HSF Discussion paper

Road traffic injury prevention:

an assessment of risk exposure and intervention cost-effectiveness in different world regions

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Summary

Background:

Road traffic injuries (RTIs) represent a leading and increasing contributor to regional and global disease burden; road crashes killed over one million people worldwide and injured a further 20-50 million in 2002. Although there is an accumulated body of knowledge concerning how this burden may be reduced via appropriate road safety measures, little is known about the relative cost-effectiveness of such measures, particularly in the context of low- and middle-income countries, where road use and injury patterns are different to those found in high-income settings.

Aims:

This study set out to a) calculate the fraction of total road traffic injuries in different world regions associated with different road user groups (pedestrians, bicyclists, motorcyclists, car occupants, and bus/lorry drivers and occupants) and various risk factors (speeding, drink-driving, not wearing seatbelts, not using motorcycle or bicycle helmets); and b) identify and estimate in different world regions the population costs and effects of a selected set of interventions for reducing the burden of road traffic injuries (enforcement of speed limits via mobile speed cameras; drink-drive legislation & enforcement via breath-testing campaigns; legislation & primary enforcement of seat belt use in cars; legislation & enforcement of helmet use by motorcyclists; legislation & enforcement of helmet use by bicyclists (under the age of 15).

Methods:

Comprehensive reviews of the international literature were made in order to determine the breakdown of road traffic injuries by road user group and risk factor in countries around the globe, from which age- and sex-specific weighted averages for epidemiologically-defined WHO sub-regions of the world were calculated. These patterns of injury - together with Global Burden of Disease study estimates of fatal and non-fatal RTIs - were then fitted to a state transition model in order to determine the expected population-level effects of intervention over a 10-year period. The disability-adjusted life year or DALY was used as the summary measure of population-level health outcome. All resources needed to initiate and maintain the selected road safety measures were identified (including those borne privately by vehicle owners, such as helmets), and costed in international dollars (I$) for the year 2005.

Results:

The distribution of road traffic deaths by road user group varies dramatically across epidemiological sub-regions. In the very low-mortality sub-regions of the Americas and Europe, the majority of road traffic deaths occur among motorized four-wheeler occupants. In the South-East Asian region, by contrast, motorcyclists contribute by far the largest to road traffic fatalities, with motorized four-wheeler occupants

constituting less than 20% of total fatalities. The magnitude of pedestrian fatalities also varies considerably across sub-regions, from more than half in African sub-regions to as little as 10%-15% in high-income sub-regions. In terms of the population attributable fractions for five specified risk factors relating to fatal road traffic injuries, speeding accounts for the largest share (an estimated 21%-28%), with other selected risk factors contributing 1%-21% depending on the epidemiological profile. The remaining fatal injury burden - approximately half - is attributable to other (unspecified) causes.

Across four selected sub-regions encompassing different motorization rates and injury patterns, enforcement of speed limits (via mobile cameras) is the single most effective strategy. Legislation and enforcement of drink-driving laws also produce consistent gains in all populations (50%-80% of the gain estimated for mobile speed cameras). Seatbelt laws and enforcement produce lower effects again (25%-40% of the gain for mobile speed cameras). Legislation and enforcement of motorcycle helmet use has a relatively large impact in the motorcycle-heavy Asian sub-regions but only a very modest impact in sub-regions where the motorcycle fleet is appreciably smaller. Assuming (contested) baseline effect sizes, legislation and enforcement of bicycle helmet use produced very little health gain in the high-income sub-region of the Americas, but was the second most effective single strategy in two sub-regions with a relatively high burden of bicycle-related injury. The single most cost-effective strategy varies by sub-region, but generally speaking a combined intervention strategy that simultaneously enforces multiple road safety laws produces the most health gain for a given amount of investment; for example, the combined enforcement of speed limits, drink-driving laws and motorcycle helmet use saves one DALY for a cost of I$ 1000-3000 in the three selected low- and middle-income sub-regions, and I$ 10 000 in the high-income sub-region. Such an investment for a year of healthy life is less than the respective per capita income of these sub-regional populations, which is an internationally used threshold for considering an intervention to be a very cost-effective use of resources.

Conclusions:

The potential impact of available road safety measures is inextricably bound by the underlying distribution of road traffic injuries across different road user groups and risk factors. Even at the aggregated level of whole sub-regions of the world, however, discernible patterns emerge of 'what works where'. For example, in highly motorized regions of the world of America or Europe, the proportion of total fatal injuries attributable to bicyclists and to children not wearing a bicycle helmet is very small (< 2%), so the public health impact of increasing helmet use among this road user group will be correspondingly modest (and relatively cost-ineffective given the fixed costs of its full implementation). By contrast, in other settings where there is a low overall motorization rate or a high dependence on bicycles as a mode of transport, fatal injuries to bicyclists account for a much larger share of the avertable burden, thereby making increased helmet use a more favorable option. More than individual interventions, however, combined enforcement strategies are the most efficient way to respond to the burden of road traffic injuries, because they benefit from significant synergies on the cost side, while generating greater overall health gains on the effect side.

1. Introduction

Road traffic injuries (RTIs) represent a leading and increasing contributor to regional and global disease burden. It is estimated that in 2002 road crashes killed over one million people worldwide and injured a further 20-50 million (WHO, 2004). RTIs are projected to become the 3rd largest contributor to global disease burden by 2020 (WHO, 2004). Most of the projected increase in RTIs will occur in low- and middle-income regions of the world, due to the rapid growth in motor vehicle numbers increasing exposure to risk factors such as speed and alcohol, and exacerbated by inadequate enforcement of traffic safety regulations and public health infrastructure (Ameratunga et al., 2006; Nantulya and Reich, 2002; WHO, 2004).

There is marked variation across the world in the way that roads are used and injuries are caused, which have important implications for road safety policy and practice. For example, road traffic injuries in highly-motorised countries mostly involve car drivers, whereas in certain countries of Asia it is motorcycle riders and in many low-income countries it is occupants of multiple passenger vehicles (such as buses) and pedestrians. There is also appreciable variation in the breakdown of these injuries by underlying cause (road infrastructure versus vehicle design versus exposure to risk factors such as speeding or not wearing a seatbelt). In order to estimate the potential impact of different road safety measures on population-level health, therefore, a good understanding of underlying patterns of road use and injury burden is required. Despite the existence of injury surveillance systems in a number of countries, such information is in short supply. There also remains a shortage of evidence on the comparative population-level costs and cost-effectiveness of different intervention strategies for reducing traffic injuries, which constitutes an important gap in the knowledge base needed to attract new investment and guide decision-making (Bishai and Hyder, 2006). As a contribution to studying the public health response to road safety at the global level, this study set out to:

- calculate the attributable fraction of total RTI injuries for different world regions associated with different road user groups (pedestrians, bicyclists, car occupants etc.) and risk factors (e.g. driving a motorcycle without a helmet or driving a vehicle under the influence of alcohol); and

- identify and estimate in different world regions the population costs and effects of a minimum set of currently used and potentially applicable interventions for reducing the burden of road traffic injuries.

A number of analytical steps needed to be performed in order to estimate the cost-effectiveness of road safety measures in different parts of the world. In each of these steps, the units of analysis are the 14 epidemiologically-based WHO reporting regions (see Appendix 1 for a list). This report provides an introduction to the methods and assumptions used in the analysis, and details concerning the derivation of input model parameters. In short, the analytical process consisted of the following steps:

- Identification of **risk factors and intervention countermeasures** for road traffic injury
- Disaggregation / attribution of the global burden of fatal and non-fatal road traffic injuries by **road user group** (by age and sex in each WHO sub-region)
- Disaggregation / attribution of the global burden of fatal and non-fatal road traffic injuries by **injury risk factor** (by age and sex in each WHO sub-region)
- Estimation and modeling of **intervention effectiveness** at the population level
- Estimation and modeling of **intervention costs** at the population level

2. Identification of risk factors and interventions for road traffic injuries

Improving road safety involves identifying the risk factors that contribute to crashes and injuries, then identifying the interventions that reduce the risks associated with those factors (WHO, 2004). A reference framework for identifying factors that have an impact on road traffic injuries is the Haddon Matrix, which divides factors into human, vehicular and environmental causes across three temporal phases - pre-crash, crash and post-crash (see Figure 1).

Figure 1 The Haddon Matrix

	Factors		
Phase	***Human***	***Vehicle***	***Environment***
Pre-crash	Information Attitudes **Impairment** **Police enforcement**	Roadworthiness Lighting Braking Handling Speed management	Road design Road layout **Speed limits** Pedestrian facilities
Crash	**Use of restraints** **Impairment**	Occupant restraints Other safety devices Crash-protective design	Forgiving roadside
Post-crash	First-aid skill Access to hospital	Ease of access Fire risk	Rescue facilities Congestion

Source: *World Report on Road Traffic Injury Prevention*, Fig 1.3; **highlighted** factors are those included in this study.

A wide array of possible intervention strategies are available for preventing or ameliorating these different factors, ranging from improved road and vehicle design, to heightened safety controls and management, to better trauma care systems for crash victims. Interventions selected for this analysis draw on the recommendations of the *World Report on Road Traffic Injury Prevention*, but are mainly focused on pre-event road safety measures that are capable of changing human factors, because they have robust evidence for their effectiveness and are more readily amenable to intervention costing at the population level. The specific interventions included in the analysis are:

- Enforcement of speed limits (via mobile speed cameras)
- Drink-drive legislation & enforcement (via breath-testing campaigns)
- Legislation & primary enforcement of seat belt use in cars (drivers and passengers)
- Legislation & enforcement of helmet use by motorcyclists (all riders)
- Legislation & enforcement of helmet use by bicyclists (aged below 15 years)

It is acknowledged that while this brief list of interventions impact on key risk factors for different road user groups, they represent only a fraction of the total possible measures that could be implemented by relevant stakeholders in order to reduce the burden of road traffic injuries (WHO 2004; Bishai and Hyder, 2006; Norton et al., 2006). A particular concern here relates to the potentially limited impact of the selected interventions on pedestrians, who are a highly relevant group of vulnerable road users in the context of low- and middle-income countries and account for much of the injury burden. Interventions that focus specifically on this group of road users include improvement of visibility, the construction of barriers, special zones and separate lanes in order to separate moving vehicles from pedestrians. While there is a body of evidence attesting to the safety improvements associated with such strategies, estimation of the resources and costs needed to construct and maintain them is highly problematic at the international level, and calculation of their relative cost-effectiveness is outside the feasible scope of the present evaluation exercise.

In a similar vein, there are considerable difficulties in correctly establishing the number (and cost) of speed bumps required at the population level in order to produce the effects observed in certain studies, and this led us to drop this intervention from the final economic analysis, even though it has been highlighted by others as a potentially cost-effective measure for curbing speeding in developing countries (Bishai and Hyder, 2006; Norton et al., 2006).

3. Attribution of road traffic injuries by road user group

This part of the analysis set out to determine age-, sex-, and region-specific attributable fractions for road user groups.

3.1 Search strategy, inclusion criteria and data quality

Published studies and unpublished reports on country specific road traffic injuries were sought by:

- A standardized online keyword search to obtain country specific information, using online search engines such as Google, Google Scholar, Pubmed, and TransportLink.
- Relevant references cited in articles identified by the electronic search were selected.
- Un-published documents and official crash statistics were obtained from international organizations and country-level institutions and organizations.

Any report or publication providing a breakdown of road traffic injuries by road user group at the national or sub-national level was considered in the review. 134 data sources were identified, 96 of which were peer-reviewed journal articles; nearly all of the peer-reviewed articles were descriptive and included hospital and traffic police records. The number of peer-reviewed articles reporting population-based distributions of road traffic injuries by road user category was limited; the majority of the data sources were mostly urban, hospital-based studies. More than one data source was identified for a number of countries; in such cases, the most representative study was selected. For countries that we were not able to find a data source that reported the *overall* distribution of road traffic injuries by road user category for the entire country, we pooled the information obtained from different road user group studies and derived an overall estimate that way. If more than one population-level study was available for a country, the most recent one was selected. Annex 2 provides a list of countries by WHO sub-region - and associated data sources - for which road user category information was found; in most of the sub-regions, 70%-100% of RTI deaths occur in countries for which we found data and thus our coverage of the most affected countries is high.

Data on fatal road traffic injuries were more widespread than for non-fatal injuries. A limited number of studies provided information on the distribution of non-fatal injuries by road user category. Additionally, very few studies provided age breakdowns or compared deaths in different road user groups by sex. Under-reporting and incomplete recording of road traffic injuries were common. It was apparent that even in the same country, different parts of the country might apply different criteria in reporting motor vehicle crashes by road user category. Classification of casualties by category of road-users was not uniform and in many instances such aggregated groupings did not allow for accurate identification of road-user categories.

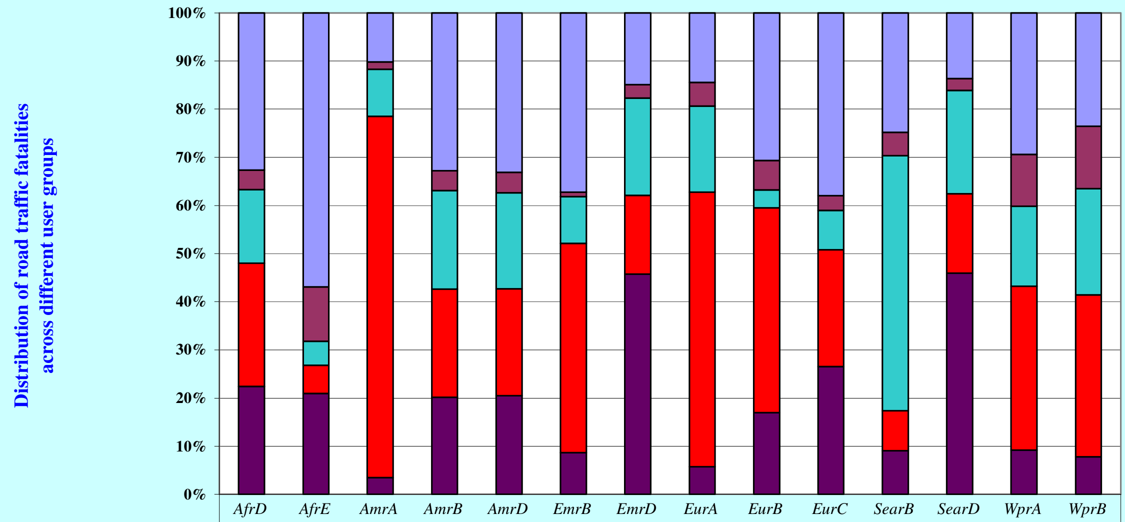
3.2 Data synthesis

Where age groupings and road user categories varied, data were re-grouped in an attempt to produce comparable data between studies. A number of data sources did not make the distinction between car occupants and truck/bus occupants; all these road users were categorized as *four-wheeler occupants*. The contribution of 'truck/bus fatalities' to the 'four-wheeler occupant fatalities' category was determined by using estimates derived from a subset of studies which clearly provided this breakdown. Even when these separate sources were studies conducted in different years, we assumed that the overall distribution of road traffic injuries by road user category would stay fairly constant (over a 5 year period).

Annex 3 shows the breakdown of fatal injuries by road user group for each country that information was available. In order to derive region-specific breakdown of fatal road traffic injuries for all 14 WHO sub-regions, all the available information for specific sub-regions was pooled in order to construct weighted averages from the country-specific data sources. Total numbers of fatal and non-fatal road traffic injuries in each country - needed to construct sub-regional weighted averages, were obtained from the Global Burden of Disease database (www.who.int/healthinfo/bodproject).

Figure 2 gives the estimated distribution of fatal injuries by road user category for selected WHO sub-regions. We were not able to derive a sub-regional weighted average for the high-mortality sub-region of the Americas (AmrD) or the Eastern Mediterranean (EmrD) because of extremely limited information available on the distribution of road traffic fatalities in these two settings. The distribution of road traffic deaths by road user group varies dramatically across epidemiological sub-regions. In the very low-mortality sub-regions of the Americas and Europe, the majority of road traffic deaths occur among motorized four-wheeler occupants (AmrA, 78%; EurA, 62%). In the South-East Asian region, by contrast, motorcyclists contribute by far the largest to road traffic fatalities (SearB, 50%; SearD, 43%), with motorized four-wheeler occupants constituting less than 20% of total fatalities (SearB, 17%; SearD, 19%). The magnitude of pedestrian fatalities also varies considerably across sub-regions, from more than half in African sub-region AfrE (55%) to 15% or less in AmrA or EurA. Elsewhere, and this includes some relatively high-income regions such as WprA and EurB, pedestrian fatalities account for 25%-40% of road traffic deaths.

Figure 2 Distribution of road traffic fatalities by road user type



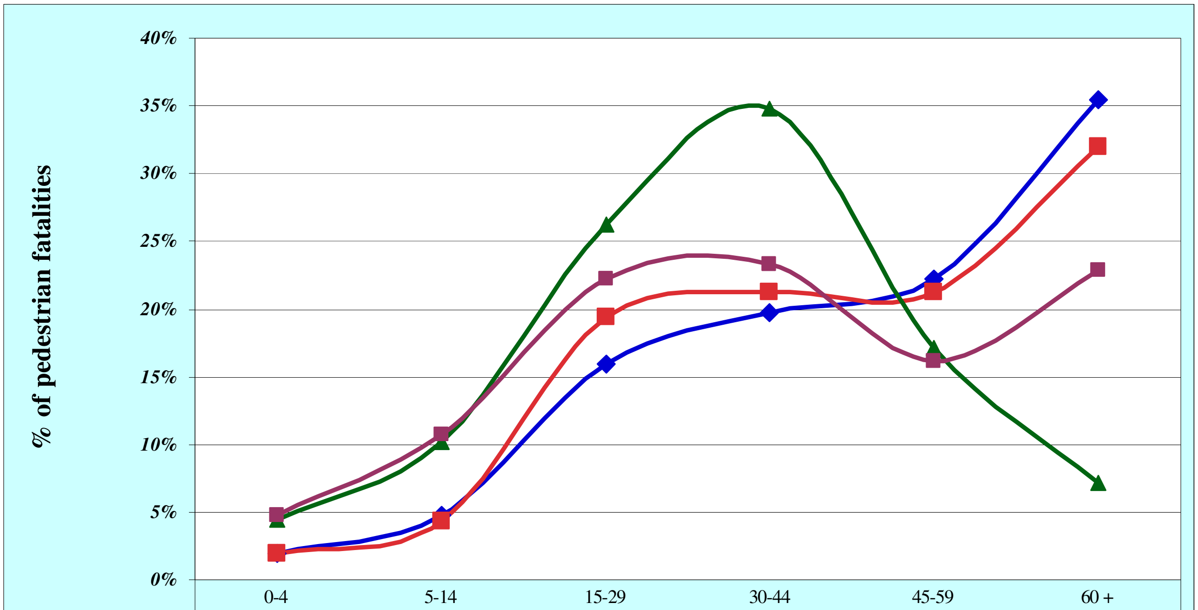
	AfrD	AfrE	AmrA	AmrB	AmrD	EmrB	EmrD	EurA	EurB	EurC	SearB	SearD	WprA	WprB
Pedestrians	33%	57%	10%	33%	33%	37%	15%	14%	31%	38%	25%	14%	29%	24%
Bicycle (riders)	4%	11%	1%	4%	4%	1%	3%	5%	6%	3%	5%	2%	11%	13%
Motorcycle (riders / passengers)	15%	5%	10%	20%	20%	10%	20%	18%	4%	8%	53%	21%	17%	22%
Car (drivers / passengers)	26%	6%	75%	22%	22%	43%	16%	57%	43%	24%	8%	17%	34%	34%
Bus & trucks (drivers / passengers)	22%	21%	3%	20%	20%	9%	46%	6%	17%	27%	9%	46%	9%	8%

Note: Due to lack of region-specific data, AmrD is based on AmrB and EmrD is based on SearD

Age/sex distribution: For attributing total injury estimates across different age groups, we had to rely upon a sub-set of countries that provided this detailed level of information (South Africa, Thailand, USA, and all countries in the European region, including the Newly Independent States and the Russian Federation). Comparison of these datasets revealed that the overall age distribution for fatalities and non-fatal injuries by road user type does not greatly differ among countries. For example, and despite large differences in the *overall* rate of injuries, Figure 3 shows how the age distribution for pedestrian fatalities is actually very similar (at least up to the age of 60; thereafter, South Africa is at variance with the other countries due to a much lower life expectancy). The pooled weighted averages from these datasets for the age distribution of fatal and non-fatal road traffic injuries for different road user types can be seen below in Figure 4. This global age distribution was assumed to hold for all countries not included in the data set. This was then fitted to the overall injury rates obtained for each of the sub-regions (which differ markedly; see Section 5.2).

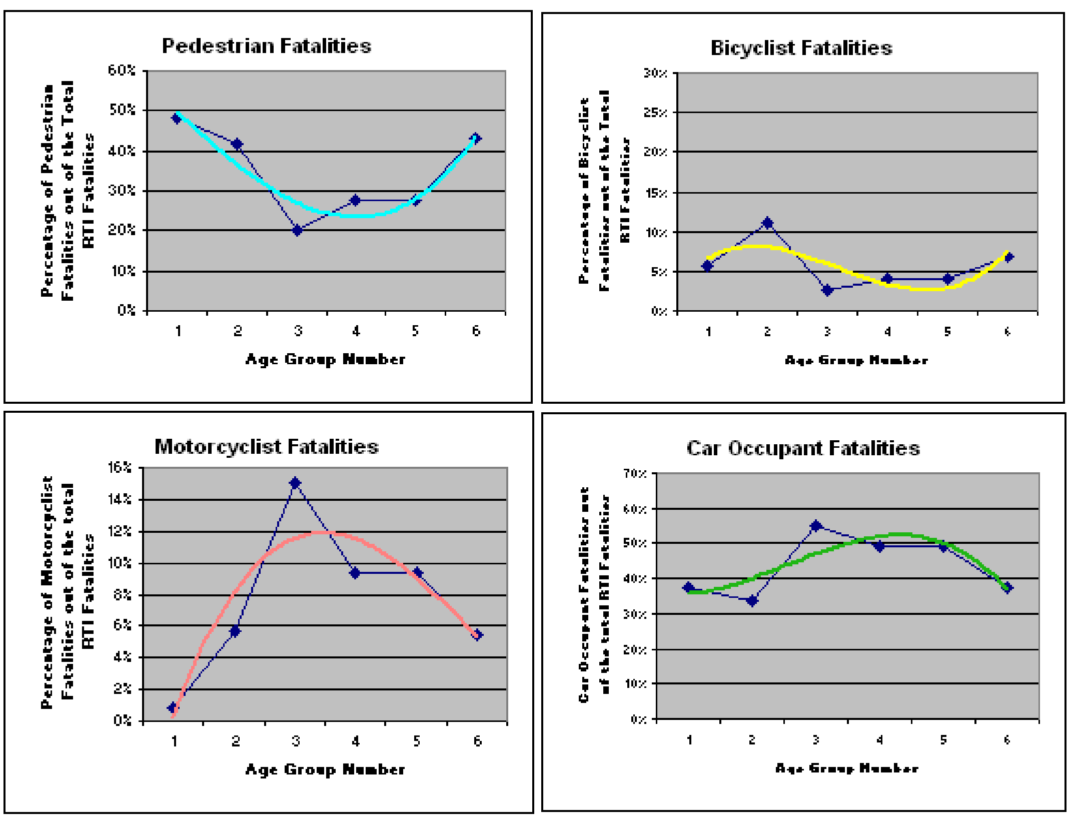
The data collection process did not yield any references suggesting a difference in the age distribution of road traffic fatalities and non-fatal injuries by road user category between males and females. Therefore, the same age distribution of fatal and non-fatal injuries by road user type was applied to males and females in all 14 sub-regions.

Figure 3 Country-specific age distributions for pedestrian fatalities



	0-4	5-14	15-29	30-44	45-59	60 +
USA	2%	5%	16%	20%	22%	35%
Europe	2%	4%	19%	21%	21%	32%
S Africa	4%	10%	26%	35%	17%	7%
Thailand	5%	11%	22%	23%	16%	23%

Figure 4 Global age distribution of fatalities by road user type



4. Attribution of road traffic injuries by injury risk factor

This part of the analysis comprises an assessment of the contribution of different risk factors to overall levels of fatal and non-fatal road traffic injuries in different regions of the world. We attempted to determine age-, sex-, and region-specific attributable fractions for specific RTI risk factors (seat-belt non-use, helmet non-use, driving under the influence of alcohol, and speeding). All road traffic injuries *not* accounted for by these discrete risk factors are grouped together under a residual category of (mainly vehicular and environmental) risk factors (see Figure 1).

4.1 Methodological approach

Due to limited data at the country level that directly measures the independent contribution of different risk factors to overall road traffic injury rates in the population (see Table 1 for an overview), for a number of risk factors we adopted the Population Attributable Fraction approach (which provides a more indirect approach to establishing the distribution of road traffic injuries across multiple causes). The PAF can be defined as the size of the fraction of incident cases in the population attributable to the risk exposure. Often, it is used as the estimate of the proportion by which the incidence rate in the population would be reduced if exposure were completely eliminated. As it relates to this analysis, the PAF can be formulated as:

$$PAF = \frac{\text{(Incidence of injury in all road users) - (Incidence of injury in road-users without the exposure)}}{\text{(Incidence of injury in all road users)}}$$

Since incidence rates are difficult to obtain, we used Levin's approach to calculation of the PAF, which is the proportion of a disease risk that can be attributed to the causal effects of a risk factor. Levin's formula for calculating the PAF is as follows: $PAF = P_{nh}(RR-1) / P_{nh}(RR-1)+1$, where P_{nh} is the proportion of the road users with the risk factor exposure of interest, RR is the relative risk of injury among road users with the risk factor exposure compared to the road users without the risk factor exposure. Therefore, only two pieces of information are needed for this formula: the proportion of road users who have the risk factor exposure of interest (P_{nh}); and the relative risk of injury for a road user with the risk factor exposure (RR). We used this method to calculate attributable fractions for seat belt non-use; motorcycle helmet non-use; and bicycle helmet non-use.

A standardized online keyword search (carried out in English-language electronic databases [PubMed, CINAHL, LEXUS, Google] using key words such as 'speeding', 'alcohol-impaired driving' and 'helmet use') was carried out in order to locate country-specific risk-factor information, not only relating to direct assessment of the contribution of specific risk factors to overall road traffic injury rates, but also relating to levels of risk factor exposure (e.g. not wearing seatbelts). Concerning direct measures, only a limited number of country specific references were found, mostly from peer-reviewed journal articles but also some grey literature sources such as police records and official governmental statistics (see Table 1 for an overview).

Table 1 International data sources for road traffic injury risk factor attributions

Author	Year	Reference	Country	Risk Factor	Findings
Servadei et al	2003	Effect of Italy's motorcycle helmet law on traumatic brain injuries in newly motorising countries. Inj Prev, 2003. 9:257-260	Italy	Helmet Use	Use of helmets has been shown to reduce fatal and serious head injuries by between 20% and 45% and to be the most successful approach for preventing injury among motorized two wheeler riders.
Scuffham et al	2000	Head injuries to bicyclists and the New Zealand bicycle helmet law. Accid Anal Prev. 2000 Jul;32(4):565-73	New Zealand	Helmet use	Helmet law lead to a 19% decrease in head injury to cyclists (95% CI=14 to23%)
Petridou et al	1998	Fatalities from non-use of seat belts and helmets in Greece: a nationwide appraisal Accid Anal Prev. 1998 Jan;30(1):87-91	Greece	Helmet Use and Seat Belt Use	The OR for death rather than injury for helmet users vs non users was 0.64 (0.51-0.81) and 0.69 (0.58-0.81) for seat belt users vs non-users. 27% of deaths could have been avoided if all car occupants used seat belts and 38% of motorcycle deaths could have been avoided of all riders wore helmets.
Evans et al	1988	Helmet effectiveness in preventing motorcycle driver and passenger fatalities. Accid Anal Prev. 1988 Dec;20(6):447-58	USA	Helmet Use	Helmets were found to be 28% effective in preventing fatalities to motorcycle riders.
Liu et al	2004	Helmets for preventing injury in motorcycle riders. Cochrane Database Syst Rev.2004;(2):CD004333	not specified	Helmet Use	Motorcycle helmets reduce the risk of head injury by 72% (65 to 77% reduction)
Chiu et al	2000	The effect of the Taiwan motorcycle helmet use law on head injuries. Am J Pub Health 2000 May;90(5):793-6	Taiwan	Helmet Use	After implementation of the law, the number of motorcycle head injuries decreased by 33%.
Odero et al	2003	Road traffic injuries in Kenya: magnitude, causes, and status of intervention. Inf Contr Saf Promot. 2003;10:53-61	Kenya	Excessive speed	Errors such as loss of control of vehicle, speeding, misjudgement and improper overtaking contributed to 44% of all police reported crashes in Kenya.
Afukaar FK	2003	Speed control in LMICs: issues, challenges, and opportunities in reducing road traffic injuries. Inj Contr Saf Promot. 2003; 10:77-81	Ghana	Excessive speed	Speed was identified as the main contributory factor in 50% of road crashes in Ghana between 1998-2000.
Pretoria, Ministry of Transport	2001	The road to safety 2001-2005: building the foundations of a safe and secure road traffic environment in South Africa. Http://www.transport.gov.za/projects/index.html.	South Africa	Excessive speed	50% of all crashes involving commercial road transport and public passenger vehicles were related to speed.
NHTSA	2006	Traffic safety facts, 2005 data	USA	Excessive speed	In 2005, speeding was a contributing factor in 30 percent of all fatal crashes, and 13,113 lives were lost in speeding-related crashes
OECD/ECMT	2006	Speed management	OECD	Excessive speed	"Excessive and inappropriate speed...often contributing to as much as one third of fatal accidents and an aggravating factor in all accidents".
Ansari	2000	Causes and effects of road traffic accidents in Saudi Arabia	Saudi Arabia	Excessive speed	Speeding is estimated to account for 42% of all reported crashes.
OECD/ECMT	2006	Speed management	OECD	Excessive speed	"Excessive and inappropriate speed...often contributing to as much as one third of fatal accidents and an aggravating factor in all accidents".
European Transport Safety Council	1995	Reducing traffic injuries resulting from alcohol impairment. Working Party on Road User Behavior. Brussels, 1995. http://www.etsc.be/documents/Reducing%20traffic%20injuries%20resulting%20from%20alcohol%20impairment.pdf retrieved at 12-06-07	EU-15 countries	Alcohol use	19% of injury accidents and 22% of serious and fatal accidents are due to alcohol consumption.
Mock et al	2001	A random, roadside breathalyzer survey of alcohol impaired drivers in Ghana. Journal of Crash Prevention and Injury Control. 2001. 2:193-202	Ghana	Alcohol use	Over 7% of drivers in a random breath test had BAC levels above 0.08g/dl.
Mishra et al	1984	Two wheeler injuries in Delhi, India: a study of crash victims hospitalized in a neurosurgery ward. Accid Anal Prev, 1984. 16:407-416	India	Alcohol use	1/3 of motorized two-wheeler riders taken to hospital admitted to driving under the influence of alcohol.
Odero et al	1995	critical review of literature. Proceedings of the 13th International Conference on Alcohol, Drugs, and Traffic Safety, Adelaide, 13-18 August 1995. Adelaide, Road Accident Research Unit, 1995: 713-720.	No country focus	Alcohol use	Alcohol was present in between 33% and 69% of fatally-injured drivers, and in between 8% and 29% of drivers involved in crashes that were not fatally injured.
Peden et al	1996	Injured pedestrians in Cape Town: the role of alcohol. South African Medical Journal. 1996, 16:1103-1105	South Africa	Alcohol use	Alcohol was a factor in around 29% of non-fatally injured drivers, and in over 47% of fatally-injured drivers in South Africa.
Peden et al	2000	Substance abuse and trauma in Cape Town. South African Medical Journal, 2000. 90:251-255	South Africa	Alcohol use	Excess alcohol was found in over 52% of trauma patients onvolved in road crashes.
WHO	2004	World Report on Road Traffic Injury Prevention. Geneva, Switzerland. 2004	South Africa	Alcohol use	More than half of transport related deaths had a BAC level above the legal limits. Pedestrians, followed by drivers, were most likely to be BAC positive. Over 50% of drivers killed had elevated BAC levels.

Available studies mostly represented the contribution of different risk factors or behaviours to overall levels of fatal and non-fatal road traffic injury in high-income nations. For exposure levels, a larger body of information was obtained (for example, 78 data sources relating to seat belt and helmet use, see Annex 4). The data inclusion strategy was the same as for the rest of the analysis; that is, if more than one data source was identified for a country, the most geographically representative data source was identified and if more than one population level study was available for a country, the most recent one was used.

4.2 Data synthesis

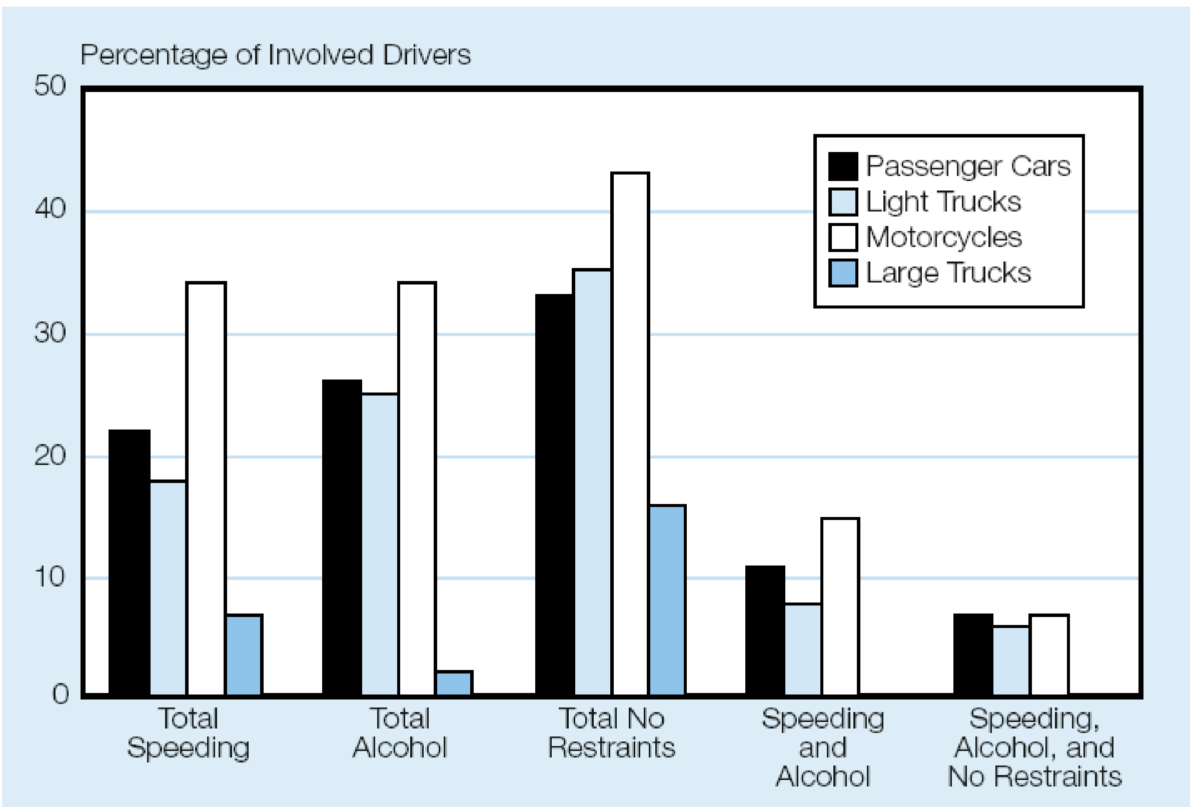
The contribution of alcohol as a risk factor to levels of road traffic injury has already been analysed as part of the WHO-sponsored Comparative Risk Assessment (CRA) (Rehm et al., 2004). The CRA study reported this information by age, sex and region. Since the specific risk factor of interest here is drink-driving (i.e. drivers under the influence of excessive / illegal amounts of alcohol), it is necessary to subtract out the proportion of alcohol-attributable road traffic injuries caused by non-drivers (such as drunken pedestrians); we conservatively put this downward adjustment at 33% (i.e. two-thirds of the alcohol-attributable fraction is caused by drivers who drink).

For rates of seatbelt, motorcycle helmet and bicycle helmet non-use, the country-specific data reported in Annex 4 were used to generate weighted averages for each WHO sub-region, to which we then applied relative risks of injury: seat belt non-use, RR 1.82 (Evans, 1986); motorcycle helmet non-use, RR 1.64 (Liu et al., 2003); bicycle helmet non-use, RR 3.23 (Attewell et al., 2001). The latter relative risk was reduced by 25% in developing regions in order to reflect a more hazardous / multi-vehicle road environment in these settings. Derived attributable fractions refer to the exposed population as a whole, so a subsequent step was to apply the relevant age distribution (as described above, see Figure 4) in order to come up with age- and sex-specific estimates.

The proportion of road users who are excessively and inappropriately speeding - that is, driving above the speed limits or driving within the limits but too fast for the prevailing conditions - is apparently as many as 50% of drivers at any given time (Joint OECD/ECMT Transport Research Centre, 2006), but such information for low- and middle-income countries is in short supply. Additionally, the corresponding relative risk estimates (effectiveness) for increasing levels of excess and inappropriate speeding were difficult to calculate. For this risk factor, therefore, we relied upon directly measured estimates from a number of countries which consistently indicate that speeding accounts for 30%-50% of all crashes and associated injuries (Table 1). Because speeding effects all road user groups, we use the overall age distribution for road traffic fatal injuries to generate age- and sex-specific estimates.

Most road crashes involve more than one risk factor. For example, alcohol intake increases the likelihood of driving at excessive speed. Simply summing up the attributable fractions as described above would exaggerate the true contribution of each risk factor to overall injury rates. Unfortunately there is currently very limited data available to guide understanding and consequent estimation of these joint risks (but see Figure 5 below for estimates from the US).

Figure 5 Speeding, alcohol involvement and failure to use restraints among fatally injured drivers; USA, 2005 (*Source: NHTSA, 2006*)



Estimation is further complicated by the fact that the degree of overlap or joint risk varies by age, with young male adults being the stand-out example of a socioeconomic group in which multiple risk exposures (or law infractions) are liable to be simultaneously present. In view of these data challenges, we generated age-specific adjustment factors which although not empirically well-founded, do ensure that the total road traffic injury envelope for each age group is not exceeded (see Figure 6 for the example of WHO sub-region SearD).

Figure 6 **Age-specific adjustment factors for different risk factors** (WHO sub-region SearD)

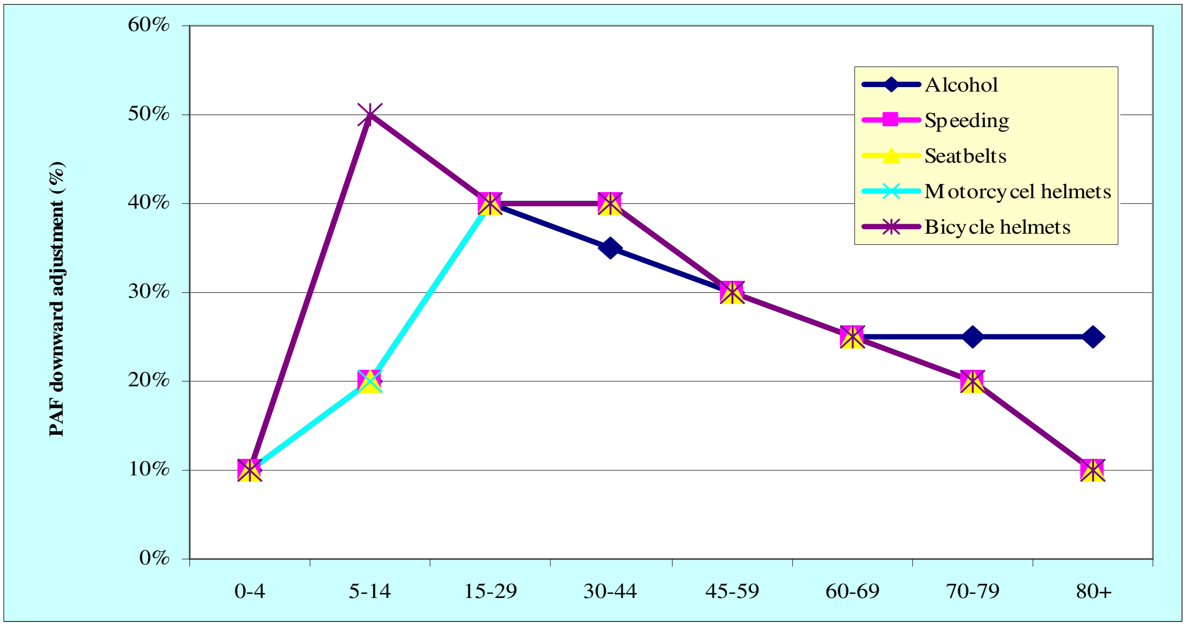
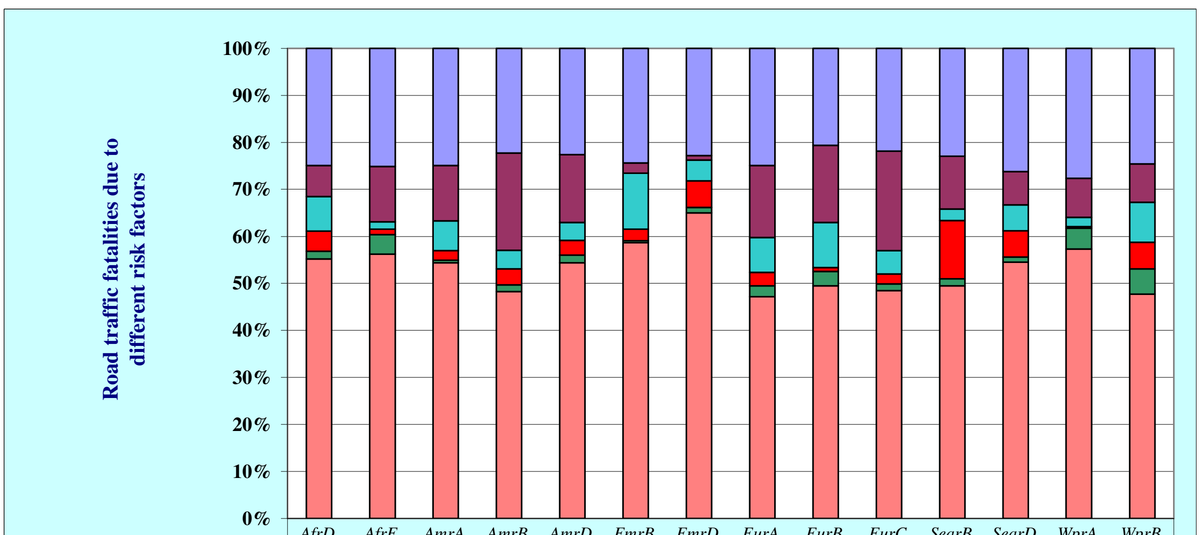


Figure 7 below provides a graphical illustration of the population attributable fractions of risk factors for fatal road traffic injuries. Speeding accounts for the largest share of fatal burden (21%-28%), with other selected risk factors contributing 1%-21% depending on the epidemiological profile. The remaining fatal injury burden - approximately half - is attributable to other causes.

Figure 7 **Contribution of different risk factors to fatal road traffic injuries**



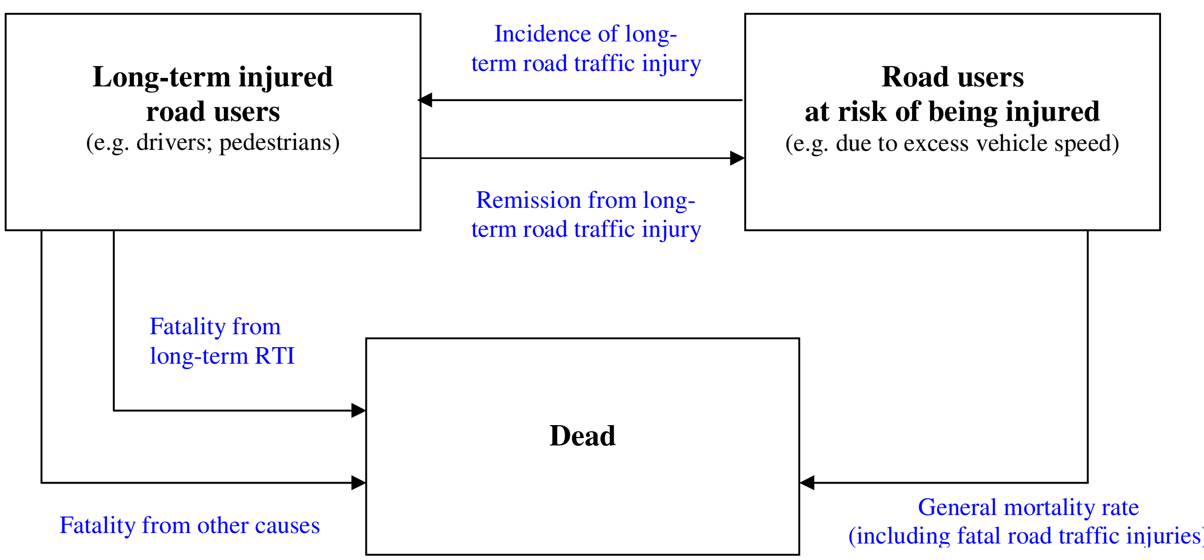
	AfrD	*AfrE*	*AmrA*	*AmrB*	*AmrD*	*EmrB*	*EmrD*	*EurA*	*EurB*	*EurC*	*SearB*	*SearD*	*WprA*	*WprB*
Speeding	25%	25%	25%	22%	23%	24%	23%	25%	21%	22%	23%	26%	28%	25%
Drink driving	7%	12%	12%	21%	14%	2%	1%	15%	16%	21%	11%	7%	8%	8%
Not wearing car seatbelts	7%	2%	6%	4%	4%	12%	4%	7%	10%	5%	2%	6%	2%	9%
Not wearing motorcycle helmets	4%	1%	2%	3%	3%	2%	6%	3%	1%	2%	12%	6%	0%	6%
Not wearing bicycle helmets	2%	4%	1%	2%	2%	0%	1%	2%	3%	2%	2%	1%	4%	5%
Other causes (e.g. road design)	55%	56%	54%	48%	54%	59%	65%	47%	49%	48%	49%	55%	57%	48%

5. Estimation and modeling of intervention effectiveness

5.1 Population injury model

WHO-CHOICE employs an epidemiological approach to the estimation of population-level effects of different health interventions (Tan Torres et al., 2003). Specifically, the effect of a given intervention on the healthy life expectancy of a population is typically derived with reference to two epidemiological situations, one with the intervention in place (for a period of 10 years), the other without the intervention (a counterfactual situation referred to as a 'null' scenario, which is derived by subtracting out the known effects of currently implemented interventions). The difference between these two situations over the lifetime of the population (set at 100 years) represents the net effect of the intervention, expressed in terms of disability-adjusted life years saved. These epidemiological scenarios can be estimated via a multi-state population model (PopMod; Lauer et al., 2003; see also Figure 8), which traces the development of a population taking into account births, deaths and the disease or injury in question.

Figure 8 Population model for estimating health impacts of road safety measures



For the RTI model, a distinction is made between long-term and acute injuries.

- For the long-term injuries, persons or road users who are at risk of being injured become seriously injured at an instantaneous transition rate *i* [incidence]; persons may recover from their (non-fatal) long-term injuries at remission rate *r* (in this case, remission is set to zero because we include only those injury sequelae that are irreversible or have very long-term duration); people with long-term injuries are subject to an elevated rate of mortality (rate *fx*);

- For the acute fatal injuries (i.e. fatalities occurring within 30 days of the crash), susceptible road users are subject to a general mortality rate *m* (a proportion of which is attributable to RTI). Non-fatal acute injuries of short-term duration were not included in the analysis (cuts, bruises, fractures of the leg or arm, etc.), since they represent less than 10% of the estimated non-fatal burden of road traffic injuries (www.who.int/healthinfo/bodestimates).

Accordingly, the key parameters of interest are the acute RTI mortality rate, together with the incidence, prevalence and case-fatality of long-term road traffic injury.

5.2 Epidemiology of road traffic injuries in different regions of the world

Age- and sex-specific road traffic fatality rates were taken from the Global Burden of Disease 2000 study (GBD); Begg and Tomijima, 2002; see also www.who.int/healthinfo/bodestimates). Until such time that GBD estimates are revised - to take into account known limitations regarding injury surveillance data sources in particular - these remain the best available set of consistent estimates for tracking the epidemiology of road traffic injury at the global level.

Estimates of the incidence of long-term road traffic injuries were also based on data from the GBD study, which provides total incident episodes of hospitalisable non-fatal injury due to road crashes for each age and sex group across 14 WHO-sub-regions. In order to derive the proportion of total hospitalisable injuries having severe, long-term consequences, we selected a 'top 5' sequelae which between them account for 80%-90% of non-fatal road traffic injury burden (fractured skull, intracranial injuries, fractured femur, injured spinal chord and injury to eyes). The proportion of these injury sequelae having a long-term duration ranges from 5% (e.g. fractured femur) to 100% (spinal chord injury). The resulting age- and sex-specific incidence estimates for long-term road traffic injury ranged from 1 to 40 per 100 000 population.

We also derived an overall relative risk of mortality (RRM) associated with these five leading causes of non-fatal burden, based on the RRMs for the specific sequelae (ranging from 1.0 for injury to eyes to 7.6 for spinal chord injury) and weighted according to their contribution to overall non-fatal burden. Using this 'top 5' method as the basis for all long-term road traffic injuries, we find a seven-fold elevated risk of mortality (i.e. an RRM of close to 7).

Incidence and relative risk estimates, together with a remission rate of zero, were entered into the disease modeling program DisMoD (http://www.who.int/healthinfo/boddismod/en/index.html), in order to generate internally consistent estimates of the incidence, prevalence, remission and case-fatality associated with long-term road traffic injury in each WHO sub-region.

A final epidemiologically-driven input parameter for the population model concerns the health state valuation or disability weight associated with long-term road traffic injuries. Again, we derived a weighted average on the basis of the 'top 5' causes of YLD and their respective GBD disability weight (on a 0-1 scale where zero denotes no disability, these ranged from 0.27 for fractured femur to 0.72 for spinal chord injury). Depending on the sub-region, the composite disability weight ranged from 0.44 to 0.59.

5.3 Intervention effectiveness and coverage

The specific impact of the five selected interventions on different road user groups are shown below in Table 2.

Table 2 Intervention effect sizes

Intervention	Effect on RTI	Size of effect (by type of road user)					
		Pedest-rians	*Bi-cycles*	*Motor-cycles*	*Cars / vans*	*Buses*	*Other*
Enforcement of speed limits (via mobile speed cameras)	Incidence of L-T RTI (non-fatal) Crash mortality rate (fatal)	-6% -14%	-6% -14%	-6% -14%	-6% -14%	-6% -14%	-6% -14%
Drink-drive legislation & enforcement (via breath-testing campaigns)	Incidence of L-T RTI (non-fatal) Crash mortality rate (fatal)	-15% -25%	-15% -25%	-15% -25%	-15% -25%	-15% -25%	-15% -25%
Legislation & enforcement of seat belt use in cars (drivers and passengers)	Incidence of L-T RTI (non-fatal) Crash mortality rate (fatal)	0% 0%	0% 0%	0% 0%	-18% -11%	0% 0%	0% 0%
Legislation & enforcement of helmet use by motor-cyclists (all riders)	Incidence of L-T RTI (non-fatal) Crash mortality rate (fatal)	0% 0%	0% 0%	-18-29% [a] -36%	0% 0%	0% 0%	0% 0%
Legislation & enforcement of helmet use by bicyclists aged below 15 years	Incidence of L-T RTI (non-fatal) Crash mortality rate (fatal)	0% 0%	-17-28% [b] -69%	0% 0%	0% 0%	0% 0%	0% 0%

[a] Effect size of a 72% risk reduction is applied to % of all motorcycle long-term non-fatal injuries attributable to head injuries (25%-40%; Shankar et al., 1992; Kelly et al., 1991; Orsay et al., 1995)
[b] Effect size of a 69% risk reduction is applied to % of all bicycle long-term non-fatal injuries attributable to head injuries (25%-40%; Robinson, 2006; Haileyesus et al., 2007).

Some interventions are specific to certain road user groups - e.g. belts, helmets - while others impact on all road user groups (e.g. speeding, alcohol use). Effect sizes for fatal and non-fatal injury prevention are taken from the international literature, as follows:

- Enforcement of speed limits (via mobile speed cameras): Exceeding the speed limit is probably the most common form of traffic violation, and contributes significantly to the overall road traffic injury toll in all regions of the world. In terms of intervention, fixed speed cameras were not considered a practical or affordable option in resource-poor settings, so we modeled the potential health impact of a sustained effort by traffic enforcement teams to raise the perceived risk of drivers being caught via the use of mobile / hand-held speed cameras at randomly chosen checkpoint sites. In their meta-analysis of the effect of stationary speed enforcement, Elvik and Vaa (2004) report a 14% reduction in fatal crashes (95% confidence interval [CI], 8%-20%) and a 6% reduction in non-fatal crashes (95% CI, 4%-9%); all source studies are from high-income countries When only studies featuring a comparison group were included, mean effect sizes are almost identical (13% and 5%, respectively), but there is greater variation and uncertainty around these point estimates. Although it is quite possible that effect sizes could differ between different road user group (and also by sub-region of world), we do not find evidence in support of this and therefore use for all sub-regions the above estimates (which refer to all types of accident or crash, including those involving pedestrians).

- Drink-drive legislation & enforcement (via breath-testing campaigns): Driving under the influence of alcohol markedly increases the risk of being involved and injured in a road crash. Many countries have passed laws that ban driving a vehicle over a certain blood alcohol concentration (BAC) limit, and this has an independent effect on some drivers' decision to drive after drinking alcohol. For greater effectiveness, however, a sustained programme of enforcement is required, together with mass media campaigns highlighting the dangers of driving under the influence and the penalties associated with breaking drink-driving laws. Here, we model the composite effect of *per se* drink-driving laws and its enforcement via random breath-testing of drivers at roadside checkpoints. Such an intervention is an example of primary enforcement, i.e. traffic enforcement officers do not require another reason for stopping a driver before administering a breath-test. Drink-driving laws are estimated to reduce traffic fatalities by 7% if widely implemented within a region (Shults et al., 2001), while enforcement via random breath testing (RBT) is estimated to reduce fatalities by a further 18% when fully implemented (Peek-Asa, 1999; Shults et al., 2001); the impact on non-fatal injuries was estimated to be a smaller reduction of 15%, based on earlier analysis of alcohol-attributable fractions for road traffic injury (Ridolfo and Stevenson, 2001; Rehm et al., 2004). Again, such effect sizes are based exclusively on studies from high-income countries.

- Legislation & enforcement of seat belt use in cars (drivers and passengers): Wearing a seat belt mitigates the risk of being injured in a road crash. We model the impact of introducing compulsory belt use in both the driver and (front/rear) passenger seats of light vehicles. Based on a meta-analysis of high-income country studies by Elvik and Vaa (2004), the average effect of legislation that makes use of seatbelts mandatory in light vehicles is a 11% reduction in fatal injuries (95% CI, 9%-11%) and an 18% reduction in serious injuries (95% CI; 18-19%); depending on the increased rate of seatbelt usage (which in turn will depend on local levels of primary and secondary enforcement), lower and higher effects are also predicted, ranging from 7% for an increase of less than 25%, to 21% for an increase of more than 50%. A separate systematic review of safety belt laws by Dinh-Zarr et al. (2001) revealed a median reduction of 9% for fatal injuries (inter-quartile range [IQR], 2-18%) and just 2% for (all, not just serious) non-fatal injuries (IQR, +11% to -15%). Finally, Rivara et al. (1999) undertook a review of the impact of primary and secondary enforcement seat belt laws in comparison with no such laws, and found an 8% reduction in fatal injuries (range 3%-14%) and a 14% reduction in (all) non-fatal injuries (range 12%-23%). Here, we employ the effect sizes from Elvik and Vaa (2004) because these provide an average estimate for the different possible impacts of legislation (which depend on increased seatbelt usage and enforcement) and relate most closely to the non-fatal outcomes of interest in this model (long-term, serious injuries).

- Legislation & enforcement of helmet use by motor-cyclists (all riders): Riders of mopeds and motorcycles have a greatly elevated risk of road traffic injury, particularly head injuries. Head injuries are classified as admissions to hospital with head wounds, skull or facial fracture, concussion, or other intracranial injury. Motorcycle helmets provide a significant level of protection against such injuries. We model the impact of the mandatory use of motorcycle helmets among this road user group. The Cochrane review by Liu et al. (2003) estimates that wearing motorcycle helmets is associated with a 36% reduction in fatal injuries (unadjusted odds ratio [OR] from 15 studies; 95% CI 0.52-0.80), which is close to the effect size reported from three controlled studies. Based on five controlled studies, the same review also established that wearing motorcycle helmets reduces non-fatal head injuries by 72% (OR = 0.28). This latter effect size was applied to the proportion of all motorcyclist non-fatal long-term injuries that are related to the head, which was estimated to range from 25% in sub-regions with high rates of helmet use up to 40% in sub-regions where rates of helmet use are low (on the basis of studies carried out in the US that compared injury rates among helmeted versus unhelmeted riders; Shankar et al., 1992; Kelly et al., 1991; Orsay et al., 1995).

- Legislation & enforcement of helmet use by bicyclists: Like riders of motorized two-wheelers, bicyclists face a considerable risk of injury if involved in a road crash. Again, head and face injuries represent a large proportion of the total injuries incurred. We model the impact of the mandatory use of bicycle helmets among children aged 15 years or less. The Cochrane review by Thompson et al. (1999) found no randomized controlled trials but, on the basis of four case control studies, concluded that helmets produce a 69% reduction in (non-fatal) head injuries (OR 0.31, 95% CI 0.26-0.37); one of these studies focused on severe brain injury (OR 0.26; Thompson et al., 1996). A separate international review of studies spanning the period 1987-1998 found a slightly lower effect on head injuries - an OR of 0.40 rather than 0.31 (Attewell (2001). Such effects are applied to an estimated 25-40% of bicyclist non-fatal long-term injuries that are related to the head (Robinson, 2006; Haileyesus et al., 2007). In a separate Cochrane review, Macpherson et al. (2007) found two studies - both undertaken in the US and in relation to children only - that reported a significant protective effect of helmet legislation on bicycle-related non-fatal head injuries (Macpherson et al., 2002; Lee et al., 2005). Neither Cochrane review provides distinct estimates of the protective effect of bicycle helmets on fatal injury, but Attewell (2001) derived an odds ratio of 0.27 (95% CI, 0.10-0.71). Both Cochrane reviews have been the subject of considerable debate and controversy, on the grounds that they do not account for confounding variables such as declining trends in bicycling and overall injury rates (Curnow, 2005), and subsequent ecological time-series analyses have cast strong doubt on the magnitude of the implied reduction in head-related bicyclist injuries at the population level (Robinson, 2006). To reflect this disparity in the evidence base, we first employed the effect sizes reported by Attewell (2001), and then subsequently assessed via sensitivity analysis the potential impact and cost-effectiveness implied by much lower effect sizes (50% and 25% of these baseline values). We do not attempt to model any predicted decrease in cycling, which it has been argued may at least offset any health gains from increased helmet use (Robinson, 2006).

The effects of these road safety measures on levels of population health were considered independently and then in combination. A multiplicative relationship was used to ascertain the expected joint effect of different combinations. In order to account for the differing epidemiology of road traffic injury across WHO sub-regions, and to assess the comparative health impact of measures at the population level, effect sizes reported above were multiplied by the fraction of total fatal/non-fatal road traffic injuries attributable to each road user group and also to each risk factor (by age and sex group). For example, the estimated impact of motorcycle helmets on fatal injuries in males aged 15-29 in the WHO sub-region AmrB was calculated as effect size (36%) * fraction of fatal injuries incurred by motorcyclists (31%) * fraction of motorcyclist fatal injuries due to not wearing a helmet (18%) = 2.03%. For measures involving all road user groups (e.g. speeding), this calculation is made for each road user group, to give a weighted average for the combined effect across all road user groups combined.

A final parameter that has a bearing on the population-level impact of interventions concerns the current and target levels of coverage. Current coverage of the selected measures ranges both by intervention and by epidemiological sub-region. Lowest coverage was estimated for bicycle helmets and speed cameras (below 10% in low-income regions, up to 25%-40% respectively in high-income regions) and highest for seat belts and motorcycle helmet use (20% in low-income regions, up to 60%-75% respectively in high-income regions). In the interests of comparability, the target coverage levels for all intervention strategies was set at 80%.

6. Estimation and modeling of intervention costs

6.1 Scope and perspective

In common with other economic evaluations comprising the WHO-CHOICE programme, the scope and perspective of the cost analysis is that of the health system, broadly defined. To illustrate, certain activities included in the analysis, notably traffic enforcement costs, might appear to fall outside the health system, but the broad (WHO) definition of a health system used here encompasses all activities whose primary intent is related to improving health or reducing disease and injury. In other words, the ultimate reason for requiring, for example, seat belt and helmet use is because they reduce the risk of injury. By contrast, certain other costs were excluded from this analysis because they clearly fall outside even this broad definition of a health system, such as property damage. We also exclude the provision of informal care-giving to injured persons by family members and friends plus the lost production of the injured persons themselves because of prevailing difficulties with their appropriate measurement and valuation at the international level.

Road traffic injury prevention costs span a whole array of possible resource inputs, including engineering and design (of roads and vehicles), safety devices and technologies, through to ambulance and trauma care services. For the selected interventions in this analysis, costs are incurred not at the level of health facilities but at a more programmatic level, including the resource costs associated with legislation, programme management and law enforcement. Up until now there have considerable difficulties in deriving and obtaining valid estimates of such costs at the international level, but developments in the comprehensive costing of such programme-level costs have recently been made as part of the CHOICE programme (Johns et al., 2003; Johns et al., 2006). Accordingly, we used existing templates for these categories of programme cost for calculating the resource requirements of the road safety measures considered here.

In addition to these programme costs, we included the privately-borne cost to bicycle and motorcycle owners of buying helmets, since this represents an integral cost component of these road safety measures. Likewise, we estimated the cost of fitting front and rear seatbelts in cars that do not already have such safety equipment (estimated to range from 20% in high-income sub-regions to 50% in low-income sub-regions).

6.2 Resource inputs

Even though certain road safety measures are already in force in some regions of the world, the reference point or counterfactual used here (as explained earlier in Section 5.1) is the situation of 'doing nothing' - the null scenario. Therefore we estimate the full set of resource inputs needed to develop and maintain interventions. The start-up period is assumed to be one year, the post start-up period is set at 10 years.

Legislation and programme management: All interventions require the passage of legislation in the 'start-up' period of implementation, and are also expected to need substantive public health expertise input. Day-to-day implementation of traffic enforcement is modeled to occur at the provincial level (see below), but all interventions are assumed to require basic programme management and evaluation inputs, not only at central and provincial levels of government, but also at district level. Table 3 below summarises these activities by intervention.

Table 3 Legislation and programme management

		Speed cameras	Breath-testing	Seat belts	Motorcycle helmets	Bicycle helmets
Legislation		*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Public health expertise		*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Administration	National	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
	Provincial	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
	District	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Supervision	National	*Yes*	*Yes*	*No*	*No*	*No*
	Provincial	*Yes*	*Yes*	*No*	*No*	*No*
	District	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Monitoring & evaluation	National	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
	Provincial	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
	District	*No*	*No*	*No*	*No*	*No*

The quantity assumptions underlying these categories of activity - in terms of personnel, transport, supervision trips, meetings, per diems, office space, utilities and furniture - can be found in a workbook available from the authors ('Quantity assumptions.xls'). These resource assumptions for a standard size of country (50 million) or province (5 million) were scaled-up to the populations of the 14 WHO sub-regions.

Media: All selected interventions involve a degree of media outreach (a relatively simple communication strategy was modeled for seatbelts and helmets, and a more intense strategy for speeding and alcohol-related measures on account of the more complex set of messages that need to be transmitted to the population). Associated levels of personnel support by managers and public relations officers can be found in 'Quantity assumptions.xls' (available from authors). For interventions requiring moderate outreach, we estimate 5 TV emissions, 5 radio emissions and 2 newspaper advertisements/articles per week, both at national and provincial levels; for minimal outreach the numbers are halved. In addition, and for all media outreach levels, we include 1 wall-poster per 10 000 population (i.e. 5000 for a population of 50 million).

Enforcement: All interventions require efforts to enforce road safety laws. The administrative level at which enforcement activities are modeled to occur is the province (reference population, 5 million). We employed the assumptions reported below in Table 4 to estimate the number of roadside checkpoints, together with associated officer time, vehicles and equipment. Speed checkpoints and roadside breath-testing are expected to require more enforcement officers and vehicles than other interventions. Checkpoints are modeled to last for 4 hours, with additional time for set-up and dismantlement. Officers are assumed to pull over an average of 4 vehicles per hour (e.g. for a team of 3, that would equate to 1 vehicle every 5 minutes). The total number of checkpoints required is dependent both on the target percentage of vehicles pulled over each year - taken to be 10% for all interventions except bicycle helmet enforcement (5%) - and on the underlying motorization rate for cars, motorcycles and bicycles; these were calculated for each WHO sub-region on the basis of country-level data taken from *World Road Statistics* (IRF, 2006).

Table 4 Traffic law enforcement resource inputs and assumptions

	Speed cameras	Breath-testing (alcohol)	Seat belts	Motorcycle helmets	Bicycle helmets
% vehicles pulled over per annum	10%	10%	10%	10%	5%
Vehicles processed per officer per hour	4	4	4	4	4
Officers per checkpoint	3	3	2	2	2
Duration of checkpoint (hours)	4	4	4	4	2
Set-up / dismantle / paperwork time (hours)	2	2	2	2	1
Vehicles used per checkpoint	2	2	1	1	0
Traffic cones used per checkpoint (sets of 10	2	2	2	2	0
Breathalyser kits used per checkpoint	0	1	0	0	0
Speed cameras used per checkpoint	1	0	0	0	0

The most sensitive resource input parameter concerning enforcement relates to the proportion of vehicles that need to be pulled over each year in order to derive the effective coverage of these interventions at the population-level. Since the impact of these traffic laws and their enforcement depends on changes in the *perceived* risk of being caught, the analytical challenge is to establish what (relatively small) proportion of vehicles actually needs to be pulled over in order to obtain the (relatively large) effective coverage/saturation of these road safety measures in the target population. We base our pull-over rate of 10% on the recommendation of the European Transport Safety Council (1999; p. 23), noting the findings of their research which shows a rapidly increasing proportion of drivers who think they will get stopped on a typical journey as the pull-over rate rises above 1 in 16 drivers. The impact on baseline results of double and half this pull-over rate (5%, 20%) were also explored.

6.2 Resource costs and prices

Unit costs or prices for almost all of resource inputs described above have been estimated for the 14 WHO sub-regions as part of the WHO-CHOICE project, based on a series of regression analyses that makes use of a large international database of observed values for these various resource items to predict prices in different countries and sub-regions (Johns et al., 2006). All prices reported here are for the year 2005. Specific values by WHO sub-region are available from the WHO-CHOICE website at www.who.int/choice/costs. Prices for road safety devices that are not available from the above source include the following: traffic cones, breathalyser kits, mobile/hand-held speed cameras, seat-belts and motor/bicycle helmets (Table 5).

Table 5 Cost of road safety devices

Device	Description / Source	Useful life *(years)*	Price *(US$, 2005)*
Traffic cone	*Wenzhou Jinniu Alarm Device Co.Ltd*	5	$3-5
Breathalyser	*Intoxilyzer S-D2; CMI Inc.*	3	$ 400
Speed camera	*Handheld Radar Gun; Optics Planet*	3	$ 575
Seat belt	*3-point non-retractable; Wesco Performance*	10	$ 20-30
Motorcycle helmet	*Hard shell helmet; Bishai & Hyder, 2006*	5	$ 20-40
Bicycle helmet	*Hard shell helmet; Bishai & Hyder, 2006*	5	$ 20

Total estimated population-level costs incurred by vehicle owners for seatbelts and helmets are shown in Table 6, using the example of WHO sub-region WprB.

Table 6 Estimated annual costs to vehicle owners (WHO sub-region WprB)

Variable	Seat belts	Motorcycle helmets	Bicycle helmets
Vehicle rate (per 1,000)	86	82	156
Population ('000s)	1,593,806	1,593,806	255,522
% car owners needing to instal seatbelts or % motor/bicyclists who are regular riders	30%	80%	70%
Coverage (current)	40%	30%	5%
Coverage (target)	80%	80%	80%
Total number in use (target coverage)	327,686,496	420,086,733	111,254,476
Useful life of safety equipment (years)	10	5	5
Unit cost of seatbelt / helmet (annualised)	$8.00	$4.00	$2.00
Total annual cost (current coverage)	**$131,074,599**	**$126,026,020**	**$2,781,362**
Total annual cost (target coverage)	**$262,149,197**	**$336,069,387**	**$44,501,791**
Cost per capita population (current)	$0.08	$0.08	$0.01
Cost per capita population (target)	$0.16	$0.21	$0.17

7. Cost-effectiveness results

Using the attributable fractions reported in Sections 3-4, plus the effectiveness and coverage estimates given in Section 5, we ran the road traffic injury model for the populations of all 14 WHO sub-regions in order to estimate the specific health impact of the selected interventions (relative to the situation of doing none of the interventions, the null scenario). In practice, this null scenario is only a partial reflection of the hypothetical epidemiological situation that would prevail in the absence of any road safety measures, since we only extracted the known effects of the measures selected for this analysis, rather than the potential effects of a fuller array of possible pre-crash, crash, and post-crash RTI intervention strategies. It nevertheless does provide a common starting point - or level playing field - against which to assess the relative contribution of the selected interventions towards improved road safety in different regions of the world.

For ease of communication, we focus in this technical report on the following four sub-regions, which cover a range of sociocultural, geographical and epidemiological settings:

- *AfrE*: Countries in the WHO Africa Region with very high levels of child and adult mortality (e.g. Kenya, United Republic of Tanzania)
- *AmrA*: Countries in the WHO Americas Region with very low levels of child and adult mortality (e.g. United States of America, Canada)
- *SearD*: Countries in the WHO South-East Asia Region with high levels of child and adult mortality (e.g. India, Nepal)
- *WprB*: Countries in the WHO Western Pacific Region with low levels of child and adult mortality (e.g. China, Viet Nam)

Results for other sub-regions can be found on the WHO-CHOICE website (www.who.int/choice).

7.1 Population-level effect of interventions

Results are expressed in DALYs saved per year of implementation, which are equivalent to the total annual number of healthy life years gained. In line with GBD, baseline DALYs have been discounted (at a rate of 3%) and subjected to an age-weighting function that attaches greater value to the middle years of life and less to the young and old; results without these weights were also been generated as part of the sensitivity analysis (see below). The population-level health gains associated with the five intervention strategies at target coverage levels (80%), alone and then in various combinations, are presented for all four selected WHO sub-regions in Table 7.

- Due to the prominence of excessive speed and its negative consequences across all road user groups, enforcement of speed limits (via mobile cameras) is the single most effective strategy in all sub-regions.

- Legislation and enforcement of drink-driving laws also produce consistent gains in all populations (50%-80% of the gain estimated for mobile speed cameras). Seatbelt laws and enforcement produce lower effects again (25%-40% of the gain for mobile speed cameras).

- Unsurprisingly, legislation and enforcement of motorcycle helmet use has a relatively large impact in the motorcycle-heavy Asian sub-regions (SearD, WprB), but only a very modest impact in the other two sub-regions where the motorcycle fleet is appreciably smaller.

- Assuming (contested) baseline effect sizes, legislation and enforcement of bicycle helmet use among children is the second most effective single strategy in AfrE, but has the least impact on population health in the other sub-regions assessed here.

Table 7 Intervention effectiveness (DALYs saved per year in selected WHO sub-regions)

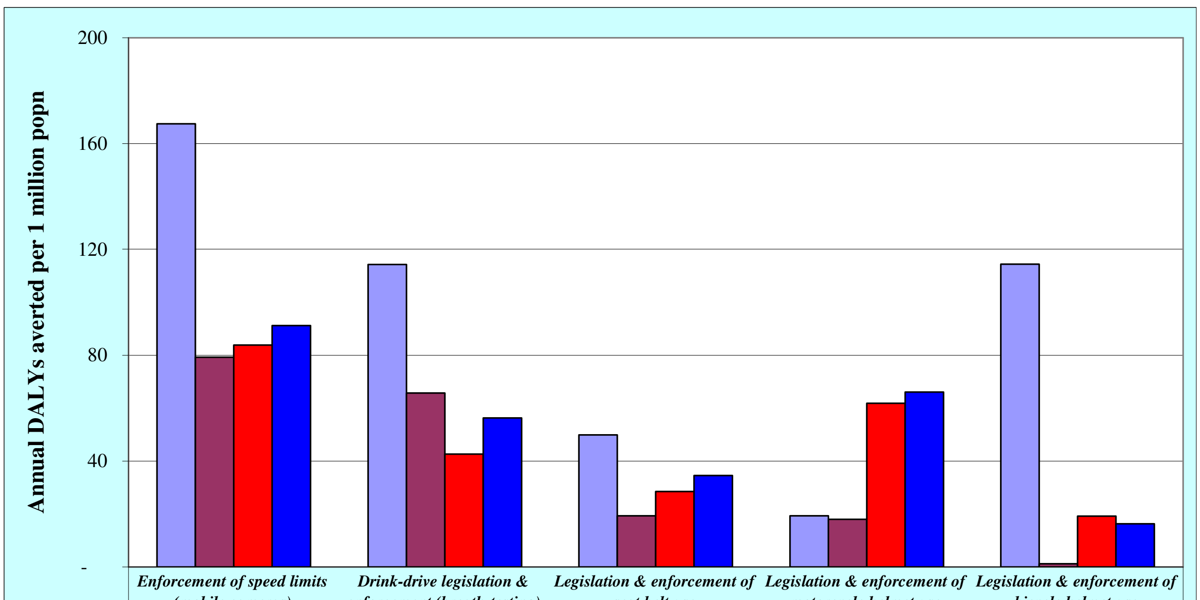
Intervention strategy	**Total DALYs saved per year** [1]			
	AfrE	***AmrA***	***SearD***	***WprB***
Enforcement of speed limits (mobile cameras)	67 310	27 191	116 418	145 443
Drink-drive laws / enforcement (breath-testing)	45 929	22 566	59 273	89 865
Legislation / enforcement of seat belt use	20 041	6 623	39 661	55 138
Legislation / enforcement of motorcycle helmet use	7 774	6 197	85 793	105 338
Legislation / enforcement of bicycle helmet use	46 013	415	26 651	26 131
Speed cameras + breath-testing	113 413	49 953	175 921	235 883
Seatbelts + motorcycle helmets	27 869	12 834	125 936	160 956
Speed cameras + breath-testing + seatbelts	133 935	56 696	216 057	291 770
Speed cameras + breath-testing + motorcycle helmets	121 259	56 262	262 383	342 507
Seatbelts + motorcycle helmets + breath-testing	74 074	35 500	185 621	251 597
Seatbelts + motorcycle helmets + speed cameras	95 456	40 155	243 090	307 659
Seatbelts + motorcycle helmets + speed cameras + breath-testing	141 837	63 019	303 010	398 883
Seatbelts + motorcycle helmets + speed cameras + breath-testing + bicycle helmets	188 399	63 436	329 933	425 093

[1] DALYs reported here are age-weighted and discounted at 3%. Results for discounted (but not age-weighted) and also unadjusted DALYs are discussed below.

Various strategies that capture the combined expected effect of two or more interventions were also modeled; their expected impacts were derived by applying a multiplicative function to the effect sizes for the individual interventions that comprise them. The combined effect of implementing all the selected measures simultaneously produces the maximum possible effect at specified levels of coverage, ranging from 63 000 DALYs saved per year in AmrA sub-region up to 425 000 in WprB.

Total numbers of DALYs saved in these sub-regions masks large underlying differences in population size (the total population of WprB, for example, is nearly five times that of AfrE and AmrA). In order to better show the comparative impact of the five individual interventions across different populations, Figure 9 depicts results for a standardized population of one million inhabitants. Even after this standardization for population size, there evidently remains considerable variation between sub-regions, which reflects not only differences in the patterns of road use and injury, but also underlying demographic characteristics; for example, it is not only the relatively high burden of bicycle injuries but also the higher proportion of people under the age of 15 in sub-region AfrE patterns that accounts for the large estimated impact of helmet legislation and enforcement in that setting.

Figure 9 Comparative effect of single interventions
(DALYs saved per year per one million population)



	Enforcement of speed limits (mobile cameras)	*Drink-drive legislation & enforcement (breath-testing)*	*Legislation & enforcement of seat belt use*	*Legislation & enforcement of motorcycle helmet use*	*Legislation & enforcement of bicycle helmet use*
AfrE	*167*	*114*	*50*	*19*	*114*
AmrA	*79*	*66*	*19*	*18*	*1*
SearD	*84*	*43*	*29*	*62*	*19*
WprB	*91*	*56*	*35*	*66*	*16*

7.2 Population-level cost of interventions

The total annualized cost of implementing each single or combined intervention over the 10-year implementation period, expressed in millions of international dollars, is presented in Table 8. Of the single interventions, measures aimed at speeding and drink-driving tend to carry the highest costs, due to the additional equipment and relatively greater human resource requirement needed to mount effective and sustained roadside law enforcement campaigns.

Total cost estimates for increased seatbelt use by car occupants and increased helmet use by motorcyclists and bicyclists are comprised of two elements: the cost to households of purchasing the safety equipment; and the cost of passing and enforcing laws. Seatbelt purchase costs consistently account for a third to a half of total costs; for helmets, costs are largely determined by motorization rates, such that in AfrE they represent only a small component of total cost, whereas in SearD and WprB they represent 55%-65% of all costs.

Table 8 **Intervention costs** (I$ millions per year in selected WHO sub-regions)

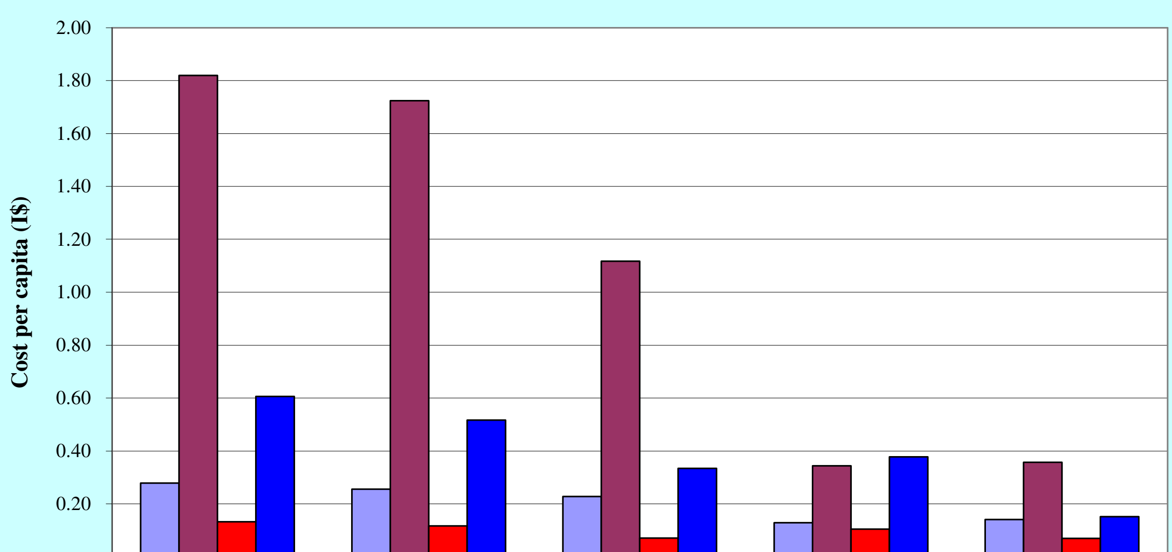
Intervention strategy	**Annualised cost per year (I$, millions)** [1]			
	AfrE	***AmrA***	***SearD***	***WprB***
Enforcement of speed limits (mobile cameras)	112	625	185	967
Drink-drive laws / enforcement (breath-testing)	103	592	162	824
Legislation / enforcement of seat belt use	92	384	99	533
Legislation / enforcement of motorcycle helmet use	52	118	146	603
Legislation / enforcement of bicycle helmet use	57	123	98	242
Speed cameras + breath-testing	159	621	253	1 082
Seatbelts + motorcycle helmets	152	696	282	1 474
Speed cameras + breath-testing + seatbelts	199	737	282	1 345
Speed cameras + breath-testing + motorcycle helmets	162	656	324	1 419
Seatbelts + motorcycle helmets + breath-testing	202	851	356	1 770
Seatbelts + motorcycle helmets + speed cameras	202	851	356	1 770
Seatbelts + motorcycle helmets + speed cameras + breath-testing	202	891	358	1 815
Seatbelts + motorcycle helmets + speed cameras + breath-testing + bicycle helmets	259	1 014	456	2 057

[1] Costs reported here are discounted at 3%.

Combinations of different interventions exhibit very notable economies of scope, owing to the significant synergies that exist between individual enforcement strategies. For example, the incremental cost of adding seat belt enforcement to an existing roadside drink-driving campaign would be very modest, because the essential resource ingredients for implementing the combined programme - enforcement officers, vehicles, roadside equipment etc. - are largely in place already. Accordingly, a clear leveling-out or plateau effect can be seen as multiple roadside interventions with a large degree of joint costs are packaged together. One intervention that we did not assume could be so easily integrated with other roadside enforcement policies is increased helmet use by child bicyclists, on the grounds that it would involve targeting a different road network (much less reliance on busy inter-city roads).

The comparative cost of individual interventions, this time expressed in millions of international dollars per one million population (equivalent to I$ per capita), is shown in Figure 10. This again clearly illustrates the variability of costs across different sub-regions, which reflects differences in the unit prices of resource inputs (particularly salaries) and associated measures of wealth (such as the overall motorization rate). For example, the per capita cost of implementing single interventions in SearD ranges between I$ 0.07-0.13, compared to I$0.34-1.82 in AmrA.

Figure 10 Comparative cost of implementing single interventions (I$ per capita)



	Enforcement of speed limits (mobile cameras)	*Drink-drive legislation & enforcement (breath-testing)*	*Legislation & enforcement of seat belt use*	*Legislation & enforcement of motorcycle helmet use*	*Legislation & enforcement of bicycle helmet use*
AfrE	*0.28*	*0.26*	*0.23*	*0.13*	*0.14*
AmrA	*1.82*	*1.72*	*1.12*	*0.34*	*0.36*
SearD	*0.13*	*0.12*	*0.07*	*0.10*	*0.07*
WprB	*0.61*	*0.52*	*0.33*	*0.38*	*0.15*

7.3 Cost-effectiveness of interventions

Dividing total implementation costs by total effects provides an estimate of the cost per unit of effect, relative to the common reference point of doing nothing (the null scenario); this is referred to as the average cost-effectiveness ratio (CER) for each intervention (see Table 9). The single most cost-effective strategy varies by sub-region, but generally speaking a combined intervention strategy that simultaneously enforces multiple road safety laws produces the most health gain for a given amount of investment; for example, the combined enforcement of speed limits, drink-driving laws and motorcycle helmet use appears on the cost-effectiveness 'frontier' in 3 of the 4 sub-regions, with each DALY averted costing I$ 1 181 (SearD), I$ 4 550 (WprB) and I$ 14 139 (AmrA), respectively. In AfrE, the single most cost-effective strategy is enforcement of bicycle helmets (I$ 1 233), which at least in part reflects the very different road traffic patterns in this sub-region (fewer cars and motorcycles). In AmrA, by contrast, legislation and enforcement of bicycle helmet use is by far the least cost-effective option, with each healthy life year gained costing nearly I$ 300 000.

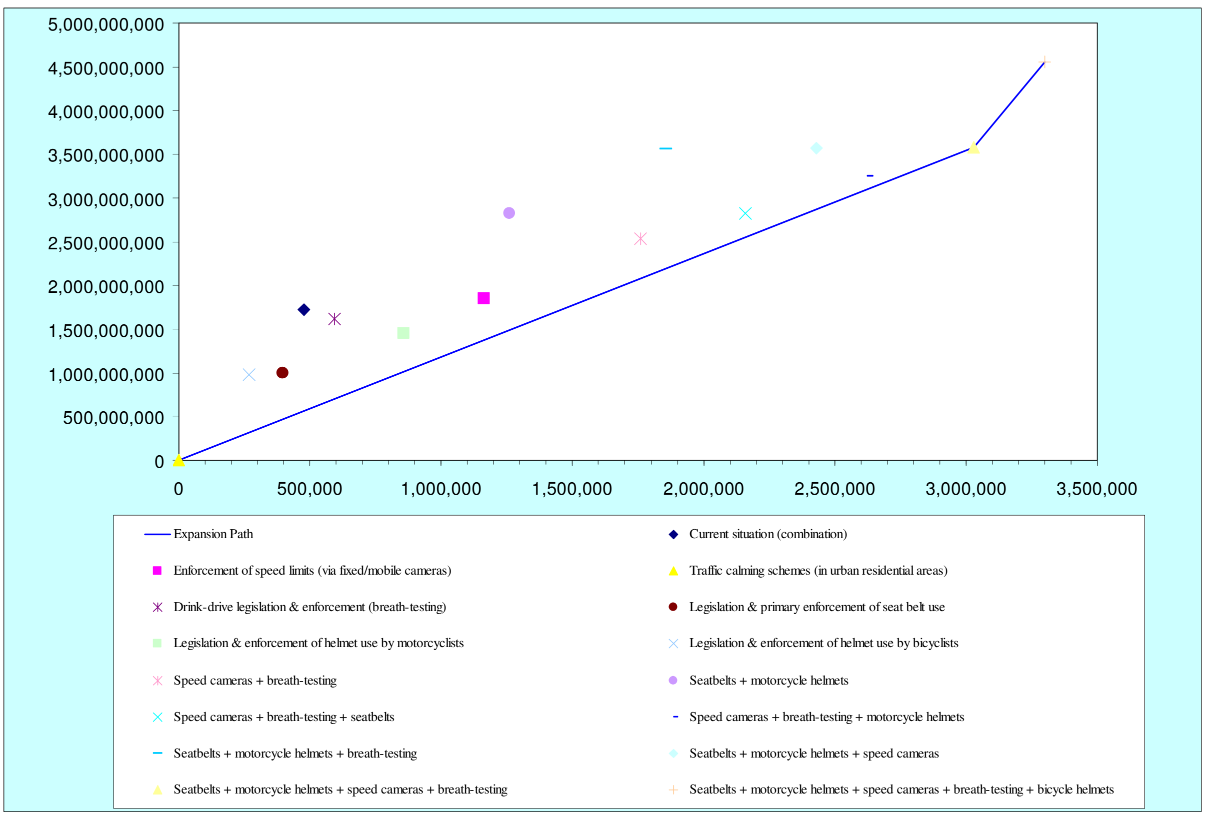
Table 9 **Intervention cost-effectiveness** (I$ per DALY saved in selected WHO sub-regions)

Intervention strategy	**Cost per DALYs saved (I$)** [1]			
	AfrE	***AmrA***	***SearD***	***WprB***
Enforcement of speed limits (mobile cameras)	1 668	22 968	1 589	6 646
Drink-drive laws / enforcement (breath-testing)	2 236	26 236	2 731	9 168
Legislation / enforcement of seat belt use	4 579	57 935	2 502	9 661
Legislation / enforcement of motorcycle helmet use	6 683	19 030	1 696	5 724
Legislation / enforcement of bicycle helmet use	**1 233**	295 965	3 678	9 256
Speed cameras + breath-testing	1 406	12 425	1 439	4 589
Seatbelts + motorcycle helmets	5 472	54 203	2 239	9 159
Speed cameras + breath-testing + seatbelts	1 483	12 994	1 305	4 608
Speed cameras + breath-testing + motorcycle helmets	1 333	**11 652**	1 237	**4 142**
Seatbelts + motorcycle helmets + breath-testing	2 725	23 974	1 919	7 033
Seatbelts + motorcycle helmets + speed cameras	2 116	21 198	1 466	5 754
Seatbelts + motorcycle helmets + speed cameras + breath-testing	1 428	**14 139**	**1 181**	**4 550**
Seatbelts + motorcycle helmets + speed cameras + breath-testing + bicycle helmets	**1 376**	**15 982**	**1 382**	**4 839**

[1] Results reported here incorporate discounting of costs and effects at 3% plus age-weighting of DALYs. Values in **bold** are interventions that lie on the cost-effectiveness frontier (see Figure 8 for an illustration).

Point estimates of the overall effect and cost of each single or combined strategy can be usefully plotted graphically to not only show their comparative impact and affordability, but also to reveal the so-called cost-effectiveness or efficiency frontier, which traces the incremental expansion path that should be pursued in order to maximize population health at successively greater budget levels. Figure 11 provides the expansion path for WHO sub-region SearD, this time reporting cost and outcomes for the full 10-year period of implementation, and shows that if a decision-maker could do one thing alone, s/he should pursue or 'buy' the combined strategy of traffic law enforcement with speed cameras, breath-testing, seatbelt checks and motorcycle helmet enforcement, then add in bicycle helmet law enforcement. With each successive step, greater strides are made towards curbing RTI burden but at an incrementally greater cost than the previous step.

Figure 11 Cost-effectiveness expansion path for WHO sub-region SearD

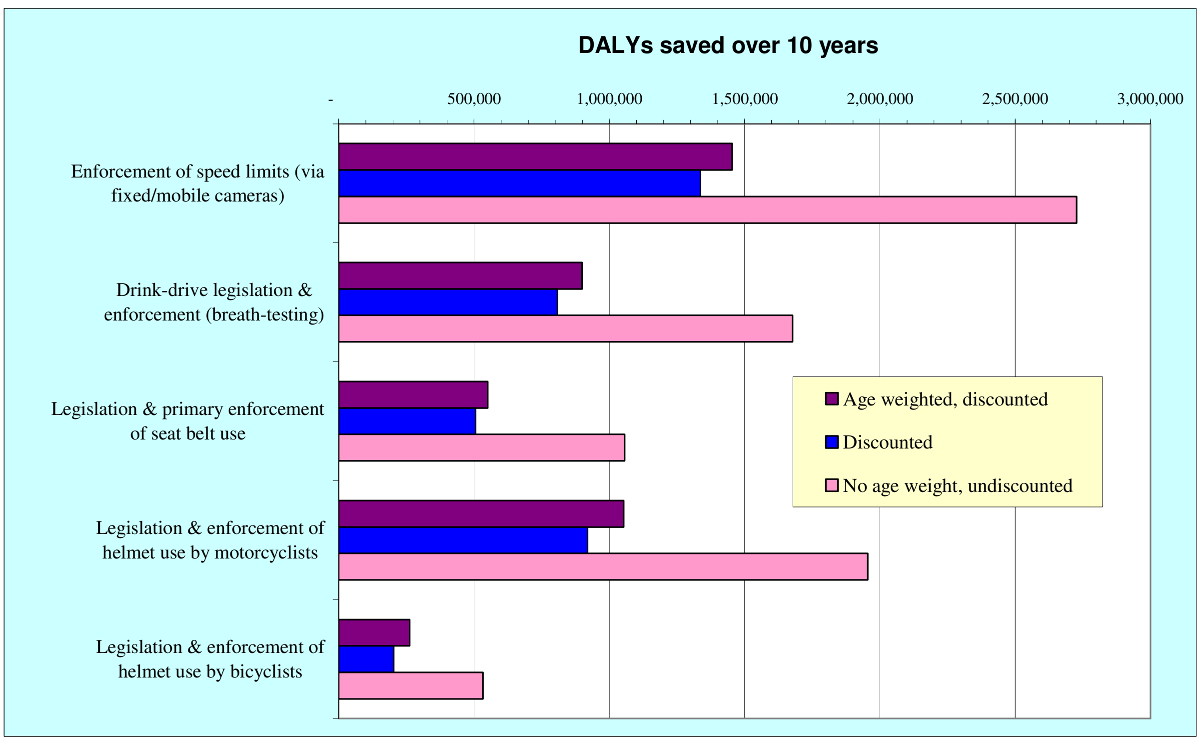


7.4 Uncertainty analysis

All of the results reported above are imbued with an inherent degree of uncertainty, either as a result of specific analytical choices (such as the discount rate or the age-weights applied to DALYs), or as a result of lack of precise information concerning data input values (specific items identified above include the effect size for bicycle helmets, the cost of fitting seatbelts in a proportion of the motor vehicle fleet, and the pull-over enforcement rate). We therefore undertook a number of analyses to explore the sensitivity of baseline results to plausible changes in analytical choices or input values.

Removing age-weights from the DALY calculus - so that each DALY averted is treated as equal, no matter at what age group it accrues to - had a minimal impact on baseline cost-effectiveness ratios (5%-15% higher). Removal of discounting, on the other hand, has a marked impact on results, such that unadjusted DALYs averted (with no discounting or age weighting) are close to double their baseline value (see Figure 12 for the WHO sub-region WprB). This would result in cost-effectiveness ratios that are nearly 50% lower (more favourable) than baseline estimates.

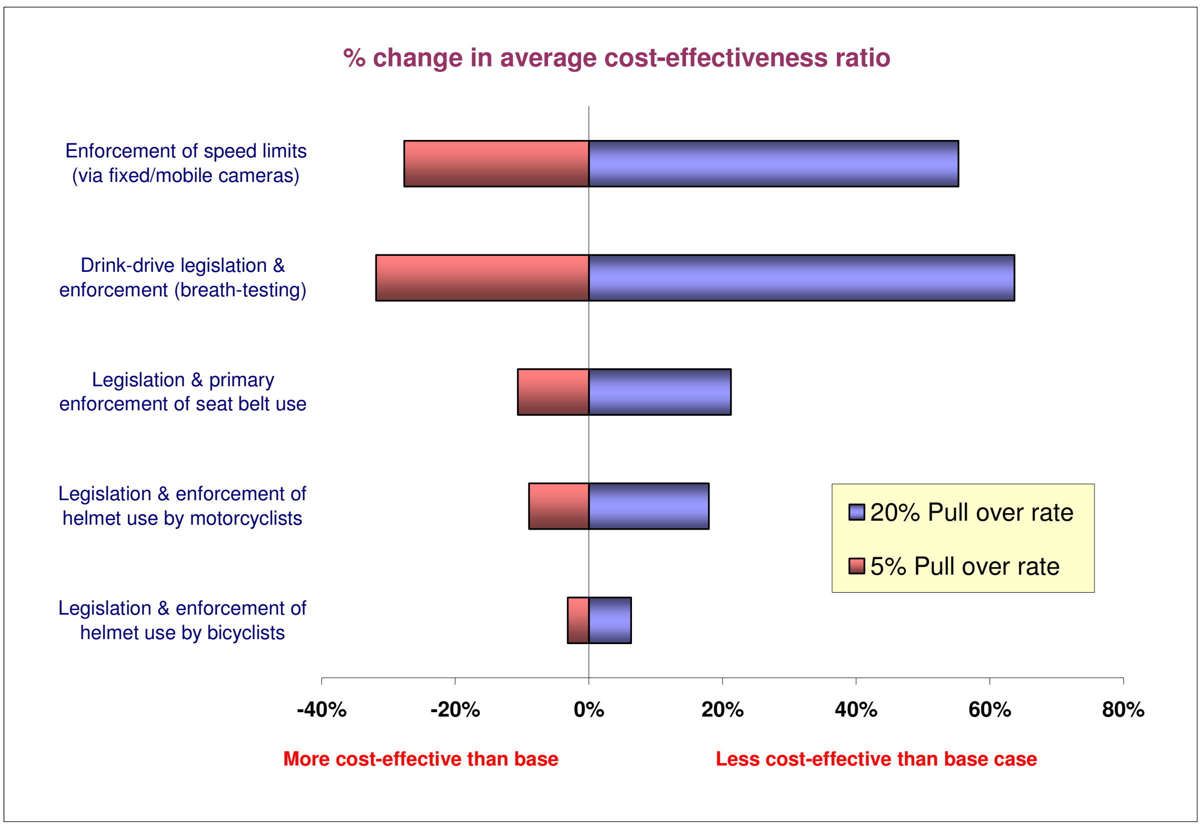
Figure 12 Impact of discounting and age-weighting (WHO sub-region WprB)



Owing to the scientific uncertainty and debate concerning the effectiveness of bicycle helmets, we assessed the impact of reducing baseline relative risk reductions, first by 50% and then by 75%, which has the effect of increasing cost-effectiveness ratios by 100% and 300% respectively. In high-income WHO sub-regions such as AmrA, this turns an already cost-ineffective intervention into an exceedingly inefficient injury prevention strategy. In certain other sub-regions such as AfrE, where baseline results showed bicycle helmets to be a cost-effective option, the sensitivity analysis indicates that even if assumed effectiveness is reduced by 50% (e.g. a relative risk reduction of about 35% rather than 70% with respect to fatal injury), this intervention remains one of the more efficient injury prevention strategies.

On the cost side, an important driver of traffic enforcement campaigns relates to the proportion of vehicles that need to be pulled over in order to derive the expected level of effective coverage in the population. As shown below in Figure 13 for WHO sub-region WprB, halving (to 5%) or doubling (to 20%) the baseline pull-over rate of 10% has a large impact on cost-effectiveness results, particularly for interventions effecting multiple road user groups (speeding, drink-driving).

Figure 13 Sensitivity of cost-effectiveness results to changes in pull-over rate (WHO sub-region WprB)



8. Discussion and conclusions

8.1 Study limitations

Fitting a mathematical model to the complex reality of risky road use behaviours and their prevention requires many simplifying assumptions to be made, as well as extrapolation of available data to geographical or socioeconomic settings beyond those in which the data were initially collected. Some of the key assumptions and limitations underlying this analytical effort can be summarized as follows:

1. <u>Epidemiological estimates of road traffic injuries</u>: The primary source of data for epidemiological estimates of the fatal and non-fatal consequences of road crashes at the international level is the Global Burden of Disease study; for this analysis, we used estimates produced at the level of WHO sub-regions for the year 2002 (which are a slight revision of the GBD 2000 estimates, which in turn depend - at least in part - on the initial GBD work carried out in 1996 for the year 1990; Begg and Tomijima, 2002). Until such time that the planned whole-scale revision of global burden of road traffic injuries is completed, the data limitations associated with earlier estimation exercises are carried through to this analysis. In particular, estimates of the incidence and prevalence of non-fatal injuries were informed by only a small number of health facility datasets from WHO member states (from which death-to-incidence ratios were calculated) and the opinion of experts concerning the severity and duration of injury sequelae (from which disability weights were derived). This approach may have produced inaccurate estimates, particularly for under-represented regions of the world.

2. <u>Exclusion of minor injuries</u>: The analytical model used here to gauge the relative impact of different injury prevention strategies on non-fatal injury only included a prominent subset of severe, long-term causes (which between them account for 80%-90% of non-fatal road traffic injury burden). Exclusion of other long-term injuries and all minor (non-hospitalisable) injuries therefore reduces the total non-fatal injury burden (by 10%-20%), and this implies that the estimated population-level impact of prevention strategies is under-estimated. The degree of underestimation, however, is expected to be very modest, because the big benefits to be reaped from these interventions come from their impact on mortality and severe, long-term injury.

3. <u>Distribution of injuries by road user group</u>: The accuracy of the regional weighted average estimates depends on how representative are the data sources from which they are constructed.

As the road user mix may vary dramatically between different sections of a country (rural vs. urban), urban hospital-based studies may not be representative of the distribution of road traffic injuries by road user category for an entire country. However, due to the paucity of available population-level data sources, we relied on hospital-based studies to derive certain sub-regional weighted average estimates. The substantial differences in data quality among high-, middle-, and low-income countries along with the lack of national-level data sources highlights the urgent need in low- and middle-income countries to establish improved road traffic injury surveillance mechanisms.

4. Distribution of injuries by sex: Since empirical evidence was lacking to suggest the contrary, we assumed that the distribution of road traffic injuries by road user category is the same for males and females. Although this may hold true in high-income nations where both genders have similar exposure levels to road traffic, different trends may arise in certain parts of the world where females could have considerably different exposure levels to road traffic compared to males.

5. Distribution of injuries by age: Since a comparison of a number of datasets revealed that the overall age distribution for fatalities and non-fatal injuries by road user category did not greatly differ among countries, we generated and applied a global age distribution to all sub-regional populations. This assumption, although based on empirical evidence from a number of countries, may not hold true for all sub-regions because age demographics between sub-regions differ appreciably, which in turn may affect the levels of road traffic exposure in different age groups. For example, the share of fatal road traffic injuries attributable to people aged above 60 years in South Africa is different to the corresponding proportions found in Europe and USA (see Figure 3).

6. Distribution of injuries by risk factor: The validity of population attributable fraction (PAF) estimates depends on the accuracy of estimates used in their calculation, made up of use rates (P) and effectiveness (RR). The available estimates of effectiveness are based on observational studies only, which are prone to bias and confounding. The quality of estimates of current risk exposure also affects the validity of PAF estimates. If the exposure rate is overestimated, the PAF will underestimate the preventive potential and vice versa. Exposure rates (seat belt use, bicycle helmet use, and motorcycle helmet use, in this case) are estimated from road user samples from countries and can be inaccurate, potentially limiting the quality of our estimates.

7. Distribution of injuries across multiple risk factors: There are important gaps in knowledge concerning the interaction of multiple risk factors that precede or precipitate road crashes, particularly in the context of developing countries where the confluence of different risk factors or causes may be distinct from those in high-income countries. In order to take some account of these known (but uncertain) interactions, a set of adjustment factors were derived that ensured that the total envelope of injuries for specific age groups were not exceeded, but there nevertheless remains a significant degree of uncertainty around these interactions, which may exaggerate or diminish the contribution of specified risk factors to the overall toll of road traffic injury As discussed by Elvik and Vaa (2004; p. 67-77), there is also a vital need to take better account of these correlations or joint effects, so that improved estimates of the marginal attributable risk of specific factors can be made (e.g. via multivariate analysis); such a development is being thwarted by the lack of complete or even partial risk factor data at the national level, due to a myriad of factors including under-reporting (by victims) and inaccurate reporting (by traffic enforcement and statutory bodies).

8. Effect sizes: Although estimates of intervention impact or effect are drawn from the best available sources in the international literature, these sources are heavily biased towards evaluative research carried out in high-income countries, where the road use environment is different to that found in low- or middle-income countries. Effect sizes may therefore under- or over-estimate the true independent effect of the selected intervention strategies. High quality evaluative research of the specific impact of traffic enforcement strategies like mobile speed cameras or roadside breath-testing needs to be carried out in a range of low- and middle-income countries in order to rectify this situation.

9. Access to medical services: The impact on fatalities and injuries reported in high-income countries would be different from those in settings where pre-hospital and emergency medical care is limited. In other words, estimates of intervention effectiveness drawn from high-income countries with good emergency and trauma services - which also happen to be the countries with greatest research funding and therefore with greatest representation in meta-analytic reviews of the literature - may understate the true independent effect of road safety devices such as motorcycle helmets in low- and middle-income regions of the world. Separation out of the influence of emergency and trauma care on road traffic injury outcomes - both in economically developed and developing countries - would have enabled us to calculate the independent effect of our selected interventions with greater precision.

8.2 Policy implications

To date, very few attempts have been made to document the breakdown of road traffic injuries by risk factor or the avertable burden of these injuries via (cost-) effective road safety measures. Where such attempts have been made, they are very partial in terms of intervention or geographical coverage, which is perhaps unsurprising in view of the availability of data (Bishai and Hyder, 2006; Norton et al., 2006). Subject of course to the limitations of economic modeling, the results of this analysis of risk exposure and intervention cost-effectiveness for road traffic injury prevention provide a renewed attempt to improving the basis for decision-making and resource allocation in global road safety. Our analysis has been carried out at a global level with inclusion of all WHO regions, employs an internationally validated and consistent approach to cost-effectiveness analysis (CHOICE), and is based on an exhaustive search of the available empirical literature relating to the epidemiology of and risk exposure to road traffic injuries in different parts of the world.

A central finding of this study is that the potential impact of available road safety measures is inextricably bound by the underlying distribution of road traffic injuries across different road user groups and risk factors. Although a number of simplifying assumptions have been made in the analysis - as discussed above - there remain clear and unequivocal differences across and within WHO regions with respect to the distribution of both fatal and non-fatal road traffic injuries. This is not a new finding or conclusion, but, on the basis of the quantitative estimates provided here, one which we believe can now be understood with greater specification. Better definition of risk contributions can and should be brought to bear on this estimation process via renewed data collection efforts at the national and international level, a development that is in fact already under way as part of other global road safety initiatives such as those coordinated by the Road Traffic Injuries Research Network (www.rtirn.net) and a new WHO initiative sponsored by the Bloomberg Foundation.

This review is limited to a small sub-set of the entire portfolio of possible intervention strategies for reducing the incidence and consequences of road traffic injury. However, findings from the cost-effectiveness component of this study provide a useful analytical baseline against which more country-specific assessments can be made. Even at the aggregated level of whole sub-regions of the world, however, discernible patterns emerge of 'what works where', depending on the underlying patterns of road traffic injury. For example, in highly motorized regions of the world such as AmrA, the proportion of total fatal injuries attributable to bicyclists and to children not wearing a bicycle helmet is very small (< 2%), so the public health impact of increasing helmet use among this road user group will be correspondingly modest (and relatively cost-ineffective given the comparatively high fixed costs of its full implementation). By contrast, in other settings where there is a low overall motorization rate (e.g. AfrE) or a high dependence on bicycles as a mode of transport (e.g. WprB), fatal injuries to bicyclists account for a much larger share of the avertable burden. Increased bicycle helmet use in such settings could bring significant health benefits at the population level and is also a low-cost option (with costs shared between public agencies and private households).

Interventions aimed at reducing the incidence of alcohol-impaired driving have greatest impact in regions with relatively high levels of hazardous drinking and associated RTI alcohol-attributable fractions (AfrE, AmrA). Because of the estimated resources needed to effectively implement this strategy (pulling over 10% of vehicles per year), RBT may not represent a particularly cost-effective strategy, but still produces an attractive investment option to policy-makers, even in lower-consumption sub-regions like SearD (where the cost per DALY saved is below I$3,000). Estimates of the cost-effectiveness of RBT reported here are less favorable than the values already produced in a separate CHOICE analysis of hazardous alcohol use for the year 2000 (Chisholm et al., 2004); this is due to the use here of the motorization rate (as opposed to the proportion of adults who drive) as the basis for establishing required number of roadside checkpoints, and also due to the application of a downward adjustment factor to take appropriate account of the alcohol-attributable road traffic injuries *not* caused by drink-driving (e.g. those caused by drunken pedestrians).

Unsurprisingly given the large proportion of road traffic injuries attributed to speeding in all sub-regions of the world, interventions that impact on this risk factor have important public health implications. In this analysis we only assess the costs and effects of one speeding-related intervention (roadside checkpoints using hand-held speed cameras) and find it to be an effective and worthwhile strategy in all settings. What we do not report - but which would have significant information value for decision-makers - is the relative efficiency of this particular interventions vis-à-vis other strategies aimed at curbing excess vehicle speed such as speed bumps, traffic-calming schemes, improved sign-posting, better separation of vehicles from pedestrians, etc.

Much of the difficulty in estimating the cost-effectiveness of these other speed control interventions falls on the costing side, in particular road design, layout and engineering aspects. In order to establish the number of speed bumps in a population, for example, an accurate profile is needed of the proportion of injuries occurring in urban (versus rural) settings, residential (versus commercial) areas and at junctions (versus inter-junction links). In their analysis of speed bumps, Bishai and Hyder (2006) made the simplifying assumption that 50% of urban road traffic fatalities occur at junctions, but that may be an overestimate in the road environment of most developing countries and does not take into account the broader road network that is needed for a genuinely population-level analysis (Downing et al., 2000). Their resulting ratios of cost per DALY (less than US$ 20 across all low- and middle-income regions) may therefore be overly optimistic, but are nevertheless more than one order of magnitude more efficient than the speeding intervention modeled here.

A final clear message to emerge from the analysis is that, more than individual interventions, combined enforcement strategies are the most efficient way to respond to the burden of road traffic injuries, because they benefit from significant synergies on the cost side, while generating greater overall health gains on the effect side. In other words, once the basic infrastructure of roadside checkpoints has been created or scaled up - in terms of human resource, vehicles and equipment - the marginal cost of adding an extra road safety check like seatbelt compliance is low.

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Annex 1 WHO Member States by epidemiological reporting region

For geographical disaggregation of the global burden of disease, the six WHO regions of the world have been further divided into 14 sub-regions, based on levels of child (under five years) and adult (15-59 years) mortality for WHO Member States.

WHO region	Mortality stratum	WHO Member States
AFRO	D	Algeria, Angola, Benin, Burkina Faso, Cameroon, Cape Verde, Chad, Comoros, Equatorial Guinea, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Madagascar, Mali, Mauritania, Mauritius, Niger, Nigeria, Sao Tome And Principe, Senegal, Seychelles, Sierra Leone, Togo
AFRO	E	Botswana, Burundi, Central African Republic, Congo, Côte d'Ivoire, Democratic Republic of the Congo (the), Eritrea, Ethiopia, Kenya, Lesotho, Malawi, Mozambique, Namibia, Rwanda, South Africa, Swaziland, Uganda, United Republic of Tanzania (the), Zambia, Zimbabwe
AMRO	A	Canada, United States of America (the), Cuba
AMRO	B	Antigua And Barbuda, Argentina, Bahamas (the), Barbados, Belize, Brazil, Chile, Colombia, Costa Rica, Dominica, Dominican Republic, El Salvador, Grenada, Guyana, Honduras, Jamaica, Mexico, Panama, Paraguay, Saint Kitts And Nevis, Saint Lucia, Saint Vincent And The Grenadines, Suriname, Trinidad And Tobago, Uruguay, Venezuela
AMRO	D	Bolivia, Ecuador, Guatemala, Haiti, Nicaragua, Peru
EMRO	B	Bahrain, Cyprus, Iran (Islamic Republic Of), Jordan, Kuwait, Lebanon, Libyan Arab Jamahiriya, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, Tunisia, United Arab Emirates
EMRO	D	Afghanistan, Djibouti, Egypt, Iraq, Morocco, Pakistan, Somalia, Sudan, Yemen
EURO	A	Andorra, Austria, Belgium, Croatia, the Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Luxembourg, Malta, Monaco, Netherlands (the), Norway, Portugal, San Marino, Slovenia, Spain, Sweden, Switzerland, United Kingdom of Great Britain and Northern Ireland
EURO	B	Albania, Armenia, Azerbaijan, Bosnia And Herzegovina, Bulgaria, Georgia, Kyrgyzstan,Poland, Romania, Slovakia, Tajikistan, The Former Yugoslav Republic Of Macedonia, Turkey, Turkmenistan, Uzbekistan, Yugoslavia
EURO	C	Belarus, Estonia, Hungary, Kazakhstan, Latvia, Lithuania, Republic of Moldova, Russian Federation (the), Ukraine
SEARO	B	Indonesia, Sri Lanka, Thailand
SEARO	D	Bangladesh, Bhutan, Democratic People's Republic Of Korea, India, Maldives, Myanmar, Nepal
WPRO	A	Australia, Japan, Brunei Darussalam, New Zealand, Singapore
WPRO	B	Cambodia, People's Republic of China, Lao People's Democratic Republic, Malaysia, Mongolia, Philippines, Republic Of Korea, Viet Nam
		Cook Islands, Fiji, Kiribati, Marshall Islands, Micronesia (Federated States Of), Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu

Source: http://www.who.int/whr/2002/MembersETC.pdf

Annex 2 List of WHO Member States that have road user type information

Subregion	Countries Represented by studies	% of regional RTI Mortality Represented by countries*
Afro D	Benin[1], Burkina Faso[2], Ghana[3 4 5 6 7], Nigeria[8 9 10 11]	47%
Afro E	Botswana[12], Ethiopia[13 14], Kenya[15 16 17 18 19 20], Mozambique[21], South Africa[22 23], Uganda[24], United Republic of Tanzania[25], Zambia[26 27], Zimbabwe[28 29 30 31]	60%
Amro A	Canada[32 33], United States of America (the)[34]	97%
Amro B	Brazil[35 36 37 38 39 40 41 42], Colombia[43 44 45 46], Jamaica[47 48], Mexico[49 50], Trinidad and Tobago[51]	73%
Amro D		0%
Emro B	Bahrain[52], Iran, Jordan[53], Saudi Arabia[54 55]	71%
Emro D	Pakistan[56 57 58 59 60 61 62]	26%
Euro A[63]	Andorra, Austria, Belgium, Croatia, the Czech Republic, Denmark, Finland, France, Iceland, Ireland, Israel, Italy, Luxembourg, Netherlands (the), Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom of Great Britain and Northern Ireland	100%
Euro B[64]	Albania, Armenia, Azerbaijan, Bulgaria, Georgia, Kyrgyzstan, Poland, Romania, Slovakia, Tajikistan, The former Yugoslav Republic of Macedonia, Turkey	89%
Euro C[65]	Belarus, Estonia, Hungary, Kazakhstan, Latvia, Lithuania, Republic of Moldova, Russian Federation (the), Ukraine	100%
Searo B	Indonesia[66 67 68], Sri Lanka[69 70 71], Thailand[72 73 74 75 76 77 78]	100%
Searo D	Bangladesh[79], India[80 81 82 83 84 85 86], Nepal[87 88 89 90]	95%
Wpro A	Australia[91], Japan[92], New Zealand[93], Singapore[94 95 96]	99%
Wpro B	Cambodia[97 98], China[99 100 101 102 103 104 105 106], Malaysia[107 108 109], Mongolia[110], Republic of Korea[111], Viet Nam[112 113]	93%

*(i.e. the % of RTI mortality that occurs in the listed countries overall)

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Annex 3 Breakdown of fatal road traffic injuries by road user type

Region/Country	% Total fatal road traffic injuries				
	Pedestrians	Bicyclists	Motorcyclists	Motorized four-wheelers	Data source
AFRICA					
Benin	38%			42%	Urban
Burkina Faso			30%	31%	Rural
Côte d'Ivoire	75%			17%	Not specified
Ethiopia	84%				Country level
Ghana	46%	4%	2%	14%	Country level
Kenya	42%	8%		50%	Urban hospital
Mozambique	55%				Urban hospital
Nigeria	28%			17%	Urban hospital
South Africa	36%			29%	Country level
Swaziland	43%	7%		50%	Not specified
Uganda	44%				Urban hospital
United Republic of Tanzania	36%	13%	5%	45%	Country level
Zambia	50%			15%	Urban
Zimbabwe	36%				Not specified
THE AMERICAS					
Brazil	29%	4%	17%	20%	Country level
Colombia	37%	8%	26%	29%	Urban hospital
Canada	14%	2%	6%	77%	Country level
Jamaica	28%	13%	10%	33%	Country level
Mexico	12%				Urban
Trinidad and Tobago	42%				Country level
United States of America (the)	11%	2%	9%	74%	Country level
EASTERN MEDITERRANEAN					
Bahrain	35%	4%		61%	Not specified
Cyprus	18%	3%	23%	55%	Country level
Iran (Islamic Republic of)	33%	1%	11%	45%	Urban hospital
Saudi Arabia	73%	2%	1%	25%	Urban hospital
EUROPE					
Albania	36%	6%	8%	23%	Country level
Andorra	11%		44%	45%	Country level
Armenia	50%	2%			Country level
Austria	17%	8%	14%	55%	Country level
Azerbaijan	50%		2%	39%	Country level
Belarus	44%	10%	6%	34%	Country level
Belgium	10%	8%	17%	60%	Country level
Bulgaria	28%	5%	7%	53%	Country level
Croatia	24%	6%	12%	49%	Country level
Czech Republic (the)	22%	11%	9%	53%	Country level
Estonia	27%	9%	2%	57%	Country level
Finland	10%	13%	7%	64%	Country level
France	11%	3%	19%	64%	Country level
Georgia	42%				Country level

Hungary	27%	13%	7%	43%	Country level
Iceland	4%		4%	88%	Country level
Israel	34%	6%	8%	39%	Country level
Italy	18%	5%	19%	53%	Country level
Kazakhstan	37%	1%	7%	48%	Country level
Kyrgyzstan	50%	3%	4%	43%	Country level
Latvia	35%	6%	6%	49%	Country level
Lithuania	34%	13%	4%	45%	Country level
Luxembourg	10%	2%		84%	Country level
Moldova	40%	6%	8%	37%	Country level
Netherlands (the)	11%	21%	16%	46%	Country level
Norway	11%	4%	14%	61%	Country level
Poland	34%	13%	3%	44%	Country level
Portugal	20%	13%	22%	41%	Country level
Romania	46%	8%	1%	39%	Country level
Russian Federation (the)	42%	2%	7%	17%	Country level
Slovakia	31%	10%	6%	49%	Country level
Slovenia	15%				Country level
Spain	15%	2%	15%	58%	Country level
Sweden	10%	8%	9%	68%	Country level
Switzerland	19%	5%	19%	53%	Country level
Tajikistan	52%	8%		40%	Country level
The former Yugoslav Republic of Macedonia	19%	3%	4%	59%	Country level
Turkey	19%	2%	5%	37%	Country level
Ukraine	43%	9%	8%	35%	Country level
United Kingdom of Great Britain and Northern Ireland	23%	4%	18%	51%	Country level
SOUTH EAST ASIA					
Bangladesh	62%				Not specified
India	9%	3%	21%	16%	Country level
Indonesia	33%	7%	42%	7%	Urban
Nepal	40%				Urban hospital
Sri Lanka	38%	9%	34%	14%	Urban
Thailand	10%	2%	73%	11%	Not specified
WESTERN PACIFIC					
Australia	9%	0%	10%	71%	Country level
Cambodia	9%	5%	72%	6%	Country level
China	26%	16%	17%	33%	Country level
Japan	32%	13%	18%	27%	Country level
Malaysia	8%	4%	66%	16%	Country level
Mongolia	40%				Country level
New Zealand	8%	3%	9%	81%	Country level
Singapore	24%	9%	49%	12%	Country level
Vietnam	5%	2%	68%	25%	Country level

Annex 4 Seat belt and helmet utilization rates, by WHO sub-region and member state

Sub-region/ Country	Seat Belt Use Rate	Motorcycle Helmet Use Rate	Bicycle Helmet Use Rate
AFRO D			
Madagascar	8%[1]	-	-
Nigeria	32%[2]	10%[3]	0%[4]
AFRO E			
Ethiopia	36%[5]	-	-
Kenya	1%[6]	-	-
South Africa	45%[7]	52%[8]	-
Uganda	0%[9]	3%[10]	29%[11]
AMRO A			
Canada	87%[12]	-	53%[13]
United States of America (the)	82%[14]	51%[15]	22%[16]
AMRO B			
Argentina	39%[17]	-	-
Brazil	63%[18]	66%[19]	-
Colombia	-	47%[20]	-
Costa Rica	82%[21]	-	-
Jamaica	75%[22]	-	-
Mexico	63%[23]	-	17%[24]
EMRO B			
Iran (Islamic Republic of)	-	3%[25]	0%[26]
Kuwait	55%[27]	-	-
Lebanon	9%[28]	-	-
Oman	87%[29]	-	-
Saudi Arabia	30%[30]	-	-
Tunisia	22%[31]	60%[32]	-
United Arab Emirates	6%[33]	-	1%[34]
EMRO D			
Pakistan	-	13%[35]	-

Continued overleaf…..

Sub-region/ Country	Seat Belt Use Rate	Motorcycle Helmet Use Rate	Bicycle Helmet Use Rate
EURO A			
Austria	77%[36]	-	13%[37]
Belgium	66%	-	-
Czech Republic (the)	75%	-	7%
Denmark	84%	-	28%
Finland	89%	-	-
France	97%	-	6%
Germany	94%	99%[38]	20%
Greece	40%	20%[39]	22%
Ireland	85%	-	-
Israel	64%	-	18%
Italy	54%	54%[40]	-
Luxembourg	88%	-	-
Netherlands (the)	86%	-	-
Norway	-	-	39%
Portugal	88%	-	8%
Slovenia	81%	-	-
Spain	86%	98%[41]	-
Sweden	92%	-	36%
United Kingdom of Great Britain and Northern Ireland	93%	-	25%
EURO B			
Poland	71%[42]	-	6%[43]
Turkey	25%[44]	35%[45]	-
EURO C			
Estonia	65%[46]	-	7%[47]
Hungary	61%	-	8%[48]
Latvia	-	-	3%[4950]
Lithuania	-	-	3%[5152]
Russian Federation (the)	50%[53]		4%[5455]
SEARO B			
Indonesia	28%[56]	70%[57]	70%[58]
Thailand	14%[59]	12%[60]	12%[61]
SEARO D			
India	5%[62]	30%[63]	0%[64]
WPRO A			
Australia	85%[65]	-	75%[66]
Japan	95%[67]	-	-
New Zealand	90%[68]	92%[69]	90%[70]
Singapore	-	100%[71]	11%[72]
WPRO B			
China	52%[73]	19%[74]	0%[75]
Malaysia	32%[76]	54%[77]	-
Vietnam	-	30%[78]	-

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