	857,007	107,965	136,451	179,056	423,473	300,381	414,460	565,639	1,280,480
Colombia	3,834	7,361	10,630	21,825	4,939	1,980	1,144	8,063	8,772	9,341	11,775	29,888
Comoros	916	1,821	2,076	4,812	613	636	555	1,804	1,529	2,457	2,631	6,617
Congo	1,991	3,555	4,055	9,601	1,488	1,666	1,486	4,640	3,479	5,221	5,541	14,241
Cote d'Ivoire	16,434	25,390	31,430	73,254	12,737	13,540	12,409	38,686	29,170	38,930	43,839	111,939
Democratic Republic of the Congo	45,500	75,832	88,709	210,041	36,990	37,918	34,416	109,323	82,490	113,750	123,125	319,365
Djibouti	368	647	867	1,882	202	188	180	570	570	835	1,047	2,452
Egypt	25,202	55,626	65,645	146,473	17,126	24,228	24,190	65,544	42,329	79,854	89,835	212,017
Equatorial Guinea	550	997	1,298	2,844	326	392	398	1,117	876	1,389	1,696	3,961
Eritrea	1,897	3,536	4,487	9,920	1,216	1,253	1,114	3,583	3,113	4,789	5,601	13,503
Ethiopia	34,513	64,550	87,936	186,999	21,623	24,635	23,426	69,685	56,136	89,185	111,362	256,683
Gabon	789	1,662	1,905	4,356	538	655	587	1,781	1,327	2,317	2,492	6,136
Ghana	20,183	36,211	48,525	104,919	9,873	11,107	10,705	31,684	30,055	47,318	59,230	136,603
Guatemala	4,960	7,895	8,769	21,623	4,485	1,833	1,026	7,344	9,445	9,728	9,794	28,967
Guinea	8,383	13,412	16,849	38,644	5,742	5,998	5,904	17,645	14,126	19,410	22,754	56,289

Guinea-Bissau	1,046	2,001	2,707	5,754	731	902	1,010	2,643	1,777	2,902	3,717	8,397
Haiti	3,516	5,513	6,902	15,931	1,636	1,757	1,572	4,965	5,152	7,270	8,474	20,896
India	122,375	394,568	870,150	1,387,094	84,142	157,389	242,338	483,869	206,518	551,957	1,112,488	1,870,963
Indonesia	68,224	138,782	159,601	366,607	31,585	49,514	50,726	131,824	99,809	188,296	210,327	498,431
Iraq	8,152	16,797	17,495	42,444	5,655	8,130	8,206	21,991	13,808	24,926	25,700	64,434
Kenya	26,559	45,046	53,520	125,126	14,473	15,407	14,071	43,950	41,032	60,453	67,591	169,076
Kyrgyzstan	3,100	5,382	5,938	14,420	1,766	2,262	1,767	5,795	4,866	7,644	7,705	20,215
Laos	1,539	4,376	6,378	12,292	1,025	2,037	2,264	5,326	2,564	6,413	8,642	17,619
Lesotho	496	850	1,131	2,477	498	609	686	1,793	994	1,459	1,817	4,271
Liberia	2,068	3,574	4,803	10,445	1,310	1,548	1,507	4,365	3,379	5,122	6,310	14,810
Madagascar	15,130	28,242	34,047	77,419	10,410	10,347	9,455	30,211	25,539	38,589	43,502	107,631
Malawi	9,657	19,417	22,592	51,666	4,885	4,465	3,404	12,753	14,541	23,882	25,996	64,419
Mali	10,911	17,188	22,771	50,871	7,186	7,468	6,820	21,474	18,098	24,656	29,591	72,344
Mauritania	2,594	3,583	4,640	10,817	2,035	2,185	2,256	6,476	4,628	5,768	6,897	17,293
Mexico	15,718	27,196	35,912	78,826	11,078	16,803	13,610	41,491	26,796	43,998	49,522	120,317
Morocco	5,737	15,553	15,983	37,272	3,778	5,690	5,608	15,077	9,515	21,243	21,591	52,349
Mozambique	28,538	62,515	76,167	167,220	14,043	14,725	13,812	42,579	42,581	77,240	89,978	209,799
Myanmar	5,907	24,693	33,545	64,145	3,756	7,796	8,210	19,761	9,663	32,488	41,755	83,906
Nepal	14,838	37,585	54,774	107,197	8,555	11,802	13,071	33,428	23,393	49,387	67,845	140,625
Niger	16,514	24,128	29,687	70,328	11,073	10,542	9,786	31,401	27,587	34,669	39,473	101,729
Nigeria	101,068	147,533	189,095	437,695	54,758	61,417	63,246	179,420	155,826	208,950	252,340	617,116
North Korea	2,296	6,258	9,683	18,237	1,430	2,818	4,212	8,460	3,726	9,076	13,895	26,697
Pakistan	152,269	280,815	372,939	806,024	150,215	185,688	201,624	537,527	302,485	466,503	574,563	1,343,551
Papua New Guinea	2,367	4,007	5,197	11,571	1,056	1,748	2,524	5,328	3,423	5,755	7,721	16,899
Peru	2,468	4,391	6,152	13,012	2,202	1,924	1,838	5,964	4,670	6,316	7,989	18,976
Philippines	20,001	41,023	61,470	122,495	13,314	19,318	21,264	53,896	33,315	60,341	82,734	176,391
Rwanda	7,414	14,443	16,752	38,609	4,469	4,473	4,099	13,040	11,883	18,916	20,851	51,650
Sao Tome and Principe	82	236	300	618	58	79	77	214	140	315	377	832
Senegal	4,014	7,560	10,427	22,000	3,625	3,916	4,026	11,566	7,639	11,475	14,452	33,567
Sierra Leone	3,435	5,773	8,244	17,453	2,655	2,899	2,920	8,475	6,091	8,672	11,164	25,927
Solomon Islands	99	230	364	693	90	172	248	510	189	402	612	1,203
Somalia	11,885	18,424	21,544	51,853	6,774	6,102	5,064	17,940	18,659	24,526	26,608	69,792
South Africa	4,175	12,346	24,585	41,106	3,880	6,545	8,484	18,910	8,055	18,891	33,069	60,015
South Sudan	7,390	11,627	13,530	32,546	4,694	4,366	3,597	12,657	12,084	15,993	17,128	45,204
Sudan	14,188	20,317	20,239	54,744	7,243	8,170	7,667	23,080	21,431	28,487	27,907	77,824
Swaziland	294	472	585	1,351	247	242	240	729	541	714	825	2,080

Tajikistan	3,589	5,737	7,634	16,960	2,318	2,629	2,454	7,400	5,906	8,366	10,087	24,359
Tanzania	66,071	99,178	106,326	271,574	43,928	39,151	32,173	115,253	109,999	138,329	138,499	386,827
The Gambia	909	1,877	2,530	5,316	529	650	663	1,843	1,439	2,527	3,193	7,159
Togo	4,867	8,158	10,967	23,991	3,804	4,397	4,816	13,016	8,670	12,555	15,783	37,008
Turkmenistan	1,039	1,985	2,426	5,450	1,065	1,271	991	3,327	2,103	3,256	3,417	8,776
Uganda	37,866	61,392	72,943	172,201	18,447	17,615	14,337	50,398	56,313	79,006	87,280	222,600
Uzbekistan	13,257	24,328	29,013	66,598	6,818	7,957	7,497	22,272	20,075	32,285	36,510	88,870
Vietnam	25,133	90,065	106,991	222,189	15,003	28,088	27,957	71,048	40,136	118,152	134,948	293,236
Yemen	7,758	11,614	12,494	31,866	5,214	6,676	6,673	18,563	12,973	18,290	19,167	50,429
Zambia	9,672	19,257	22,506	51,435	5,332	5,270	4,634	15,237	15,004	24,527	27,141	66,672
Zimbabwe	4,101	5,833	6,992	16,926	2,843	2,848	2,690	8,380	6,943	8,681	9,682	25,306
Total	1,523,720	2,842,827	3,930,933	8,297,474	922,473	1,180,101	1,322,260	3,424,827	2,446,192	4,022,920	5,253,192	11,722,302

Table 10: Costs, economic benefits and benefit-cost ratios, discount rate 3%

	Cost USD million	Discounted Benefits USD million	Benefit-cost ratio
Afghanistan	447	2,424	5.4
Angola	1,001	27,959	27.9
Azerbaijan	440	3,417	7.8
Bangladesh	1,221	67,000	54.9
Benin	158	3,538	22.4
Bolivia	527	3,279	6.2
Botswana	318	2,665	8.4
Brazil	16,805	131,714	7.8
Burkina Faso	125	5,952	47.5
Burundi	84	868	10.4
Cambodia	469	3,183	6.8
Cameroon	599	10,714	17.9
Central African Republic	142	674	4.7
Chad	275	2,786	10.1
Chile	1,138	14,094	12.4
China	26,777	547,744	20.5
Colombia	2,666	13,383	5.0
Comoros	9	615	66.6
Congo	141	2,528	18.0
Cote d'Ivoire	1,008	14,386	14.3
Democratic Republic of the Congo	1,417	16,161	11.4
Djibouti	32	391	12.2
Egypt	1,368	38,105	27.9
Equatorial Guinea	122	2,063	17.0
Eritrea	13	448	34.3
Ethiopia	1,046	11,822	11.3
Gabon	188	3,329	17.7
Ghana	1,257	16,833	13.4
Guatemala	395	8,181	20.7
Guinea	282	3,469	12.3
Guinea-Bissau	30	366	12.3
Haiti	90	1,567	17.4
India	26,718	154,200	5.8
Indonesia	7,868	108,251	13.8
Iraq	1,672	23,292	13.9
Kenya	1,681	17,592	10.5
Kyrgyzstan	173	1,278	7.4
Laos	397	2,496	6.3
Lesotho	38	318	8.4
Liberia	74	524	7.1
Madagascar	330	3,053	9.3
Malawi	156	1,560	10.0
Mali	168	3,916	23.3
Mauritania	191	1,748	9.1
Mexico	6,920	74,626	10.8
Morocco	577	10,717	18.6
Mozambique	246	6,082	24.7
Myanmar	623	5,810	9.3
Nepal	133	6,865	51.6
Niger	208	3,760	18.1
Nigeria	2,447	75,309	30.8
North Korea	99	1,770	17.8

Pakistan	3,201	77,159	24.1
Papua New Guinea	165	3,272	19.8
Peru	1,522	6,996	4.6
Philippines	2,787	32,449	11.6
Rwanda	65	2,524	39.0
Sao Tome and Principe	3	102	29.4
Senegal	160	3,264	20.3
Sierra Leone	74	834	11.2
Solomon Islands	20	260	13.3
Somalia	193	1,530	7.9
South Africa	4,523	24,335	5.4
South Sudan	201	2,595	12.9
Sudan	178	3,870	21.7
Swaziland	43	624	14.5
Tajikistan	212	1,121	5.3
Tanzania	711	22,725	31.9
The Gambia	31	374	12.2
Togo	105	1,446	13.8
Turkmenistan	549	2,764	5.0
Uganda	319	11,737	36.8
Uzbekistan	566	7,227	12.8
Vietnam	1,455	36,732	25.2
Yemen	473	3,239	6.8
Zambia	547	5,670	10.4
Zimbabwe	498	2,446	4.9

Summary and Conclusion

Fatalities and serious injuries from road traffic accidents are a major issue for LMICs, inflicting widespread economic and social harm. They can and should be addressed by local adaptation of policies and interventions that have been well developed in high-income countries. Road traffic accidents are particularly relevant to young people, as they are one of the leading causes of death and serious injury among this cohort. Consequently this report focuses on the impact of road safety interventions on the 10 to 24 age cohort using the GBD 2019 data for 77 LMICs.

This report builds on previous work by Chisholm and Naci (2012), Sheehan et al. (2017) and Symons et al. (2019) in several ways, including more detailed and robust baseline trend forecasts by gender, age and mode, additional modelled interventions together with finer grain infrastructure analysis, urban and rural disaggregation and an optimisation component to the economic analysis. Additional components to the model were investigated including physical activity and air pollution benefits, however, these were considered not feasible for the current project.

The modelling shows that if the interventions are implemented across the 77 countries, then between 2022 and 2050 the lives of over 1.9 million young people will be saved, as well as 11.7 million serious injuries averted.

In addition to the enormous reduction in fatalities and serious injuries, the economic analysis shows implementing the modelled interventions would be a very good economic and social investment, with BCRs at a 3% discount rate ranging between 4.6 to 66 for the 77 countries. While this report gives a broad indication of the lives saved and serious injuries avoided together with the economic benefits, a more detailed analysis is provided in the case studies for Tanzania, Vietnam and

Colombia, that may assist policymakers to develop effective road safety programs that fit with the social and cultural contexts of those countries.

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