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The potential for vehicle safety standards to prevent deaths and injuries in Argentina, Brazil, Chile and Mexico: a 2018 update

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Executive Summary

The World Health Organization estimates that the number of road traffic deaths has reached 1.35 million per year, with the highest road traffic fatality rates in low-income countries (WHO, 2018). The Global Status Report on Road Safety 2018 highlights that while vehicles in high-income countries are increasingly safe, only 40 of 175 countries (23%) have adopted the priority vehicle safety standards as recommended by the United Nations (WHO, 2018).

The overall aim of this research is to support the adoption of priority vehicle safety standards for all new vehicles globally. Four countries (Argentina, Brazil, Chile and Mexico) are used as a case study.

The three highest priority vehicle safety standards are considered to be:

1. Minimum standards for crashworthiness, i.e. regulations that help to protect occupants in front and side impact crashes;

2. Electronic Stability Control (ESC) for crash avoidance; and

3. Pedestrian protection measures to improve safety for Vulnerable Road Users (VRUs) including pedestrians and bicyclists.

This project extends previous work (Cuerden et al. 2015 & Wallbank et al. 2016) to consider the lives that could be saved and injuries that could be prevented by application of a wider range of vehicle safety regulations from 2020 to 2030 in the same four countries considered previously (Brazil, Argentina, Chile, and Mexico). It also goes further to demonstrate the cost-effectiveness of the application of these regulations. The full set of priority safety standards considered in this study includes:
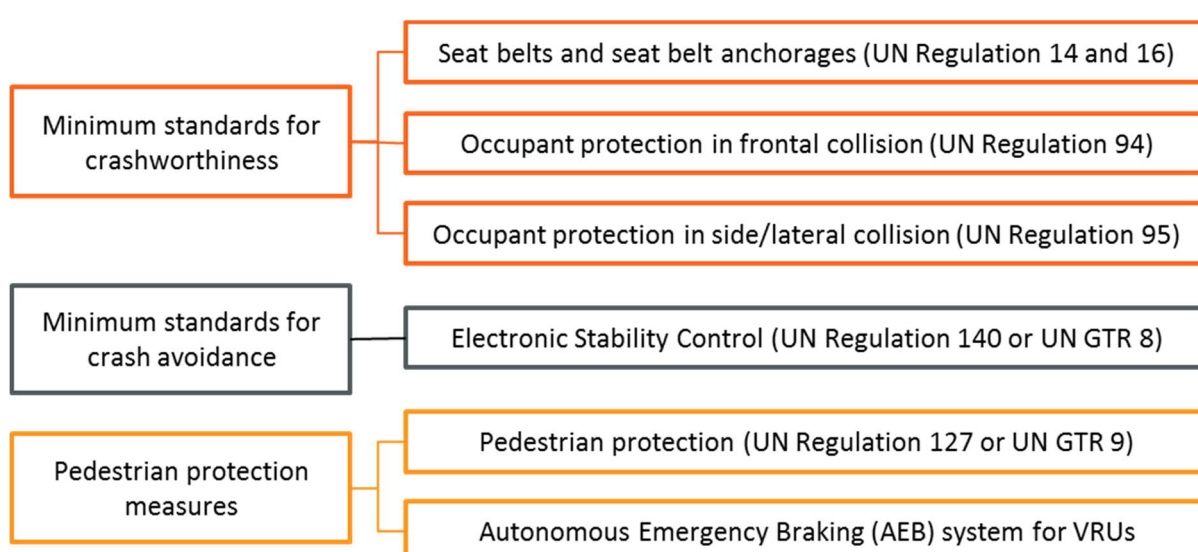
Some progress has already been made towards implementation of these priority standards, as a result of efforts within the four countries to adopt minimum standards for crashworthiness. If these initiatives continue, this study estimated that these crashworthiness regulations will save 11,000 car occupant fatalities up to 2030. It also estimated that if regulations for ESC, secondary safety pedestrian protection and AEB for VRU are adopted, an additional 14,000 lives could be saved during the 2020 to 2030 period (12,000 of which would be VRUs).

In total, if Argentina, Brazil, Chile, and Mexico adopted the full set of priority vehicle safety standards from 2020, more than 25,000 lives could be saved and over 170,000 serious injuries prevented, by 2030.

The benefits and costs for the measures that go beyond minimum standards of crashworthiness were calculated for each country considering fatalities and serious injuries. The results from each country were used to determine the years in which the measures become cost-beneficial (benefit-to-cost-ratio greater than 1) in each of the four countries:

Table 1: Years in which measures become cost-beneficial

Country	Year in which ESC becomes cost-beneficial	Year in which measures to protect VRUs become cost-beneficial
Argentina	2022	2024
Brazil	2022	2023
Chile	2021	2022
Mexico	2024	2023
Overall	2022	2023

In addition, the cumulative benefit-to-cost-ratio between 2020 and 2030 was calculated for the four countries, again considering both fatalities and serious injuries[1]:

- ESC = 2.75

- Measures to protect VRUs = 1.98

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[1] Counting the benefits to fatalities only, then the cumulative benefit-to-cost-ratio between 2020 and 2030 for the four countries is: 1.58 for ESC and 0.61 for Measures to protect VRUs.

The results show that across the region, the ESC regulation will be cost-beneficial within two years of implementation, although in Mexico it will take four years to achieve this, twice as long as any other country. Of the four countries, Mexico has the second largest car fleet to equip with ESC, and the oldest. Recent trends show a reduction in fatal and serious injuries to car occupants and a relatively slow introduction of new cars in Mexico; therefore, the estimated benefit-to-cost ratio increases more slowly than in Argentina, Brazil and Chile.

In addition to the fatality savings predicted above, it is estimated that a further 15,000 lives would have been saved between 2020 and 2030 if earlier regulatory action had ensured that ESC was fitted throughout the whole vehicle fleet by 2020. This additional benefit will not be achieved because of the time it will take for the fleet to turnover and for older cars which don't have ESC fitted to be replaced.

It should be noted that the modelling presented here is based on the assumption that current trends continue, but there is limited casualty data on which to base these trends for some countries. As a result, if the implied car occupant safety improvements in these countries slow, or if the reported fatality figures are subject to a degree of underreporting and an alternative trend emerges, then the benefits of ESC could be much greater. Equally, if the proportion of the car fleet renewed each year increases then the return on the ESC fitment investment will be greater and realised sooner. Therefore, it is proposed that the situation should be monitored and the implications for ESC economics reconsidered if new evidence becomes available.

For VRU protection measures, the benefit-to-cost ratio for the region is expected to increase above 1 by 2023, although in Argentina this will not happen until 2024. Of the four countries, Argentina has the smallest proportion of pedestrians within the road traffic collision fatalities for the country (10%). Car occupants (50%) and motorcyclists (30%) account for most of the road users killed in Argentina. This explains why changes to protect vulnerable road users (pedestrians and bicyclists) would require the longest time before providing a positive return on the investment in vehicle fleet changes.

The method applied for this study considers the effects of the introduction of vehicle safety standards on the number of car occupant and pedestrian and bicyclist (referred to collectively as Vulnerable Road Users or VRUs) fatalities and serious injuries. Specifically, for cars, the model calculates the cost-benefit for car occupants of regulating ESC, approved seat belts and anchorages for all seating positions, and occupant protection in frontal and lateral collisions. For VRUs (pedestrians and cyclists), the cost-benefit model estimates the impact of regulating a VRU-AEB system, which prevents collisions, and the pedestrian protection regulation regarding front bumper and bonnet design, which mitigates the injuries resulting from a collision.

The benefits presented represent the economic benefit to society of reducing fatalities or serious injuries. The Valuation of Statistical Life (VSL) was used to provide these estimates. It equates the economic loss due to a traffic collision in terms of GDP per capita (and is based on a 'willingness to pay' approach, measuring the preference of individuals to pay to avoid injury). The costs are the consumer costs, i.e. the amount extra that consumers would be expected to pay to equip a new vehicle with the associated technology. Benefit-to-cost

ratios (BCRs) are presented for each road user group; values greater than 1 indicate that the benefits are greater than the costs incurred. For example, a BCR of 2.3 can be interpreted as follows: "for every dollar spent by consumers in purchasing vehicles with these technologies, there's a $2.30 return in economic benefit to society".

Due to uncertainties in the input values and assumptions used, and the fact that predictions of the future are inherently uncertain, the final results are also subject to a degree of uncertainty. As noted above, the fatality data used in this study was obtained from reported road casualty data and there may be issues of underreporting, which could affect the casualty benefits estimated (potentially underestimating them if the true number of casualties was increasing more quickly or decreasing more slowly than the reported numbers). Additionally, there are substantial assumptions made about the number of serious injuries, which were estimated using a simple factoring process based on data from Great Britain, meaning that the estimated number of serious injuries prevented may not truly reflect the numbers observed in each country. Given these uncertainties, it is recommended that the benefit-to-cost ratios predicted are considered with suitable caution.

It should be noted that Original Equipment Manufacturers and Suppliers are often unable to provide cost information directly because it is commercially sensitive information. Therefore this study used costs provided in publically available reports, which were then verified by Global NCAP. It is understood that pricing of cars is complex with strong market pressures influencing retail prices, particularly in lower price segments. Therefore, the accuracy of the costs used in this study is further limited by uncertainty over the proportion of it that would be transferred to the end customer. As reported within this study, the full market value of costs has been compared with the societal benefits; though it could be the case that the retail price for a car does not (or cannot) increase by this much.

The main recommendations emerging from this research are:

- Given the potential for saving lives and preventing serious injuries, it is recommended that the four countries studied build on current regulations for seat belts, seat belt anchorages and crashworthiness protection, where necessary implementing them, and enforcing them without further delay, as well as implement regulations for ESC and pedestrian protection measures immediately.

- The benefit-to-cost ratios predicted for ESC indicate that it should be implemented in all four countries, as it will be cost-beneficial in each country by 2024 at the latest, and the overall BCR is considerably higher than 1. This benefit to the region would not be realised if one or more of the countries did not implement, or delayed implementation of, the regulations. Consistency is vital for manufacturers supplying into the region and a delay could cascade through to all four countries waiting for alignment. Legislation would also ensure that ESC penetrates to all segments of the car market (including smaller vehicles). Therefore, for reasons of harmonisation, equality of protection and to maximise the stated potential to save lives, consideration should be given to coordinated implementation of an ESC regulation throughout all four countries as soon as possible.

- The benefit-to-cost ratios predicted for the VRU measures indicate these should also be implemented in the region. Once again, a delay in implementation by any of the countries would mean that the full level of benefit is not realised.

- It is recommended that Brazil immediately implement UN Regulation 95 for impact protection of car occupants in the event of a side impact, or lateral collision. The other three countries in this study have announced that they will be adopting this regulation (although the timeline is uncertain in Mexico). The best-case scenario would be for UN Regulation 95 to be harmonised across Latin America without further delay, particularly given the potential for these secondary safety measures to save lives in the region. Therefore it is further recommended that Mexico completes the implementation of crashworthiness regulations to fulfil its part in this harmonisation.

- With the implementation of any regulation, appropriate measures will be necessary to enforce compliance. This research has not investigated in detail whether substantive changes would be required to legislative vehicle safety enforcement in any of the four countries to obtain the benefits predicted. However, this need should be recognised alongside the predictions presented.

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1   Introduction

The World Health Organization estimates that the number of road traffic deaths has reached 1.35 million per year, with the highest road traffic fatality rates in low-income countries (WHO, 2018). The Global Status Report on Road Safety 2018 highlights that while vehicles in high-income countries are increasingly safe, only 40 of 175 countries (23%) have adopted the priority vehicle safety standards as recommended by the United Nations (WHO, 2018). Figure 1 shows which countries apply the major international vehicle safety standards (in green).
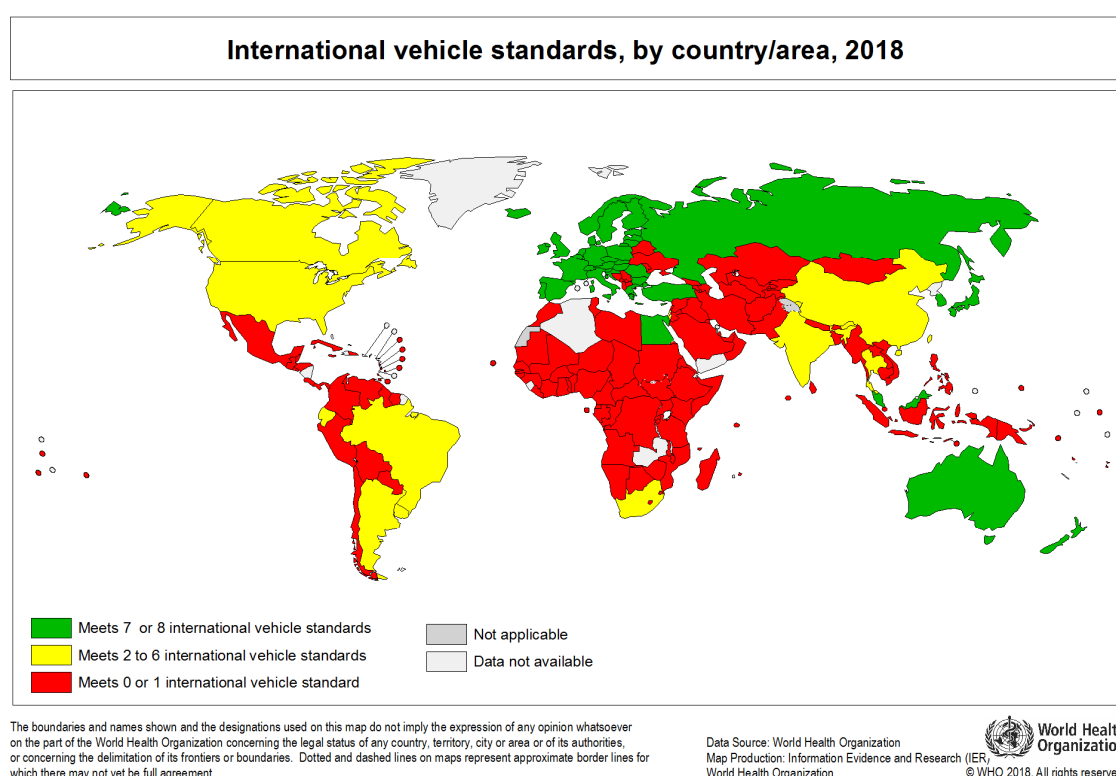
International vehicle standards, by country/area, 2018

The boundaries and names shown and the designations used on this map do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted and dashed lines on maps represent approximate border lines for which there may not yet be full agreement.

Data Source: World Health Organization
Map Production: Information Evidence and Research (IER,
World Health Organization

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Figure 1: Countries applying priority UN vehicle safety standards (WHO, 2018) [2]

The three most important safety standards are considered to be:

1. Minimum standards for crashworthiness, i.e. regulations which help to protect occupants in front and side impact crashes. This corresponds to United Nations (UN) Regulations 94[3] and 95[4].

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[2] The Global Status report on Road Safety 2018 - ISBN 9789241565684. Countries applying priority UN vehicle safety standards. Figure 15 (page 616) in the Global Status report on Road Safety (gho_road_safety_vehicle_standards_2018.png)

2. Electronic Stability Control (ESC) for crash avoidance (UN Regulation 140[5]).

3. Standards to improve safety for non-car occupants, in particular Vulnerable Road Users (VRUs) including pedestrians and pedal cyclists. These systems can be either primary safety (or crash avoidance) systems or secondary safety (or crashworthiness/ injury mitigation) systems. UN Regulation 127[6] for pedestrian protection encourages the design of more "forgiving" car fronts.

Globally, only 49 countries (27%) apply the UN frontal impact test regulation and 47 (26%) apply the side impact test regulation. Similarly, 46 countries adhere to the UN regulation for ESC and 44 for pedestrian protection. The countries applying ESC and pedestrian protection regulations are high-income countries (WHO, 2015).

In 2015 the United Nations outlined 17 Sustainable Development Goals and 169 targets, which will stimulate action over the next 15 years in areas of importance to humanity and the planet. Amongst other things, the goals aim to end poverty and hunger, combat inequality, and ensure the lasting protection of the planet and its natural resources. Road safety is part of Goal 3: ensure healthy lives and promote well-being for all at all ages. Specifically, Goal 3 sets out target 3.6: "By 2020, halve the number of global deaths and injuries from road traffic accidents" (United Nations, 2016. p.20).

In order to achieve this goal, it is clear that more needs to be done to improve vehicle safety, in particular that of passenger cars which make up the majority of the vehicle fleet in many countries. As shown in Figure 1, Latin America lags far behind the number of international vehicle safety standards seen in Europe. Whilst this figure doesn't account for local safety standards, there is still likely to be substantial opportunity for lives to be saved if harmonised minimum safety standards were applied through worldwide safety initiatives.

The UN General Assembly recently adopted a resolution welcoming 12 voluntary performance targets for road safety risk factors (United Nations, General Assembly, 2018). The proposed target of relevance to this project is:

> "Target 5: By 2030, 100% of new (defined as produced, sold or imported) and used vehicles meet high quality safety standards, such as the recommended priority UN Regulations, Global Technical Regulations, or equivalent recognized national performance requirements." (WHO, 2018)

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[3] United Nations (1995, as amended). Regulation No. 94. Uniform provisions concerning the approval of vehicles with regard to the protection of the occupants in the event of a frontal collision.

[4] United Nations (1995, as amended). Regulation No. 95. Uniform provisions concerning the approval of vehicles with regard to the protection of the occupants in the event of a lateral collision.

[5] United Nations (2017). Regulation No. 140. Uniform provisions concerning the approval of passenger cars with regard to Electronic Stability Control (ESC) Systems.

[6] United Nations (2012, as amended). Regulation No. 127. Uniform provisions concerning the approval of motor vehicles with regard to their pedestrian safety performance.

The priority UN Regulations for vehicles, as given within the proposed Global Indicator for this target, are:

- UN Regulations Nos. 94 and 95 (front and side impact protection);

- UN Regulation No. 140 (Electronic stability control (ESC));

- UN Regulation No. 127 (Pedestrian safety);

- UN Regulation No. 16 and 14 (Safety-belts and safety-belt anchorages).

1.1   Background

In 2015, TRL carried out a statistical analysis to determine how many lives could be saved in Brazil if minimum car secondary safety regulations and consumer testing programmes were applied to new vehicles (Cuerden et al., 2015). This analysis was then extended by Wallbank et al. (2016) to predict how many car user deaths and injuries could be prevented in four Latin American countries (Argentina, Chile, Mexico and, from the previous study, Brazil). The major regulations considered were UN Regulations No. 14[7], 16[8] (seat belts and their anchorages), 94 (occupant protection in frontal collision) and 95 (occupant protection in side or lateral collisions).

The results suggested that implementation of these regulations would save:

- Between 570 and 1,400 fatalities in Argentina

- Between 390 and 750 fatalities in Chile

- Between 900 and 3,500 fatalities in Mexico

- Between 12,000 and 34,000 fatalities in Brazil.

Primary safety systems (e.g. ESC) were not considered, and neither was the impact of systems designed to reduce collisions or injuries associated with VRUs.

1.2   Objectives

The overall aim of this research study is to support the adoption of minimum vehicle safety regulations for vehicles globally, using the four Latin American countries of Argentina, Brazil, Chile and Mexico as a case study. This project aims to build on the previous research to demonstrate the cost-benefit of applying regulations in this region between 2020 and 2030.

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[7] United Nations (1970, as amended). Regulation No. 14. Uniform provisions concerning the approval of vehicles with regard to safety-belt anchorages, ISOFIX anchorage systems, ISOFIX top tether anchorages and i Size seating positions.

[8] United Nations (1970, as amended). Regulation No. 16. Uniform provisions concerning the approval of:
  I.   Safety-belts, restraint systems, child restraint systems and ISOFIX child restraint systems for occupants of power-driven vehicles
  II. Vehicles equipped with safety-belts, safety-belt reminders, restraint systems, child restraint systems and ISOFIX child restraint systems and i-Size child restraint systems.

The study considers the introduction of minimum car safety standards in Argentina, Brazil, Chile and Mexico (the four countries of the study). The standards considered are:

- Approved seat belts and anchorages for all seating positions (UN Regulations 14 and 16)

- Occupant protection in frontal collisions (UN Regulation 94)

- Occupant protection in side or lateral collisions (UN Regulation 95)

- Electronic Stability Control (ESC) (UN Regulation 140 or the equivalent Global Technical Regulation, UN GTR 8[9])

- Pedestrian protection (UN Regulation 127 or UN GTR 9[10])

- Autonomous Emergency Braking (AEB) system for Vulnerable Road Users (VRU)

1.3   Content of this report

This report documents the research undertaken to determine the potential benefits and costs associated with the implementation of the regulations (as listed in the previous paragraph) in the Latin American countries (Argentina, Chile, Mexico and Brazil).

- Section 2 describes the analysis method and modelling used to investigate changes to the car occupant and vulnerable road user casualty populations.

- Section 3 introduces background population and road safety characteristics for each of the four countries. It also provides the evidence obtained on the size of the vehicle fleet and existing vehicle safety levels.

- Section 4 provides the future casualty forecasts based on the existing data regarding road traffic fatalities.

- Section 5 contains the predicted benefits associated with each of the regulatory measures.

- Section 6 contains the estimated costs associated with each of the regulatory measures.

- Section 7 brings together the estimated benefits and costs with discussion of the likely cost-effectiveness of the regulations.

- Section 8 presents the conclusions coming from this research and the implications for future regulatory changes in the four countries.

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[9] United Nations (2008, as amended). Global Technical Regulation (GTR) No. 8. Electronic Stability Control Systems.

[10] United Nations (2010, as amended). Global Technical Regulation (GTR) No. 9. Pedestrian safety.

It should be noted that during the review of road safety characteristics it was determined that by 2020 (the implementation date of interest for this study) all four countries will have already implemented the secondary safety regulations covering seat belts and their anchorages and frontal and side impact protection. The timescales for implementing the frontal and side impact protection regulations in Mexico seem unlikely now, with little time before the proposed dates; however, alternative implementation dates are not available for inclusion in the model. Therefore, the benefits of these measures are already incorporated within the 'current timeline' fatality estimates presented in Section 4.1. As a result, the sections investigating benefits (Section 5), costs (Section 6) and cost-effectiveness (Section 7) are limited to the other three regulatory measures (ESC and vulnerable road user protection through the adoption of both the pedestrian safety regulation and AEB for VRUs.

The benefits accrued from the secondary safety regulations were calculated in order to support the development of the 'current timeline' trends. The number of lives saved by implementing these regulations is provided in Appendix F. If the Mexico implementation of the secondary safety regulations is cancelled or postponed, then the figures for Mexico could reflect the lost potential in casualty savings, instead of benefit.

2   Method

The method applied for this study considers the implications for vehicle safety standards on two road user populations:

1. Car occupant fatalities and serious injuries

2. Pedestrian and pedal cyclist fatalities and serious injuries (referred to collectively as Vulnerable Road Users, or VRUs, in this report) and excluding other VRUs (e.g. motorcyclists)

Specifically, the model calculates the cost-benefit for car occupants of regulating the primary safety measure ESC (with system performance conforming to UN Regulation 13H) and the following secondary safety regulations: approved seat belts and anchorages for all seating positions (UN Regulations 14 and 16) and occupant protection in frontal and lateral collisions (UN Regulation 94 and 95).

Similarly, the cost-benefit model for VRUs estimates the impact of regulating a VRU-AEB system which prevents collisions, and the pedestrian protection regulation (UN Regulation 127) which mitigates the injuries in a collision.

It should be noted that the benefits presented in the main body of this report are limited to the economic benefits associated with reducing the number of fatalities and serious injuries, and do not account for other benefits e.g. reducing injuries that are not serious. Since the vehicle safety systems examined in this study are likely to be effective at reducing all types of injury, the results are a slight underestimate of the benefit-to-cost ratio. It should also be noted that the calculations relating to serious injuries are based on substantially more assumptions than those for fatalities due to the limited available information on non-fatal injuries in each country.

Note also that the benefits of these regulations are not necessarily distinct for the two populations. For example, it is possible that the introduction of ESC will also reduce the number of VRU fatalities and serious injuries, since it will reduce the number of drivers which lose control of the vehicle and subsequently collide with a pedestrian. However, the available casualty data from the four countries is limited, and thus information on the number of collisions of each type and potential overlapping populations is impossible to obtain. In addition, the estimate of how effective each safety feature is at eliminating or mitigating fatalities and serious injuries, is typically limited by an assumption in the analysis to the primary group of interest (e.g. car occupants in the case of ESC). As a result, two models are developed, one for car occupants and one for VRUs, and only the impact of the safety features outlined above are considered within each model. The authors acknowledge that this might lead to a slight underestimate of the benefits of some technologies when considered as individual measures. The potential for overestimation due to double-counting casualties within a package of measures is avoided with the hard assumption that no benefit can be attributed to a measure from the other target population.

2.1   Car occupant model

The main steps for the car occupant model are outlined in Figure 2. Each of these steps is described in more detail in the following sections.
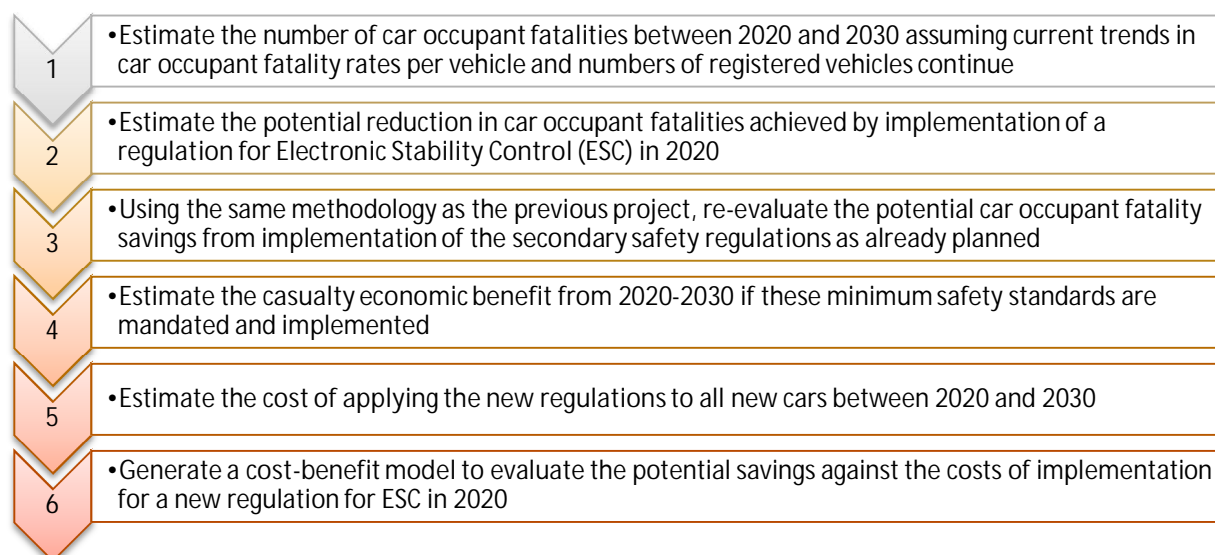
1. •Estimate the number of car occupant fatalities between 2020 and 2030 assuming current trends in car occupant fatality rates per vehicle and numbers of registered vehicles continue

2. •Estimate the potential reduction in car occupant fatalities achieved by implementation of a regulation for Electronic Stability Control (ESC) in 2020

3. •Using the same methodology as the previous project, re-evaluate the potential car occupant fatality savings from implementation of the secondary safety regulations as already planned

4. •Estimate the casualty economic benefit from 2020-2030 if these minimum safety standards are mandated and implemented

5. •Estimate the cost of applying the new regulations to all new cars between 2020 and 2030

6. •Generate a cost-benefit model to evaluate the potential savings against the costs of implementation for a new regulation for ESC in 2020

Figure 2: Modelling steps for the car occupant model

2.1.1   Baseline fatalities

Prior to estimating how many lives could be saved through implementing the vehicle safety regulations, it is important to understand how many fatalities there will likely be in each country between now and 2030 if vehicle safety standards develop as planned. These baseline fatality estimates need to account for the current regulation timeline (i.e. are any regulations planned for introduction between now and 2030?) and the proportion of the fleet fitted with each technology (e.g. through voluntary uptake of the technology driven by consumers, or through manufacturers fitting the equipment as standard on vehicles even though this is not required by regulation). This planned implementation of regulations in the current timeline, voluntary uptake of technologies and baseline estimates includes some of the regulations listed in Section 1.2.

When estimating the number of car occupant fatalities, it is important to account for levels of exposure. For example, the number of fatalities is likely to be influenced by the amount of car travel (more casualties are expected when there is more car travel) and the size of the population (more casualties are expected in countries with a higher population).

The first step to estimate these baseline fatalities was to extrapolate forwards the car occupant fatality rate. There are a number of measures of exposure which could be used for this rate, some of which are likely to be better correlated with casualty numbers than others. A hierarchy of these exposure measures is presented in Table 2.

Table 2: Hierarchy of exposure measures for car occupant casualties

Rank	Measure	Description	Comments
1	Car passenger kilometres	The unit of measurement representing the transport of one passenger by car over one kilometre	The preferred measure of exposure for car occupant risk.
2	Car vehicle kilometres	The unit of measurement representing the travel of one car over one kilometre	This takes no account of the number of passengers in each vehicle and therefore can underestimate occupant risk for vehicles with more occupants.
3	Registered cars	The number of cars registered in each country	This takes no account of how far each car is driven and therefore how much exposure to collision risk the occupants experience.
4	Population	The number of people who live in each country	This takes no account of how many people travel by car, or how far. This is a crude estimate of road safety risk.

For the four countries modelled in this report, a review of available exposure measures was conducted. Table 3 shows the exposure measures used, where measures with highest rank were prioritised over other measures available.

Table 3: Exposure measures used for the modelling by country

Country	Measure (rank)	Source
Argentina	Registered cars (3)	International Organization of Motor Vehicle Manufacturers (OICA, 2017)
Brazil	Registered cars (3)	International Organization of Motor Vehicle Manufacturers (OICA, 2017)
Chile	Registered cars (3)	International Organization of Motor Vehicle Manufacturers (OICA, 2017)
Mexico	Passenger kilometres[11] (1)	Road Passenger Transport estimates from the Organisation for Economic Co-operation and Development (OECD, 2018)

[11] Note that these figures are labelled 'passenger kilometres' and not 'car passenger kilometres' – we have assumed these figures actually represent the latter and do not include passenger kilometres by other modes (we acknowledge this may not be correct but the magnitude of the exposure measure is not actually of importance for this work, provided the trend over time in this measure is similar for car passenger kilometres).

To make the fatality predictions, the car occupant fatality rate[12] was plotted for the latest available years. The rate over recent years will account for any regulations which have already been introduced (as of 2015, the latest available year of casualty data in most countries). The fatality rate was then extrapolated forwards assuming an exponential trend[13]. This recent data does not include significant contributions to safety from frontal or side crash protection, or pedestrian protection or AEB for VRUs. However, it could include influences of existing seat belt regulations and potentially the voluntary uptake of ESC as these measures have had an opportunity to be present in collision-involved vehicles to a substantial level.

To estimate fatalities, the exposure measure was also predicted forwards, assuming a similar linear trend to that seen in recent years. Other scenarios were modelled as part of the sensitivity analysis (see Appendix D). The fatality rate predictions and the registered car/passenger kilometre predictions were combined to estimate baseline fatalities.

However, these fatality estimates do not account for any regulations that are planned between now and 2030 or are to be included in a new regulatory scenario, since the impact of these will not be evident within the current casualty trend. Table 4 outlines the timescales for each of the regulations. It contains those regulations planned for implementation as well as those already adopted into legislation.

To account for these regulations, the model combines estimates of technology effectiveness from the literature (discussed in more detail section 2.1.2 for ESC, 2.2.2 for VRU AEB and 2.2.3 for pedestrian protection) with estimates of the technology fitment within the car fleet.

These latter estimates are based on a modelling process which accounts for both:

- Voluntary uptake where the propagation of technology is led by the willingness of manufacturers to fit the necessary components to vehicles and the willingness of consumers to pay for them.

- Mandatory uptake brought about by a policy intervention. In this case, all vehicles or all vehicle types will be required to meet the regulatory requirements by an implementation date.

Further details of this modelling are given in Appendix A. Secondary safety regulations (frontal and lateral collision testing and seat belts) are also modelled, using a similar method to that applied in the previous TRL project (Wallbank et al., 2016).

The final baseline fatality estimates predict how many car occupant fatalities there will be in each year between now and 2030, assuming that nothing changes from the current regulation timeline and that road safety continues to change as it has done in recent years.

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[12] The fatality data was sourced, where possible, from in-country sources or from published summary statistics by the World Health Organisation (WHO) or the International Transport Forum (ITF). These data were converted to the standard definition (death within 30 days of the accident), as described in Section 3.2.

[13] An exponential trend was chosen since this was shown to fit the data well and ensures that the fatality rate does not reach zero (which would be unrealistic) for any country during the timescale of interest for this analysis (2020-2030).

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Table 4: Regulation (mandatory measures) timeline by country

	Pre 2015	2015	2016	2017	2018	2019	2020	2021	2022
Argentina	Installation and use of safety belts Frontal collision testing for new models Anti-lock braking systems (ABS)	Seat belt reminders in all new vehicles for the driver's position	Frontal collision testing for all new vehicles ISOFIX or LATCH in new models		Lateral collision testing for new models ESC regulation planned – now delayed ISOFIX or LATCH in all new vehicles				Lateral collision testing for all new vehicles
Brazil	Frontal collision testing (no control over conformity of production) Mandatory fitment of frontal airbags and ABS	Installation and testing of safety belts and anchorage points							
Chile	Seat belt anchorages Seat belts for the front seats ISOFIX or LATCH in all new vehicles ABS	Seat belt reminders Mandatory fitment of frontal airbags	EC Directives for front and side crash protection						
Mexico	Seat belt wearing in the front seats Seat belt safety specifications	Seat belt wearing in the rear seats	Installation and testing of safety belts and anchorage points			Front and side impact tests, ABS and Seat belt reminders for new models	Front and side impact tests, ABS and Seat belt reminders for new vehicles		

2.1.2   ESC regulations

Literature sources were reviewed to determine how Electronic Stability Control (ESC) can affect target groups of fatally injured car occupant casualties.

The literature review identified a large selection of high-quality retrospective studies on the effectiveness of ESC at preventing collisions. Arriving at a best estimate value that is representative of the range of results from these studies is not trivial, because the reported values vary widely due to different focuses regarding:

- Geographic regions (mostly USA, Australia, or European countries),

- Vehicle categories (e.g. passenger cars (US or EU definition), SUVs, LTVs, 4WDs),

- Collision types (e.g. all collisions, single vehicle collisions, rollovers, or multi vehicle collisions), and

- Collision severities (all collisions including property damage only, all injury collisions, serious, KSI or fatal).

The meta-analysis conducted by Høye (2011), which incorporates most of the relevant individual sources identified, was deemed to be the most appropriate source for a single value estimate because it reconciles the different results and increases the statistical power of estimates for smaller casualty groups. The focus of this car occupant modelling task is on fatal casualties in passenger cars (including SUVs as per the European definition of M1 vehicles). The most applicable effectiveness estimate by Høye for this focus was identified as being 38%, for a target population of cars involved in 'ESC-related' crashes. Alternative (higher and lower) effectiveness estimates are also modelled as part of the sensitivity analysis (Appendix D).

In the 'STATS19' national police-reported collision data for Great Britain, (from 2011–2015), 1,133 car occupants were killed in crashes involving 'loss of control' as a contributory factor for the car. These were classed as the 'ESC-related' target population. The sample contained a total of 3,252 car occupant fatalities, of which 2,991 occurred in crashes where a police officer attended the scene (i.e. contributory factors could be assigned). Therefore, 37.9% of car occupant fatalities (1,133/2,991) were in the target population of ESC.

However, this sample (GB, 2011–2015) was part-fitted with ESC (to the extent of about 55% according to fleet dispersion calculations), i.e. many ESC-relevant collisions have already been prevented. As per Høye (2011), ESC is assumed to be 38% effective for fatal collisions in the target population. Therefore, the number of fatalities that would have occurred without the part-fitment can be approximated as 1,432. This means the proportion of ESC-relevant car occupant fatalities (if the fleet was not equipped at all) could be as high as 43.5%.

The comparative number from the FARS national data for fatal road traffic collisions in the U.S.A. is estimated to be 26.3%. A central estimate of these two values (from GB and U.S.A.) was used for approximation to the target population for ESC effectiveness in the four Latin American countries in this study. The mean of 43.5 and 26.3% is 34.9% (the higher and lower estimates are both used in the sensitivity analysis – see Appendix D).

Applying the effectiveness value to this subset of the car occupant fatality population generates an effectiveness value for the total population of 13.3%.

2.1.3 Secondary safety regulations

Once the effect of ESC had been accounted for in the fatality estimates, the methodology applied to the previous projects (Cuerden et al., 2015 & Wallbank et al., 2016) was repeated to estimate how many lives could be saved due to the introduction of secondary safety improvements. These improvements include occupant protection in frontal and lateral collisions (UN Regulation 94 and 95) and seat belts and anchorages for all seating positions (UN Regulations 14 and 16). Note that the impact of these is modelled as a collective and the impact of the individual regulations cannot be disaggregated.

For brevity the full method is not presented in this report but full details can be found in Wallbank et al. (2016). Broadly, the method applied at this stage consists of three main tasks:

a) Evaluating the impact that car secondary safety developments in Britain have had on the reduction in car occupant casualties since 1990.

b) Identifying the baseline years in Britain that the current vehicle fleet and safety situation in the four Latin American countries most closely reflects.

c) Assuming similar secondary developments could be seen in the emerging markets following adoption of the same regulations, predicting the impact of vehicle safety changes in these emerging markets given the estimated impact in Britain and the baseline year.

Task a) developed statistical models using data from Great Britain to predict the number of car user fatalities which would have occurred if secondary safety had not improved over time. Using this model it was possible to estimate that between 2002 and 2020, improvements to the secondary safety of cars will have saved around 1,600 (11%) fatalities. It is necessary to extrapolate beyond the existing data so that the Great Britain trend can be mapped to the four Latin American countries for the whole evaluation period.

It is recognised that these models are likely to represent an underestimate of the actual casualty benefit for two reasons: firstly, improvements to secondary safety are likely to have reduced the total number of casualties as some casualties who would have previously been slightly injured in the collision are not injured in more modern cars; this reduction in total casualties cannot be incorporated within the model, leading to an underestimate of the effectiveness. Secondly, the seat belt regulation requires seat belt reminders to be installed at least for the driver's seat. These were shown to be effective in encouraging seat belt use (Lie et al., 2008), (Freedman et al., 2009) and seat belt wearing rates are lower in Latin America than seen in GB both now and at the time of implementing the frontal and side crash regulations (see Table 10 in Section 3.3). As such, if the seat belt regulation can substantially improve belt wearing in Latin America, then there would be a potentially larger benefit associated with the protection the regulations provide for belted occupants.

Task b) compared the results of Latin NCAP tests on the top selling cars in each market to historic safety levels of the fleet in Britain. The NCAP testing videos for the most popular makes and models were viewed by vehicle safety experts and classified using scoring criteria (see Section 2.2 in Wallbank et al. (2016)). This established a baseline year for each country which represents the equivalent year for vehicles in Euro NCAP (see Table 5).

Table 5: Baseline year for each country (established from previous work by Cuerden et al., 2015 and Wallbank et al., 2016)

Country	Baseline year
Argentina	2002
Brazil	2001
Chile	2003
Mexico	2000

These figures were based solely on frontal offset crash test data because this was the only crash test configuration available for many of the Latin NCAP vehicles.

Since the Wallbank et al. work was completed in 2016, study of the results published by Latin NCAP shows that the star rating for cars has no clear pattern of improvement in adult occupant protection. The adult occupant star rating awarded by Latin NCAP for cars assessed between 2010 and 2018 is shown in Figure 3; years are grouped (2010-2012, 2013-2015, 2016-2018) since there are, on average, only 12 cars tested each year.
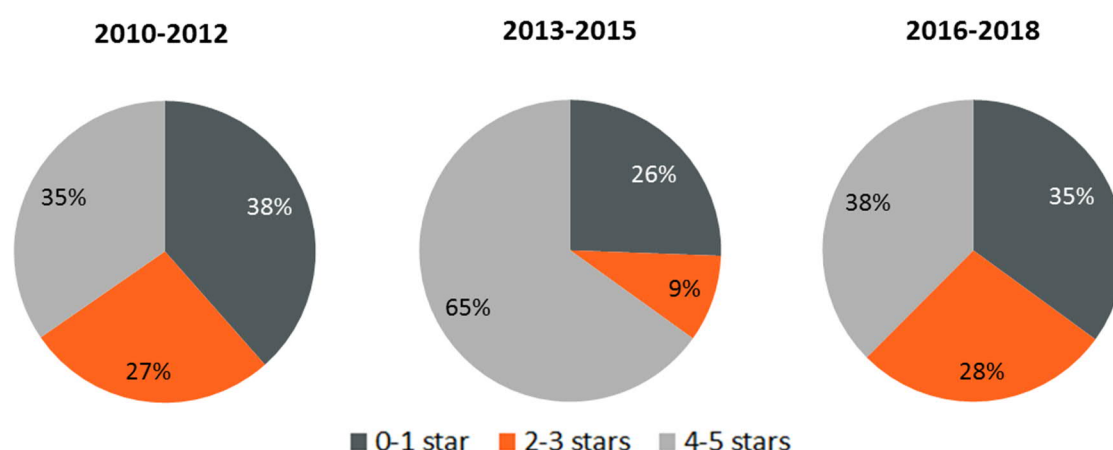

Figure 3: Adult occupant star ratings awarded for models tested by Latin NCAP by year

The distribution of star ratings in 2016-18 is similar to that observed in the early Latin NCAP years (2010-12), suggesting that there was little improvement in the adult occupant protection during this time[14]. The data suggests that that there might have been a change in 2013-15, with proportionately more 4-5 star ratings awarded to those cars tested; however, this is likely to be related to the higher proportion of manufacturer-sponsored tests (58% compared to 42% in 2010-12), since one would expect higher star ratings for the 'best' cars which these manufacturers produce and test. Evidence from the sales data for each country suggests that the most popular models sold do not reflect the models sponsored by manufacturers for Latin NCAP testing and, since these popular models have shown little change over this period, there is no evidence to suggest the baseline years have moved on substantially from the Wallbank et al. work.

That said, with proposed, but not yet implemented, regulatory timelines approaching for the frontal and lateral collision protection in Mexico[15], it seems reasonable to revise the baseline year slightly since the previous study. It is recognised that the dates for implementation (as identified in Table 4) are unlikely to be achievable now. However, the regulatory instruments are at least being discussed. To account for this intention and to help remove any false impression of accuracy, the same date was applied to all four countries and this was set to 2001. It could be inferred from this date that safety has been degraded in Argentina, Brazil and Chile since the 2016 research report. This is not the intention; although according to Latin NCAP test results, improvements are still necessary for all new cars in the region to meet the car occupant crash protection standards that applied in Europe in 2003. Instead, the implication of the 2001 date is that vehicle secondary safety in the four countries included in this study is generally 15 years behind that in Great Britain; in 2016 the standards in these countries are at approximately the same level as in Great Britain in 2001.

To account for the absence of a side impact test and differences in the fitment of front passenger and side airbags between Europe and the emerging markets, an additional baseline (1995) was also applied to all markets in the previous modelling. In this study, this figure was moved on a year (1996) to account for the progression towards regulatory requirements for lateral collision protection in Latin America. This secondary analysis offers an upper limit on the car user casualty savings which could be achieved by efficient implementation of the regulations – the results of this analysis are presented as part of the sensitivity analysis in Appendix D.

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[14] There were some changes to the Latin NCAP star rating in 2013/14 and 2016, and thus star ratings are not directly comparable over time. For instance, side impact testing was added to the adult occupant protection rating. However, this still only subjects the vehicle to the same requirements as for cars in Europe from 1997 onwards (within Euro NCAP and regulatory testing – mandatory for new models in 1997 and all new vehicles in 2003). It is not that the performance limits have been changed in response to demonstrable advances in safety performance.

[15] As stated in Norma Oficial Mexicana NOM-194-SCFI-2015.

Task c) quantified the changes in fatalities expected in each country if secondary safety regulations were introduced, taking into account the savings observed in GB, the baseline year for vehicle safety standards and the current turnover of vehicles. This involves a decision being taken as to how quickly the impact of improved safety standards will be felt. Table 6 summarises the characteristics of each vehicle fleet.

Table 6: Summary of fleet characteristics in each country

	Argentina 2015	Brazil 2015	Chile 2015	Mexico 2015	Great Britain 2001
Population	43,418,000	205,962,000	17,763,000	125,891,000	57,424,200
No. registered vehicles	13,736,000	42,743,000	4,445,000	37,354,000	29,747,130
No. registered cars	10,413,000	35,471,000	3,125,000	26,937,000	23,898,844
% of registered vehicles that are cars	76%	83%	70%	72%	80%
Growth in registered cars from previous year	3%	2%	4%	5%	3%
No. of new cars registered	481,000	2,123,000	212,000	892,000	2,431,770
% of registered cars which are <1 year old	5%	6%	7%	3%	10%
Motorisation rate (cars per population)	0.24	0.17	0.18	0.21	0.42

These data demonstrate that a similar proportion of vehicles in each country are cars (around 70-83%), and this is comparable to GB during the baseline year (80%); growth in registered cars is also similar but, compared to GB, a much smaller proportion of cars are new each year (from 3% in Mexico in 2015 to 7% in Chile in 2015 vs. 10% in GB in 2001.

Based on these data, the secondary safety savings estimated using the GB model were adjusted to account for the fact that the car fleets in the four Latin American countries are currently turning over at a slower rate than in GB during the baseline year. The savings were factored[16] to represent a 'similar timescale' where the GB casualty savings were multiplied by 45% for Argentina, 59% for Brazil, 67% for Chile and 33% for Mexico.

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[16] Factors were calculated by dividing the '% of registered cars which are <1 year old in the Latin American country' by the '% of registered cars which are <1 year old in GB in 2001'.

2.1.4 Casualty economic benefit

Once the overall reduction in fatalities was predicted as a result of the regulations, this figure was then used to estimate the potential reduction in serious injuries. The serious injury estimate is based on a simple factoring process, using national data from Great Britain (STATS19) to estimate the ratio of fatal to serious casualties in each of the relevant scenarios, and then accounting for differences in the effectiveness of ESC to mitigate fatal or serious casualties. More details on the approach taken can be found in Appendix H.

Then, in line with the methodology used in the previous study (Wallbank et al. (2016)), the valuation of a statistical life (VSL) method has been used to quantify the economic benefit of the casualty reductions predicted due to the introduction of the regulations.

VSL methods are based on a willingness to pay to avoid injury and are related to GDP per capita. These figures can be compared cross-nationally and are readily computable from health burden data. However, since the evidence on willingness-to-pay is varied, a range of estimates are produced for each country.

Bhalla et al. (2013) reviewed a number of relevant VSL studies and show that the economic loss of death due to a traffic collision has been estimated to be between 70 and 137.6 units of GDP per capita. In addition, the economic loss of a serious injury due to a traffic collision has been estimated to be 17 units of GDP per capita.

Table 7: Economic loss of death using VSL method

	Forecast GDP per capita (2018) (2018 USD) – see Figure 11	Economic loss of one death due to traffic collision (2018 USD, thousands)	Economic loss of one serious injury due to traffic collision (2018 USD, thousands)
Argentina	12,924	904 – 1,778	220
Brazil	8,807	616 – 1,212	150
Chile	14,186	993 – 1,952	241
Mexico	8,321	583 – 1,145	141

For the purposes of this analysis, the mid estimate of the two values presented for the economic loss of one death in each country was used in the analysis. The impact of the higher and lower estimates is examined in the sensitivity analysis (Appendix D).

As outlined in Wallbank et al. (2016) there is a lack of agreement in what should be included in these VSL estimates, in particular in relation to essentially unquantifiable measures such as the value of pain, grief and suffering. For example, the UK Department for Transport estimates costs (Department for Transport, 2012) to be substantially greater than those in Table 7 (around $ 2.8 million) and therefore these should be interpreted with some care.

2.1.5   Costs of the regulations

The requirements included within the secondary safety regulations for car occupant safety will place a burden upon vehicle design. As mentioned in Section 2.1.3, the regulations being considered are those associated with occupant protection in frontal and lateral collisions (UN Regulation 94 and 95) and seat belts and anchorages for all seating positions (UN Regulations 14 and 16). These safety measures will require specific design features for the following elements of a car:

- The seat belt (three-point) and a locking retractor

- The anchorages for the seat belt, their geometry and the local strength of the structure around the anchorage

- A seat belt reminder for the driver (as required in UN Regulation 16)

- Potential inclusion of a seat belt load limiter and pretensioner (not strictly necessary to comply with UN Regulations 94 and 95, but necessary to meet industry norms in Europe and other regions and also for enhanced real-world performance)

- Airbags (in front of, and to the side of, the front seat occupants)

- Additional strength through the 'A-pillars' (the two foremost pillars, in front of the occupants, extending from the chassis of the car to the roof)

- Managed load paths from the front of the car back to the occupant compartment

- Additional strength in the side sills and door frames and the doors

- Additional strength in the 'B-pillars' (the second row of pillars from the chassis to the roof, between the first and second row of seats)

Published information about the cost of these design features was sought from the literature. It was the intention of the research to find a price indicating the cost of adding these elements to a vehicle design which did not meet the regulatory requirements (that is the cost for making a non-compliant vehicle become compliant). In response to this search, insight came from studies commissioned by the U.S. Department of Transportation, National Highway Traffic Safety Administration (NHTSA) alongside implementation of Safety Standards in the U.S. These studies are extremely thorough in their approach to costing estimates. Vehicles are stripped down to individual components and any new or modified parts are then priced taking into account material, manufacturing, commercial contributions, etc. Prices are intended to be representative of the industry rather than coming from a single manufacturer. A limitation is that the prices come from U.S. cars rather than vehicles in the four countries considered for this study. It is not known what bias this may create, or if costs are broadly equivalent between these two regions, but it is assumed that U.S. prices are likely to be conservative (higher than in the four countries) for most of the elements contributing to the cost. Where several prices were available for the same element, a mean value was derived before treating for inflation.

Whilst the detail of the NHTSA studies is peerless, some are becoming quite dated now; so to create an equivalent value for comparison between costs, and also with calculated benefits, all prices were inflated to 2018 values. An inflation calculator internet site was used for this purpose[17]. At the extreme, the influence of inflation was to more than triple the cost of seat belts, from the original value provided in 1978 to present value for 2018. It should be noted that the automotive sector may have seen different inflation rates (above 'all good's up to the early 1980s and below 'all goods' afterwards), so it is likely that this inflation process is conservative (yielding higher predicted costs than may actually occur).

In contrast to this general trend for inflation, discounting was also applied to account for learning effects and production efficiencies in responding to the regulatory requirements. The majority of the manufacturers selling cars in Latin America will be operating high-volume manufacturing. Therefore, based on the practice applied by agencies such as NHTSA[18] and the U.S. Environment Protection Agency in past regulatory cost-effectiveness evaluations, cost reductions through learning by doing (accumulated production volume and small redesigns that reduce costs) were applied to the initial cost estimates. In particular, a 20% reduction was assumed for all technologies over three years old. This was reduced to 16% for a 2016 valuation of three-point seat belt requirements and was increased to 90% for airbags (based on observed progress with airbag technology and an economic analysis (Abeles, 2004)).

The car occupant elements where a cost was obtained from the literature are shown in Table 8. Summing these elements yields a total cost per vehicle of $ 1,116. This value was calculated using the Consumer Price Index as the measure of inflation. To illustrate the influence of using an alternative inflation measure, the last column shows the equivalent costs with inflation based on new vehicle sales (U.S. Bureau of Labor Statistics, 2018). The effect on the total cost of these safety measures is to bring the total down to 63 % of the total based on CPI.

It should be noted that a consumer cost[19] of $ 1,116 per vehicle is unreasonably high. This represents about 10% of a vehicle's retail price for small cars; sometimes more, for the base model of some new small cars in Mexico or Chile. Given the sustainable way in which these additional elements have been added to vehicles in other world regions, then such an increase in price is unrealistic. Recently, NHTSA estimated that the total cost of safety technologies that are linked to all of the FMVSS {Federal Motor Vehicle Safety Standards} added an average of $1,929 (in 2012 dollars) and approximately 7.6 percent of the cost and 5.1 percent of the weight of a model year 2012 passenger car in the U.S. (Simons, 2017). This would also support the reasoning that the small subset of additional technologies considered within these regulatory measures should not cost the consumer as much as

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[17] http://www.usinflationcalculator.com/

[18] https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/fmvss/DEIS_Appx_C.pdf

[19] According to the NHTSA definition, the consumer cost includes materials, labour, tooling, assembly, overhead, manufacturer's and dealer's mark-ups and taxes. The cost of a specific post-Standard model's component subsystem, minus the cost of a corresponding pre-Standard model's subsystem, equals the incremental consumer cost.

$ 1,116. However, these are the numbers obtained from the literature and hence represent the best, referenceable, estimates of cost. Further discussion of this issue is provided later, in Section 6.3. Ultimately, these costs were not assigned to new interventions as the regulatory requirements are already being implemented or are planned for implementation in the four countries.

Table 8: Cost of secondary safety elements for car occupant protection

Item	Cost in literature (USD, $)	Source	Cost (2018 USD, $)	Cost, automotive linked CPI ($)
Front seat belts	46.46	(McLean et al., 1978)	147	71
Driver's seat belt reminder	7.5	(McCarthy and Seidl, 2014)	6	6
Rear seat belts	10.92 for VW Passat 25.13 for Ford F-150 26.00 for Hyundai Santa Fe	(Dailey, 2016)	3 x 18 = 54	51
Airbags	323.42 for Asian sedan	(Dang, 2008)	38.5	35
Side impact structure	494 for Honda Accord 720 for Ford Taurus 764 for GM Saturn	(Fladmark and Khadilkar, 1997)	832	542
Total for secondary safety elements			1,116	705

An equivalent cost was sought for the fitment of ESC to a car. Again a teardown study for the U.S. National Highway Traffic Safety Administration (NHTSA) provided this cost of $ 111, which is reported in the introduction to the UN GTR. With inflation to 2018 prices and application of a 20% learning effect, the cost attributed to fitting ESC to a car was $ 102 per vehicle. However, the minimum cost for a system in that teardown study was $ 36.76 per vehicle, in 2018 prices. It could be argued that if a system was available in 2005 for this price then it is reasonable to expect that the same is true for 2018. However, industry advisors recommended that a consumer cost of about $ 50 should be used to represent the current industry prices and practices. Based on this advice a central estimate of $ 50 has been adopted for the cost of fitting an ESC system to a car already equipped with ABS. The outlying figures of $ 36.76 and $ 102 have been incorporated in the sensitivity analysis (as documented in Appendix D).

2.1.6   Cost-benefit model

To assess the value of implementing the regulations and associated safety measures then it is necessary to compare the benefits with the costs. The final component of the model therefore brings together both the predicted benefits and costs. These are compared using a benefit-to-cost ratio, where the benefit value is divided by the cost. In these circumstances:

- A value of less than 1 indicates that the cost of the measure exceeds the monetary valuation of benefits

- A value of exactly 1 reflects the breakeven point where benefits to costs are balanced evenly

- A value of greater than 1 indicates that the benefits outweigh the costs, and it is these measures which become most easily recommended for implementation

For predictions of future benefits it is important to note that discounting has been applied (Appendix E). This represents the concept that, generally, people prefer to receive goods and services now rather than later.

Finally a sensitivity analysis is included in the modelling to investigate whether any of the inputs are overly influential on the outputs (Appendix D). It also supports a quality check as to the confidence level which is appropriate given the limitations of some of the input data and assumptions.

2.2   VRU model

The main steps for the VRU model are outlined in Figure 4. These broadly align with those used in the car occupants models described in Section 2.1.

1 • Estimate the number of pedestrian and pedal cyclist fatalities between 2020 and 2030 assuming the current regulation timeline for each country is applied

2 • Estimate the potential reduction in pedestrian and pedal cylist fatalities achieved by implementation of a VRU Automatic Emergency Braking (AEB) system in 2020

3 • Estimate the potential reduction in pedestrian and pedal cylist fatalities achieved by implementation of a regulation for pedestrian protection in 2020

4 • Estimate the casualty economic benefit from 2020-2030 if these minimum safety standards are mandated

5 • Estimate the cost of applying the regulations to all new cars between 2020 and 2030

6 • Generate a cost-benefit model to evaluate the potential savings against the costs of implementation

Figure 4: Modelling steps for the VRU model

2.2.1   Baseline fatalities

As with the car occupants model, baseline fatality estimates were also required for pedestrians and pedal cyclists. These estimates account for the current regulation timeline and uptake of technologies into the fleet.

To estimate this, the trend in the casualty rate (e.g. pedestrian fatalities per population[20]) was extrapolated assuming an exponential trend[13,21,22] and the influence of the regulations (in this case VRU AEB and pedestrian protection) were estimated using the same modelling method as for car occupants – this is described in detail in Appendix A.

As such, the extrapolation of the baseline fatalities provides a target population for the pedestrian safety measures to influence. In this case, the total numbers of pedestrians and pedal cyclists killed in road traffic collisions are the target groups. The next step in the model was then to establish the potential effectiveness of either Autonomous Emergency Braking, which detects and responds to Vulnerable Road Users (VRUs, including pedestrians and pedal cyclists), or conventional passive protection provided by changes to the geometry and stiffness of car fronts.

2.2.2   VRU AEB

A literature review was conducted to establish the reported effectiveness of Autonomous Emergency Braking (AEB) for Vulnerable Road Users (VRUs). A systematic process was adopted for this review. The process and search findings are documented in Appendix B.

To summarise, 193 potential sources of information were identified, but after filtering based on direct relevance, only 8 remained. This is likely to reflect the fact that AEB for VRUs is a relatively recent technology, one where detailed implementation strategies are protected by manufacturers and their suppliers and hence only analysed in forward-looking (predictive benefit) research projects. After critical appraisal four sources were excluded and only four sources were deemed to provided relevant effectiveness estimates of a suitable quality. The review of these four sources is provided in Appendix B, Section B.6.

The paper by (Rosen, 2013) was the primary source which provided the estimates used in the modelling. In particular, Rosen predicted that AEB for VRUs could be effective in preventing fatal injuries occurring for 48% of the pedestrian casualty population and 55% of the fatally injured pedal cyclist population. Alternative (lower) effectiveness estimates are modelled are part of the sensitivity analysis (Appendix D).

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[20] Note that population was used as the measure of exposure for pedestrians and pedal cyclists since no exposure data were available on the number of walking trips, number of pedal cycles or distance travelled using each mode in the four countries.

[21] Note that Argentina is the exception to this, where a logarithmic trend was applied instead because this gave more plausible predictions based on the current trend.

[22] As with the car occupants model, alternative trends were investigated as part of the sensitivity analysis (Appendix D).

Application of these percentages to the baseline fatality numbers allows the model to calculate the number of lives saved each year by complete implementation of the regulation. However, not all cars in the regions will have AEB for VRUs fitted. Therefore an additional step was needed again to predict the proportion of the car fleet that would have the necessary technology fitted. The process for this was mentioned in the car occupant model, in Section 2.1.1, but is described in detail within Appendix A.

2.2.3 Pedestrian protection regulation

As with AEB for VRUs, another literature review was used to determine the effectiveness of secondary safety measures for pedestrian protection. In particular, this concerned the changes to vehicle front-end design necessary to meet the requirements of UN Regulation 127 and GTR No. 9.

Appendix C describes the review undertaken and the findings generated. For this passive pedestrian protection 534 potential sources of information were identified based on the search terms. However, only 40 appeared to be relevant after reviewing the abstracts and only 10 were critically appraised with suitable methodological quality. Subsequently, only four sources were deemed to provide relevant effectiveness estimates that could be applied to the population of fatally injured VRUs and were of a suitable quality. The review of these four sources is provided in Appendix C, Section C.6.

Unlike AEB for VRUs, the implications of the regulation for vehicle design are very well understood, given that regulations have been in place for Europe and Japan for more than ten years. It was then surprising to find no formal retrospective analysis has been carried out to determine the effectiveness of this legislation. Instead, prospective studies were identified. In particular, European research was obtained showing the potential effectiveness of the phases of EC Directives on pedestrian protection (Hardy et al., 2006). Also, the UN GTR provides estimates of its effectiveness throughout Europe and other world regions. This latter information has been generated by contributors to the informal working groups developing the GTR and supports the general values provided in the regulatory preamble.

Given that the prospective effectiveness prediction from Europe falls within the range stated for the GTR, then this was used for the modelling. A value of 3.9% effectiveness was justified for the pedestrian fatality population and 1.4% for pedal cyclists killed in road traffic collisions. Alternative (both higher and lower) effectiveness estimates are modelled as part of the sensitivity analysis (Appendix D).

These values may seem low compared with the other technologies investigated in this research. However, this reflects the points that:

- Not all pedestrian fatalities are caused by cars

- Not all pedestrian fatalities are caused by the fronts of vehicles

- The regulation focuses on the central area of the vehicle front

- The regulation excludes the vehicle components that were not considered feasible to include (at the time the regulation was developed, e.g. the windscreen surround, the windscreen, and the bonnet leading edge).

- Some injuries will occur from secondary contacts with the ground or other parts of the vehicle or other vehicles.

- Improving protection levels will reduce the impact severity of a collision, but might not improve the outcome (e.g. very high severity collisions are still likely to be fatal).

Accounting for all these aspects leads to the small effectiveness claims made in the regulation and earlier research work.

2.2.4   Casualty economic benefit

As for the car occupant model, the predicted reduction in fatalities among VRUs was used to estimate the potential for reducing serious injuries, using the approach described in Appendix H. Then, the same VSL approach was used for the pedestrian and pedal cyclist casualties as was used for car occupants (see Section 2.1.4). Table 7 shows the figures used for the economic benefit calculations completed at this step.

2.2.5   Costs of the regulations

As for the car occupant model, there is the provision in the VRU model to account for the costs associated with the implementation of AEB for VRUs and regulatory requirements on secondary safety pedestrian protection.

Recent discussions surrounding the General Safety Regulation review for the European Commission have derived the 'per vehicle' implementation cost for AEB for VRUs (Seidl et al., 2017). This was built on inferences from a NHTSA cost and mass analysis for forward collision warning systems and related braking systems for light vehicles (Ricardo Inc., 2012). The range of values derived for that study was € 186 to € 249 assuming that no existing AEB system was present. Taking the central point gives the value for AEB for VRU of $ 261 per vehicle which has been used in this model.

Costs for changes to a vehicle necessary to comply with the pedestrian protection requirements of UN GTR No. 9 have also been established via a NHTSA teardown study (Waltonen Engineering, Inc., 2014). The basic cost was around $ 300 per vehicle (in 2012 USD). After inflation and discounting for the learning effect, then the cost used for passive pedestrian protection measures was $ 258 per vehicle.

2.2.6   Cost-benefit model

The same approach was used in the VRU model as in the car occupant model for comparing cost and benefit estimates and providing a benefit-to-cost ratio.

A similar process was also used to investigate the sensitivity of the model outputs to variations in inputs and the assumptions used to generate them.

3   Core data

This section presents the core data used for the modelling. It summarises the current trends in population (Section 3.1), road accident fatalities (Section 3.2) and the vehicle fleet (Section 3.5) for each country. It also provides an overview of road safety developments related to specific user groups (Section 3.2) and summarises the recent changes to vehicle safety legislation (Section 3.5.4).

3.1   Population data

Figure 5 shows how the population of each country has changed between 1950 and 2015.
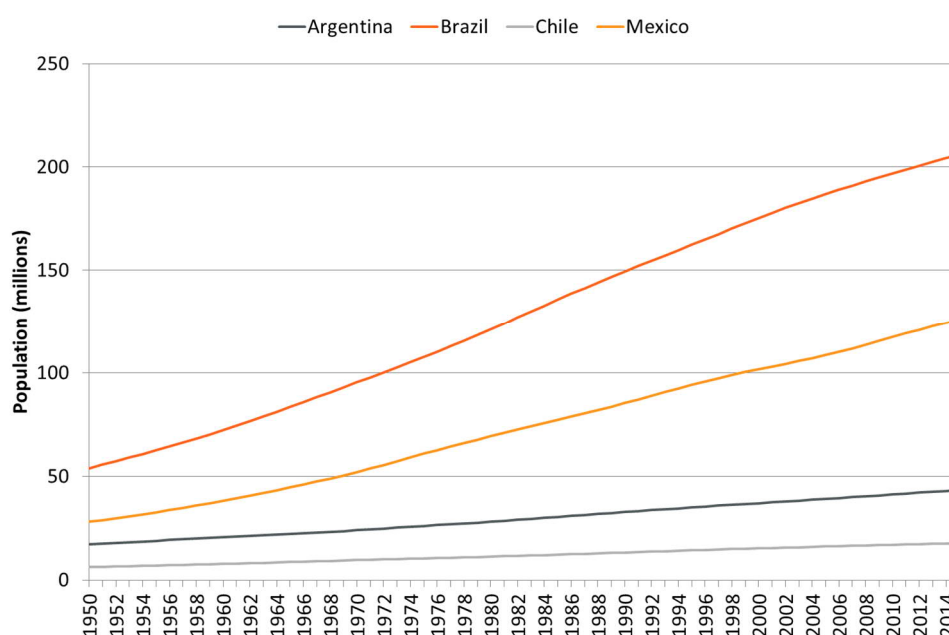
Figure 5: Population of Argentina, Brazil, Chile and Mexico, 1950-2015 (United Nations, Population Division, 2017)

In all four countries the population more than doubled between 1950 and 2015 and in Mexico, the population was over four times higher (28 million to 126 million). The rate of growth in all four countries has slowed in recent years with an annual increase from 2014 to 2015 of 1.0% in Argentina, 0.9% in Brazil, 0.8% in Chile and 1.3% in Mexico.

The UN makes a range of projections for population growth, based on a number of different assumptions about fertility rates, mortality and migration. The following variants have been selected as the best option for each country, based on the current trends in each country:

- Argentina and Mexico: medium variant (i.e. medium fertility rate[23], normal mortality and normal migration)

- Brazil and Chile: low variant (i.e. low fertility rate[24], normal mortality and normal migration)

Full details of the definitions for these variants can be found in 'World Population Prospects The 2012 Revision' (United Nations, 2013). Other variants are tested as part of the sensitivity analysis (see Appendix D).

Figure 6 shows the predicted population growth in each country under these variants.
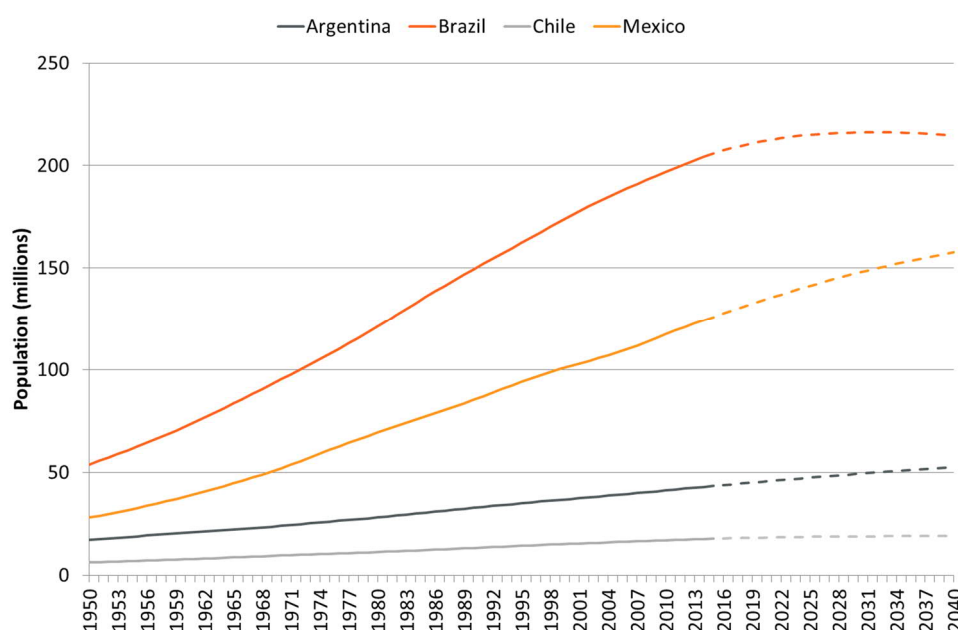
Figure 6: Predicted future population of Argentina, Brazil, Chile and Mexico, 1950-2040 (United Nations, Population Division, 2017)

3.2   Road accident fatality data

Across the world there are many different definitions regarding how road traffic fatalities are counted. For example, within the four Latin American countries studied in this project the definitions are as follows:

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[23] Medium-fertility countries are defined as those where fertility has been declining but whose estimated level is above the replacement level of 2.1 children per woman in 2005-2010. In 2005-2010 Argentina had a rate of 2.35 and Mexico had 2.29.

[24] Low-fertility countries are defined as those with total fertility at or below the replacement level of 2.1 children per woman in 2005-2010. The figure for Brazil was 1.78 and Chile was 1.82.

- Argentina: death within 30 days of the collision

- Brazil: death any time after the collision (as a result of the injuries sustained)

- Chile: death within 24 hours of the collision

- Mexico: death any time after the collision

The widely recognised 'official' definition is death within 30 days, and 100 countries across the world now adopt this practice (WHO, 2018).

As a result of the differences in the definitions, reported fatality data from different countries are not directly comparable without some adjustment. For the purposes of this study, fatality data from Brazil, Chile and Mexico have been adjusted to present fatality numbers at 30 days. The adjustment factors used are 0.97 for Brazil and Mexico and 1.30 for Chile (Iaych, n.d). Figure 7 shows the adjusted road accident fatality figures for each country. Where national data existed, different sources of information were used to supplement the World Health Organization and OECD International Transport Forum reports in order to obtain as much data as possible for the trend analysis.

Comparing the latest available year of data to 2005 shows that the number of fatalities has increased in all four countries. This increase was largest in Brazil (22%) and Argentina (20%) and relatively small (1%) in both Chile and Mexico.

The four countries have very different populations (as shown in Figure 6) and hence in order to compare the fatality numbers it is important to account for these differences. Figure 8 shows how the fatality rate per 100,000 population compares across the four countries.
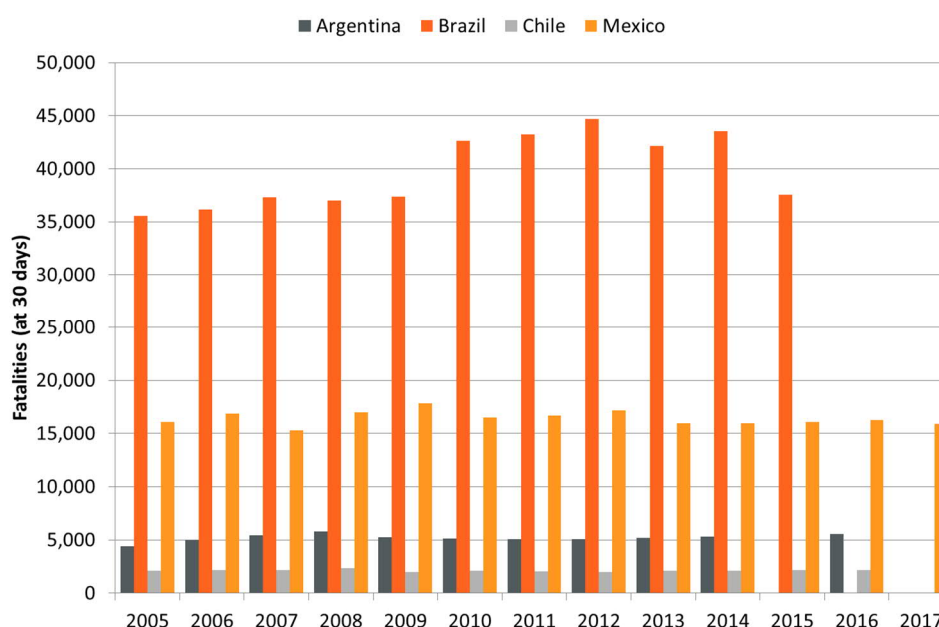
Figure 7: Number of road accident fatalities (at 30 days) in Argentina (OECD/ITF, 2017a) (WHO, 2018), Brazil (WHO, 2016), Chile (CONASET, 2017) (WHO, 2018) and Mexico (INEGI, 2017), 2005-2017 (where data available)
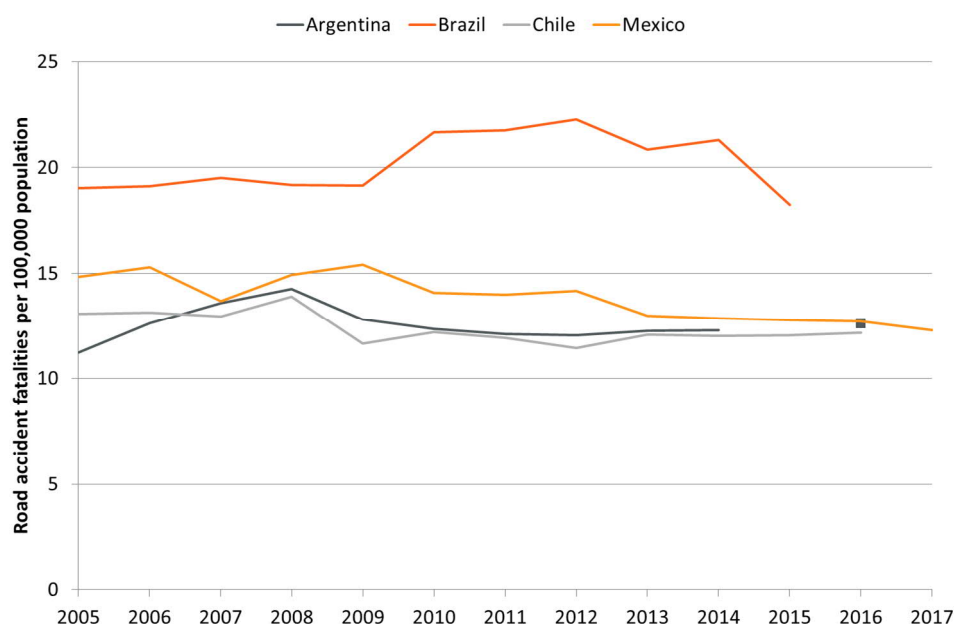
Figure 8: Road accident fatalities per 100,000 population in Argentina, Brazil, Chile and Mexico, 2005-2017 (where data available)

Brazil has the highest number of fatalities per 100,000 population and this figure has been increasing in recent years, until 2015 when there was a decrease compared with 2014. The fatality rates for the other three countries are similar (around 120-130 per million population) and have remained relatively unchanged since around 2010.

Figure 9 shows the distribution of fatalities by road user type. The distribution of fatalities differs substantially by country, although car occupant fatalities are a relatively large group, particularly in Argentina and Chile. Argentina and Brazil have a large number of motorcyclists (30% and 28% respectively) and the literature suggests that motorcycle safety is an increasing concern in Latin America:

- In Argentina the motorcycle fleet more than doubled in 5 years, and the number of motorcyclists killed increased by 46% from 2010 to 2014. Since 2012 the safe interaction between pedestrians, cyclists and motorcyclists in urban areas has become a priority (OECD/ITF, 2016). Measures with safety improvements transferable to the motorcyclist group are likely to be especially valuable under these conditions.

- A similar trend has been seen in Chile: since 2010 the number of motorcyclists killed increased by more than 45%, while the number of motorised two-wheelers increased by 64%. In 2014, the government launched a national plan to improve the safety of motorcyclists (OECD/ITF, 2016).

- A study in Pelotas, Southern Brazil showed that although motorcycle use is widespread in the population, 40% of motorcycle users surveyed reported not properly using the helmet strap. However, despite these findings, the report

concludes that increasing number of motorcycles has not been followed by public policies focussing on this specific vehicle (Seerig et al., 2016).

- In Mexico, between 2010 and 2015, the number of motorcyclists killed increased by more than 79%. This aligns with the 78% increase in the number of motorised two-wheelers during the same time frame (Statistica, 2017). It may be that decreases in car use and car occupant fatalities have been accompanied by a concomitant increase in motorcycle use and motorcyclist fatalities.
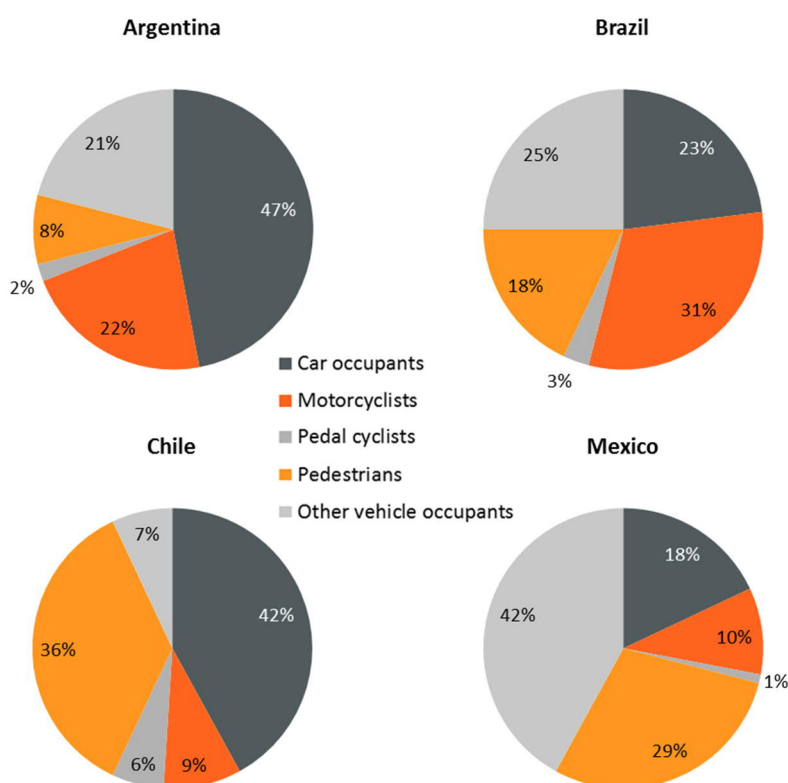
Figure 9: Distribution of road accident fatalities by road user type in Argentina, Brazil, Chile and Mexico, 2016 (WHO, 2018)

Compared to the other countries, Figure 9 shows that Chile and Mexico have a high proportion of pedestrian fatalities (36% and 29% respectively). In Argentina, the number of pedestrians killed increased by more than 72% since 2010; increases in the number of vehicles and a lack of specific policies targeting this group are important influential factors in this trend (OECD/ITF, 2016).

Pedal cyclists make up a small proportion of total fatalities (6% in Chile but fewer in other countries). The OECD/ITF Road Safety Annual Report (2016) highlights that cycling is growing in popularity in Chile, and in response to this growth the National Road Safety Commission (CONASET, Comisión Nacional de Seguridad de Tránsito) has implemented a number of awareness campaigns.

In Brazil and Mexico there are large proportions of road traffic fatalities reported as being "Other vehicle occupants". For Mexico it was determined that the "other" category (42%) included the drivers and passengers of buses and goods vehicles, as well as 42% assigned with an "other road transport" road user category (INEGI, 2017). Since it is not clear which road user group these should be assigned too, within the model these fatalities were redistributed proportionately between the other categories (for Brazil and Mexico).

3.3 Road safety developments

There are a number of factors influencing road safety in each country including infrastructure developments, the extent of open highway versus city driving, road safety initiatives (e.g. education, changes to laws or the level of enforcement), changes to the level of exposure to collision risk, the economy and vehicle fleet/safety changes. This section (and subsequent Sections 3.4 on the economy and 3.5 on the vehicle fleet/vehicle safety) highlights some of the recent developments in each country which may have influenced the casualty trends seen in Section 3.2.

Infrastructure developments include (OECD/ITF, 2017a):

- In Argentina, since 2011 a total of 37,855 kilometres of road were surveyed by the National Road Safety Agency (ANSV) to determine their risk level. The ANSV is now working together with the National Road Direction (DNV) to carry out road safety audits and to survey road sections, which in turn will enable the implementation of road safety improvements.

- In Chile, there is now a greater vehicle concentration in the main cities and as a result, congestion is increasing, especially during rush hours. Infrastructure is being developed and new public transportation alternatives are under construction to help mitigate this.

- In 2015/16 analysis was conducted to assess the performance and condition of the federal highway network in Mexico using the methodology of the international road assessment programme (iRAP). This has resulted in the development of an investment plan for safer roads. The iRAP Mexico project has helped address significant road safety problems and identify appropriate solutions (e.g. road signs on a vertical pole and road markings). Several important infrastructure improvement projects are now being carried out including the installation of protective barriers, improved intersections, pedestrian bridges, bus stops, road markings, and emergency escape roads for runaway vehicles.

Other road safety initiatives (those listed relate specifically to Chile) include (OECD/ITF, 2017a):

- Changes to the driving licence procedure in 2014, with new theoretical and practical exams.

- The adoption in September 2014 of "Emilia's Law" which increases the severity of punishment for drunk drivers who cause serious injuries or death.

- In August 2015, the Ministry of Transportation and Telecommunications submitted a bill to congress that proposes reducing the urban speed limit from 60 to 50 km/h, bringing the default speed limit in these areas in line with most IRTAD countries.

Despite this, Chile still has amongst the highest speed limits in the Latin American countries – see Table 9.

Table 9: Speed limits for passenger cars, 2017 (km/h) (OECD/ITF, 2017a)

Country	Urban areas	Rural roads	Motorways
Argentina	40-60 (Buenos Aires City has a range of 20 to 70 km/h speed limits)	110	120-130
Brazil	unknown	unknown	unknown
Chile	60 (50 proposed)	100	120
Mexico	10-80	50	110 (100 on high-speed roads)

In addition, in Mexico since 2009, the health agency has promoted and strengthened strategic action against drunk driving with four times as many checkpoints set up in 2016 than in 2010 (OECD/ITF, 2017a).

Table 10 summarises the differences in drink drive regulations (blood alcohol content, BAC, for prosecution), seat belt regulations, helmet and mobile phone laws for each country. In summary:

- Brazil followed by Chile has the strongest drink drive regulations (and biggest penalties).

- Seat belt regulations have been implemented for both front and rear seat passengers in all countries, although wearing rates tend to vary (both by country and seating position) – all are lower than observed in GB (98% for drivers, 96% for front seat passengers and 81% for adult rear seat passengers in 2014 (DfT, 2015)).

- Helmet laws typically apply to motorcyclists (although not to moped riders in Chile) but the same cannot always be said for pedal cyclists.

- Hand held mobile phone use whilst driving is illegal in all four countries.

Finally, the literature revealed some specific facts about road safety strategies in the four countries, which provide some useful context for this study (OECD/ITF, 2016):

- The Argentina Road Safety Plan is based on the pillars recommended by the UN Decade of Action for Road Safety. Road safety targets are being developed.

- The Chilean Government has launched an ambitious development agenda that is the basis for the country's ultimate goal of achieving a high-income developed status by 2018. The government are currently developing a new National Road Safety Strategy, which will be based on the five pillars of the Global Plan for the Decade of Action for Road Safety 2011-20.

- In 2011 Mexico launched its National Road Safety Strategy 2011-20. Its main target is to reduce by 50% the number of fatalities and to reduce as much as possible injuries and disabilities due to road crashes.

- In Brazil, although there are several thematic plans, there is not a national road safety strategy (OECD/ITF, 2017b).

Table 10: Drink drive regulations, seat belt regulations, helmet and mobile phone laws by country (wearing rates, where available)

| | Drink drive regulation BAC (g/l) (OECD/ITF, 2017b) [BAC for professional drivers (OECD/ITF, 2017a)] | Drink drive penalty options (OECD/ITF, 2017b) | Seat belt regulation year of introduction (OECD/ITF, 2017b) [wearing rate, latest available data (OECD/ITF (2017a) or (2017b))] | | Helmet law (OECD/ITF, 2017b) [wearing rate, latest available data (OECD/ITF (2017a) or (2017b))] | | Law on mobile phone use (prohibiting hand held) (OECD/ITF, 2017b) |
			Front seat	Rear seat	Motorcyclists	Pedal cyclists	
Argentina	≥0.5 [>0.0 (anything over 0.0 for professional drivers]	$250-1200 fine (indexed on the price of petrol) Up to 12 hour imprisonment	1995 [50% driver in 2016]	1995 [23% in 2016]	Yes (for both mopeds and motorcycles) [65% drivers, 44% first passengers, 22% additional passengers in 2016]	No	1995
Brazil	Between 0 and 0.6	$930-1860 fine 12-24 months licence withdrawal Vehicle seizure	1997 [79% in 2013]	1997 [50% in 2013]	Yes (for both mopeds and motorcycles) [83% for drivers, 80% for passengers in 2013-14]	unknown	1997
	≥0.6	$930-1860 fine Up to lifelong licence withdrawal 6 months to 3 years imprisonment Vehicle seizure					
Chile	Between 0 and 0.3	$65-300 fine 3 months licence withdrawal	1991 [76% drivers, 59% passengers in 2015]	2002 [14% in 2015]	No (for mopeds) Yes (for motorcycles) [99% for drivers, 98% for passengers in 2016]	Yes, in urban areas	2005
	≥0.3	$500-1200 fine Lifelong licence withdrawal 3 to 10 years imprisonment					
Mexico	≥0.8 [>0.3 - may vary by state]	$40-2000 fine 12-32 hours imprisonment Administrative arrest (in some areas)	2012 for urban roads & 2015 for federal roads [54% in 2016]	2012 for urban roads & 2015 for federal roads [21% in 2016]	Yes (for mopeds in 26/32 federal states) Yes (for motorcycles) [82% for drivers, 57% for passengers in 2014]	No	2003

3.4 The economy

It is well recognised that the economy influences road safety (Wegman et.al., 2017 & IRTAD/OECD/ITF, 2015). Wegman et al. (2017) investigated the causal mechanisms for the reduction in road accident fatalities in OECD countries during the economic recession which started in 2008. This paper concludes that the principal mechanisms bringing the reductions observed are a disproportionate reduction of driving among high-risk drivers (in particular young drivers) and a reduction of fatality rate per kilometre of travel probably related to changes in driver behaviour. However, other plausible mechanisms include changes to traffic volumes, reductions in new car sales and changes to the expenditure on road infrastructure (IRTAD/OECD/ITF, 2015).

The most widely recognised measure of the economy in a country is Gross Domestic Product (GDP). Figure 10 shows how this measure has changed in each country over the period 1960 to 2016.
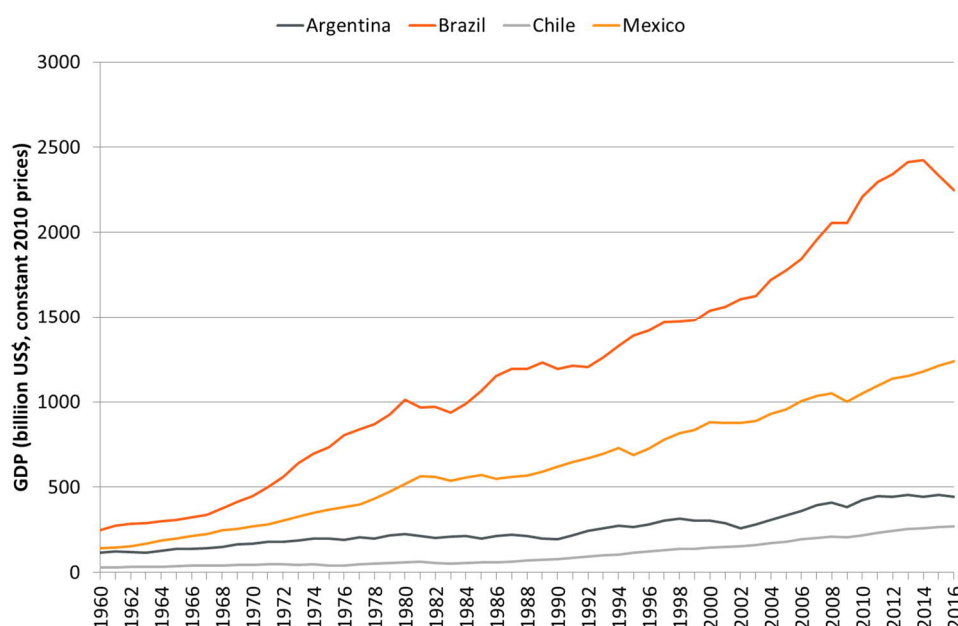
Figure 10: GDP (in constant 2010 US$) in each country (1960-2016) (World Bank group, 2018)

In all four countries GDP has been growing but this has fallen in recent years for Brazil, aligning with the country entering a period of recession. The recession ended in 2017 (Financial Times, 2017) and GDP is forecast to continue to grow in all four countries (Figure 11). The GDP forecast has been calculated using World Bank growth estimate figures until 2020. The geometric mean of the growth rate between 2000 and 2020 has been calculated and used as the constant growth rate from 2020-2030. This describes the calculation method adopted for this study, though it is recognised that other projections of economy exist focussing on different points in the future and may be slightly different in the period to 2030.
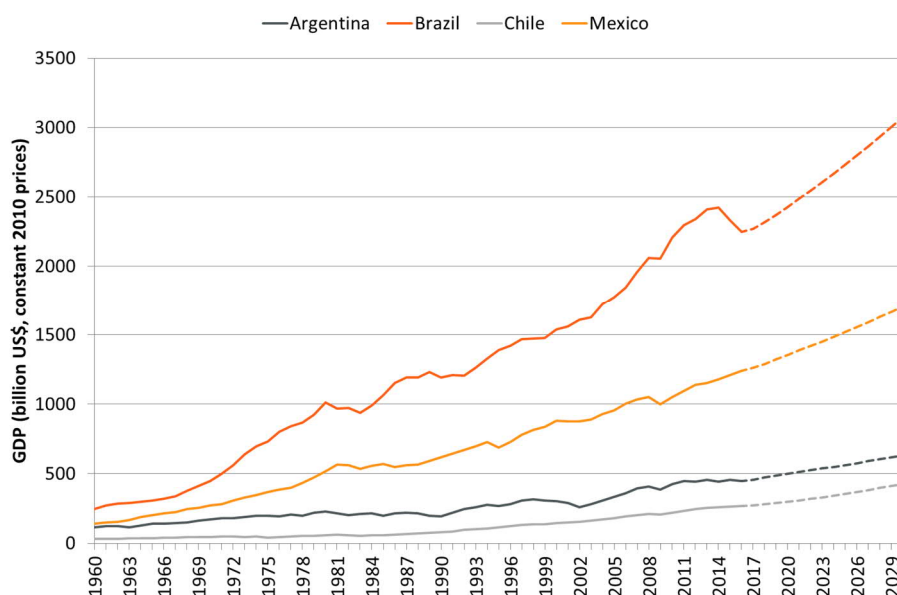
Figure 11: Forecast GDP (in constant 2010 US$) in each country (1960-2030) (calculated using the World Bank Group, 2018 data from 1960-2016)

3.5 Vehicle fleet and vehicle safety

3.5.1 Registered vehicles

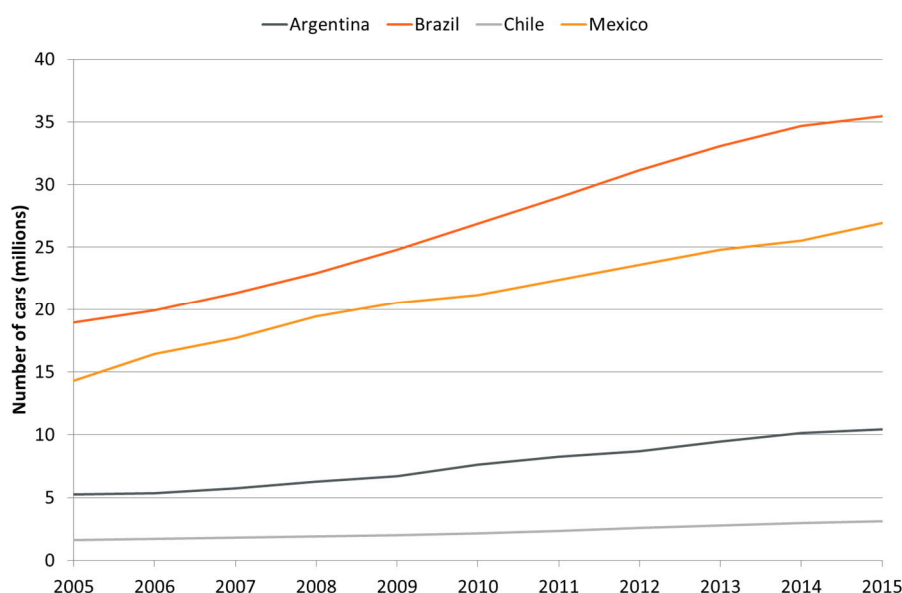Figure 12 shows the total number of registered cars in each of the four countries between 2005 and 2015.

Figure 12: Total number of registered cars in Argentina, Brazil, Chile and Mexico, 2005-2015 (OICA, 2017)[25]

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[25] Note that the figures for Argentina and Brazil do not match with those presented in the ITF report on Latin America (OECD/ITF, 2017b). However, since the ITF report only gives a single estimate of the number of

The trend shows that the number of cars has almost doubled in each of the four countries over the 11-year period.

Combining this information with the trend in population we can see that the motorisation rate (i.e. cars per population) is increasing across all four countries (Figure 13).
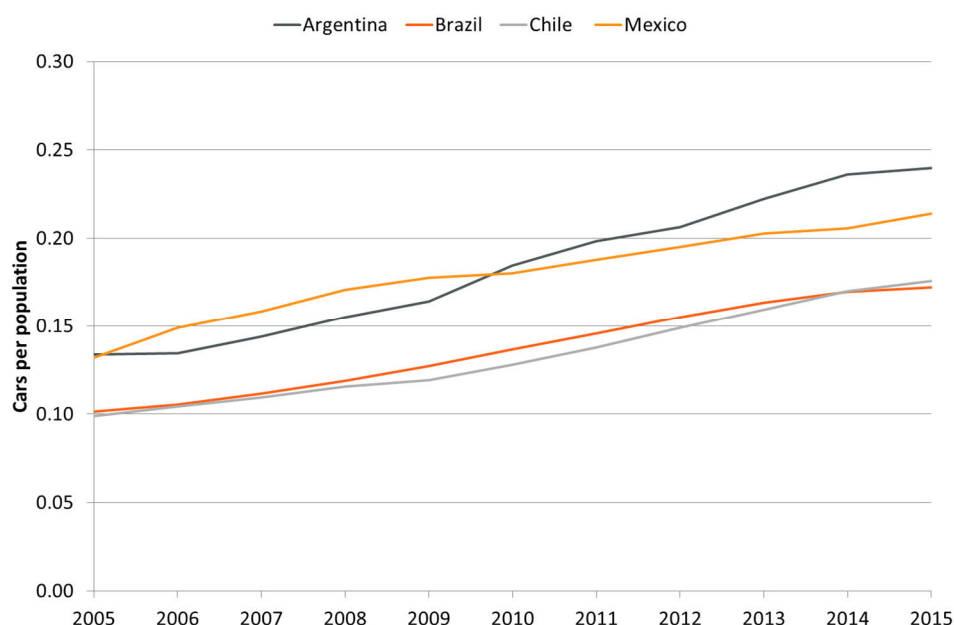
Figure 13: Motorisation rate (cars per population) in Argentina, Brazil, Chile and Mexico, 2005-2015

In addition to examining the trend for registered cars, it is important to understand how new cars infiltrate the fleet in order to understand the fleet turnover. Figure 14 shows the number of new cars sold in each country between 2005 and 2016.

passenger cars (2013) and no information on new passenger car registrations, the decision was made to use the figures from OICA for the purposes of this analysis. The impact of increasing the Argentina and Brazil figures to align with the ITF estimate for 2013 has been investigated as part of the sensitivity analysis (Appendix D).
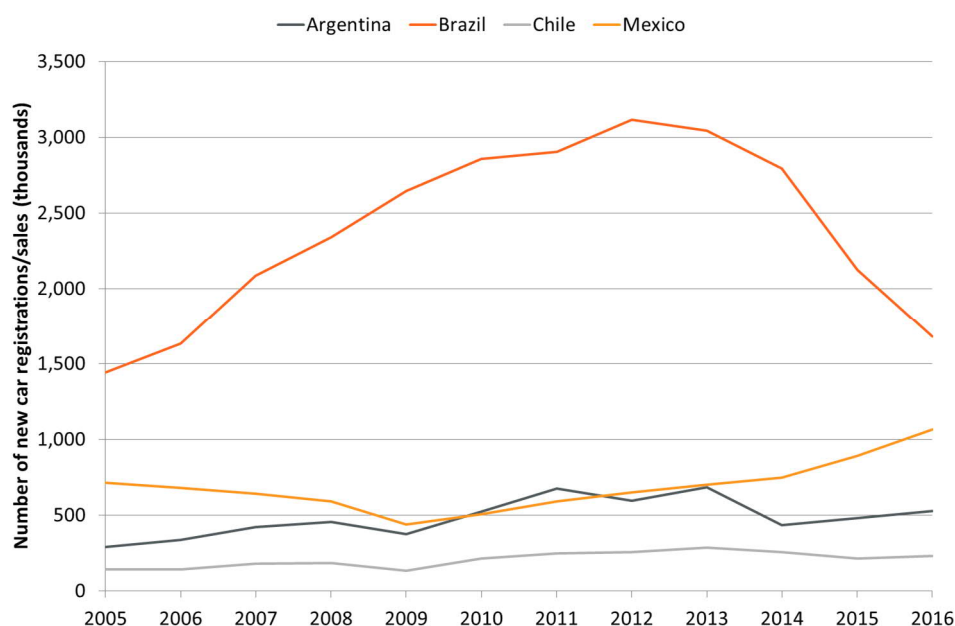
Figure 14: New car sales in Argentina, Brazil, Chile and Mexico, 2005-2016 (OICA, 2017)

There was a large reduction in vehicle sales in Brazil around 2014 due to the economic decline (see Section 3.4). In Chile, Argentina and Mexico, car sales have been growing gradually.

Given the number of new car sales in each country each year and the year-on-year change in number of registered vehicles, it appears that relatively few are removed from the fleet each year. Coupled with the low fleet fitment rates of the ESC and VRU protection systems in the period considered for regulatory implementation, this allowed the assumption to be made that few 'equipped' vehicles would be removed from the fleet each year; that the fitment would increase by approximately the number of new cars sold in each country.

3.5.2   Imports and exports

Vehicles are not always produced and sold in the same country:

- Some vehicles are manufactured in-country and then subsequently sold in-country (referred to as 'domestic' vehicles)

- Others vehicles are manufactured in-country and then exported to other countries (either within Latin America or externally)

- Finally, some vehicles are manufactured in other countries and then imported into Latin America.

There is little information available about the number of vehicles which fall into each category in the four countries. However, in Brazil in 2013, it was estimated that 83% of the vehicle fleet was produced domestically and the remaining 17% was imported. In addition, in 2013 Brazil supplied more than half of all vehicles sold in Latin America; this decreased in 2014 following the economic downturn, but Brazil is still reported to be one of the world's top five vehicle markets (Posada and Facanha, 2015).

In Chile, the opposite is true: the supply of vehicles to the Chilean automobile market is totally by importation (BBVA, 2012). South Korea is the primary source of new cars sold onto the local market but since 2013, new suppliers have penetrated the market from China and India, which has increased the number of options accessible to consumers and steered growth in the lower-priced segments (BBVA, 2013).

The origin of the vehicles used in each country is important if it is assumed that both the originating and final regions place regulatory requirements upon vehicles. If a production line produces vehicles for two different regions then it may be that the vehicles meet the requirements for both. However if an independent production line directs vehicles only to one country or region then the requirements for those vehicles could be less onerous having to satisfy only the stipulations for sale into that country or region.

As an example, cars produced for Latin America which are based on European vehicles will have a frontal profile and shape that is able (with specific energy absorbing components and structures) to satisfy the requirements for pedestrian protection. However, there is no requirement for vehicles produced for the U.S. market to meet pedestrian protection requirements. Hence, carry-over pedestrian protection benefits for exports to Latin America may not be the same if they share designs with vehicles design either for European or U.S. markets. In this example, the U.S. market vehicles would not meet the requirements.

Argentina (U.S.Commercial Service, Third Edition)

- Recent controls have made exporting goods from any country to Argentina more difficult as the Argentine Government has implemented more processes that Argentine importers must complete in order to import goods into the country.

- In the domestic market, sales are expected to decrease as well, due to the reduction in the number of cars authorized for importation, coupled with internal tax on high-end vehicles.

Brazil (U.S.Commercial Service, Third Edition)

- The domestic demand for automobiles has drastically increased in the past years, from 1.6 million in 2005 to 3.8 million in 2013, as government programs and economic stability increased consumer spending and raised large portions of the population upwards in the consumer market. Credit availability and government incentives to the automotive sector were also essential for the market growth.

- Because of the importance of the automotive industry to Brazil's economy, its job creation capacity and the political influence of the OEMs, government policies have traditionally protected Brazil's domestic auto industry from international competition. As an example, in 2011 the Brazilian Ministry of Industry, Trade and International Trade, increased the tax on imported automobiles from outside of the Mercosur trade zone[26] by 30 percent. In some cases, higher IPI (sales tax), the 35

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[26] "Mercosur" trade zone is comprised of five sovereign member states: Argentina, Brazil, Paraguay, Uruguay and Venezuela (suspended since December, 2016); and incorporated recently, Bolivia (since July 17, 2015).

percent import tax and other related taxes, increase the price of imported cars by over 100 percent. The effect of higher prices of imported vehicles is reflected in the 35.2 percent reduction in sales of imported cars in 2012 and 13.4 percent in 2013, after having reached a record level of 853,000 units in 2011. Sales of the Chinese brands Chery and JAC, as well as the Korean brand Kia, were the most hurt. On the other hand, domestic purchases of imported luxury models such as BMW, Land Rover and Audi increased by 30 percent in 2013. It is important to note that the import statistics do not include purchases from the Mercosur countries and Mexico, with whom Brazil has free trade agreements; as well imports of those OEMs that have manufacturing plants in Brazil.

Chile (U.S.Commercial Service, Third Edition)

- Chile does not produce or assemble vehicles. As there is no appreciable local production of auto parts (only 10 percent), almost all vehicle parts and accessories are imported.

- Chile has a flat 6 percent import duty. However as the U.S-Chile Free Trade Agreement (FTA) concludes its tenth year, trade in products and services continue to be a resounding success. The FTA was signed and implemented in January 1, 2004, and duties have been reduced to zero on 99 percent of U.S. exports to Chile with all remaining tariffs to be phased out by 2015.

Mexico (U.S.Commercial Service, Third Edition)

- Mexico expects to capture USD 230 million in automotive investment. Assembly plants producing new parts are now requiring that their suppliers be as close to them as possible, to reduce inventory volumes and facilitate just-in-time delivery. This shift has forced many U.S. first- and second-tier suppliers to move locally so that they can produce at lower costs, reduce freight and handling expenses, and deliver parts and components very quickly.

- Mexico remains the eighth largest vehicle producer in the world, with 2.9 million cars. It is also the fifth largest auto part producer worldwide with 75 billion dollars. Most exports from Mexico go to the U.S. (73%), Canada (6.7%), Germany (5.7%), Brazil, U.K. (both 2.3%), Argentina (1.5%), etc. Recent investments by established automakers and new OEMs have increased business opportunities throughout the country.

3.5.3   Types and age of cars

In addition to the trends examined above, the literature revealed some specific facts about vehicle growth and composition in the four countries, which provide some useful context for this study. The following bullet points provide a summary of these findings:

- For many years Brazil incentivised sales of cars with one-litre engines, which became the mark of the Brazilian automotive industry in the 1990s, reaching above 70% of sales in 2001. This share of one-litre engine cars has been falling since then (reaching 36% in 2013) in favour of medium sized vehicles with larger engines. There is an increasing demand for larger vehicles such as SUVs. However, compared with other regions (including the EU and US), the Brazilian vehicle fleet is still typically smaller in size, lighter and less powerful (Posada and Facanha, 2015).

- Chile is faced with a comparable problem to Brazil, where there is a challenge to meet the demands for larger vehicles such as SUVs (BBVA, 2013).

- On average, cars in Chile are around 9.5 years old, making Chile one of the countries with the youngest car parcs in the region. However, 11% of vehicles are more than 20 years old (Mazzucco, 2015) showing that scrappage of older cars is still at a low level compared with other regions (for instance, the equivalent value in the U.K. is about 1% (Driver and Vehicle Licensing Agency (DVLA), 2016)).

- In Mexico, the average age of cars in the fleet is estimated to be 16 years (PwC, 2014).

- In Argentina, the average age of circulating vehicles was 13 years in 2014, a significant reduction from 18.5 years registered in 2011 (U.S.Commercial Service, Third Edition). This radical transformation was helped by the Argentinian government which provided financing for purchases of new cars; by, for instance, loaning buyers up to eighty per cent of the money (Gilbert, 2014).

- In Brazil, the average age of vehicles has started growing again due to the significant decline in sales. Including passenger cars, light-utility vehicles, trucks and buses, the average age of the fleet in 2016 was almost 9 years (Valour Internations, 2016).

The age of vehicles within the fleet and the distribution between vehicle types and market segments is important because it influences the ability of technologies fitted to new vehicles to propagate through the fleet. As an example, under voluntary conditions, ESC uptake in Europe started with the larger more expensive classes of vehicle, the Luxury and Executive car segments. There was then propagation to the Large and Medium (compact) segments. Finally, there was uptake within the smallest and often cheapest, Small and Mini, segments of the market, but in many countries the voluntary uptake in these segments was very limited. Therefore, it is unlikely that voluntary uptake will reach all vehicles in all vehicle segments and it will not happen at an equivalent time without legislative intervention.

3.5.4   Vehicle safety developments

<u>Argentina</u>

- In 2011 an agreement was reached with car manufacturers and importers to fulfil European standards for new vehicles sold in Argentina (for example, from January 2014, every new car must have Antilock Brake Systems and airbags). A new agreement was also signed in 2014 between car manufacturers and the Ministry of Industry to make Electronic Stability Control obligatory in all new vehicles as of 2018 (OECD/ITF, 2015). However, this has not happened and is said to have been postponed until 2020, at least (Cars Magazine, 2018).

- o It should be noted that airbags are not mandatory in Europe, nor are they necessary, strictly, for compliance with the impact protection regulations, UN Regulation 94 and 95. Furthermore, whilst airbags have been shown to be extremely effective at mitigating injury from crashes (Kahane, 1996), the evaluations have been linked with the introduction of a crash test procedure. Therefore the evidence is that it is an airbag tuned to function in conjunction with the rest of a restraint system that provides the benefit, not just the airbag itself.

- The National Road Safety Agency is proposing an integral modification of the Road Traffic Bill, which includes the recognition and regulation of electric vehicles and quads (OECD/ITF, 2016).

Brazil

- In 2014 all the cars sold and manufactured in Brazil must be fitted with airbags for the front occupants and ABS breaking systems (Alves, 2015).

- In order to further stimulate the automotive industry and attract investments, in October 2012, the Brazilian Government issued a program, known as the Inovar Auto (Decree 7819), designed to support the automotive industry's technology development, innovation, safety, environmental protection, energy efficiency and quality improvement. In order to benefit from tax reduction incentives, OEMs are expected to invest in research and development in Brazil and to achieve production of more economical, lower priced and safer vehicles. The Inovar Auto program was valid until December 2017, and benefitted both those OEMs that have already established manufacturing plants in country and other international OEMs whose new production plant projects have been approved by the government. Companies that apply for Inovar Auto commit to having their Made-in-Brazil models achieve increased energy efficiency levels (i.e. an average drop of 12 percent in fuel consumption). (https://www.trade.gov/td/otm/assets/auto/CS_Resource_Guide.pdf)

Chile (OECD/ITF, 2016)

Recent improvements to vehicle safety include:

- Mandatory frontal airbags (for drivers and passengers) on new light vehicles sold in Chile (2015)

- ISOFIX or LATCH anchoring systems for vehicles of 2,700 kg or less to simplify correct installation of child restraint systems without the need of seat belts (2014)

- Increased safety requirements for motorcycles, including standards for motorcycle features in line with international regulations (2014)

- Safety devices for interurban buses, such as Antilock Brake Systems, Electronic Stability Control, rear fog light, and reversing alarms (2013)

Mexico (United States of Mexico, Ministry of Economy, 2016[27])

A major driving force for vehicle safety in Mexico came through the release of the Standard NOM-194-SCFI-2015. This standard concerns safety devices in vehicles. In particular it set a timeline for requirements governing many of the items considered as key safety features. For instance,

- Head restraints

- Seat belts and seat belt reminders (SBR)

- Lights

- Brakes and anti-lock braking systems (ABS)

- Frontal and side impact testing

However, application of the requirements for SBR, ABS and the full-scale crash tests was set for the future (see Table 4). Implementation of these requirements supports the notion that safety progresses as it did in Europe 15 years earlier. It is also a fundamental basis for the casualty savings predicted alongside the secondary safety improvements (as calculated in Appendix F). Without implementation, then those lives may still be lost.

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[27] http://dof.gob.mx/nota_detalle.php?codigo=5436325&fecha=09/05/2016

4 Baseline fatality forecasts

This section presents the baseline fatality estimates for each country. As described in Section 2, these estimates take into account the current trend in the fatality rate (to account for general improvements to road safety over time) and the planned implementation of the vehicle safety regulations under the current timelines.

Section 4.1 shows the baseline fatality forecasts for car occupants and Section 4.2 shows the equivalent for VRUs (pedestrians and cyclists).

4.1 Car occupants

As explained in Section 2.1.1 the best exposure measure was selected for the fatality rate modelling for each country. Figure 15 shows the rate for car occupant fatalities per 100 million passenger kilometres in Mexico and Figure 16 shows the trend in car occupant fatalities per million registered vehicles for the other three countries. An exponential trend line has been fitted to each country's data to show how this rate is decreasing over time.
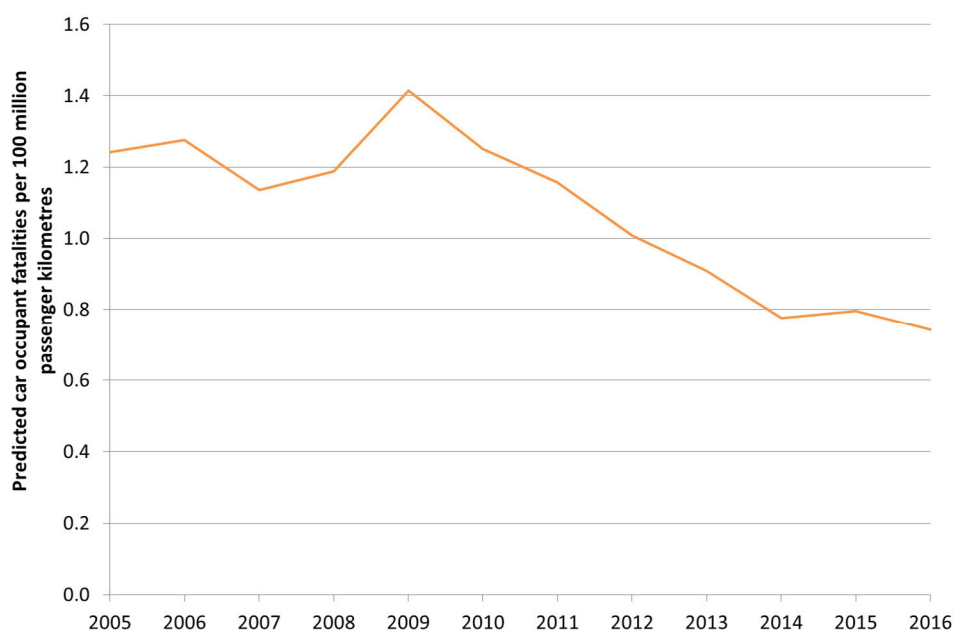
Figure 15: Car occupant fatality rate (per 100 million passenger kilometres) in Mexico (2005-2016)
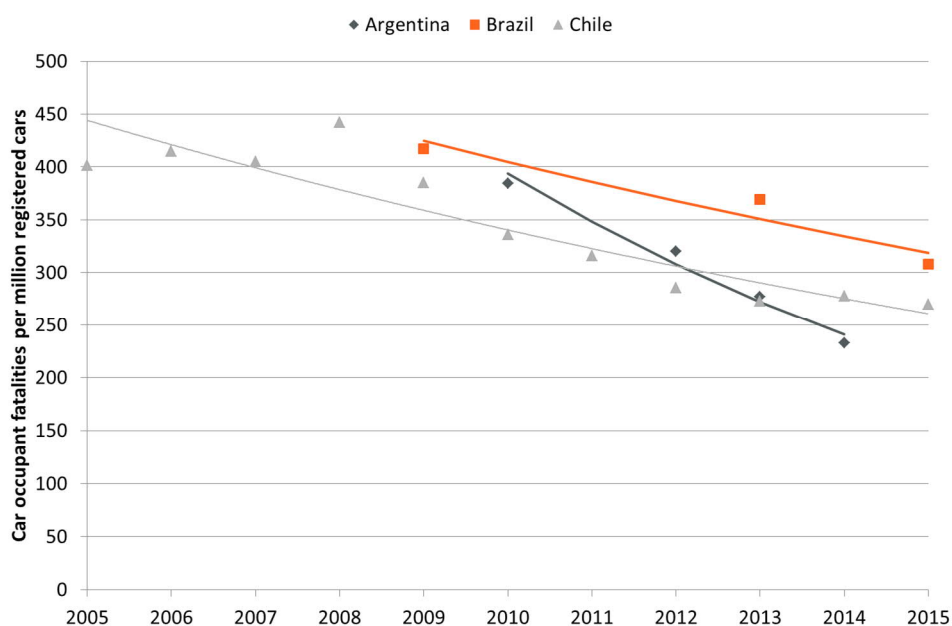
Figure 16: Car occupant fatality rate (per million registered cars) for Argentina, Brazil and Chile (2005-2015, latest available data shown in each case)

The first step in the baseline fatality forecasts is to extrapolate this trend forwards to estimate the fatality rate up to 2030, assuming the current trend in road safety developments continues (Figure 17 and Figure 18).
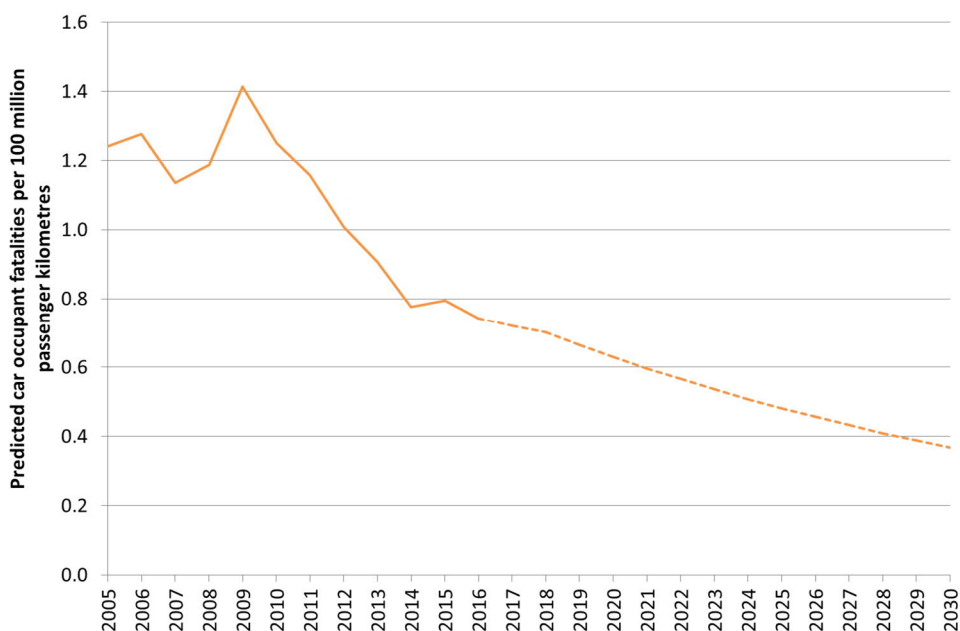

Figure 17: Predicted car occupant fatality rate (per 100 million passenger kilometres) in Mexico (2005-2030)
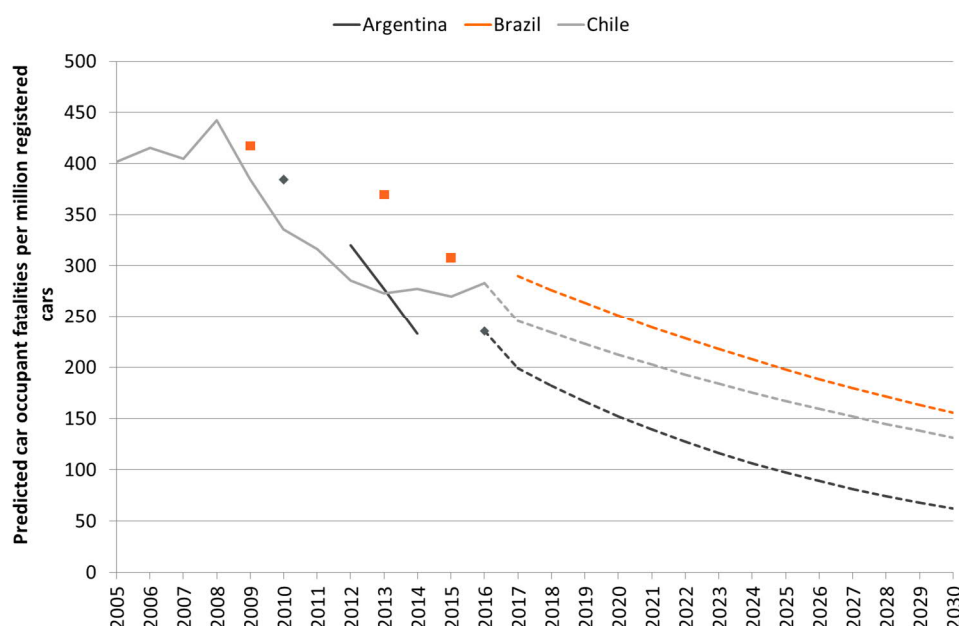
Figure 18: Predicted car occupant fatality rate (per million registered cars) for Argentina, Brazil and Chile (2005-2030)

Based on these predictions, the number of car occupant fatalities per million registered cars will reach around 62 in Argentina by 2030. The 2014 rate in GB was estimated to be around 28. In Mexico, the prediction is for 0.37 car occupant fatalities per million passenger kilometres, with the corresponding GB value for 2016 being 0.12. Thus, if they continue, these trends would represent a significant achievement; however, the difference from GB indicates that more could be done, particularly if there can be closer alignment on vehicle safety regulations and interventions.

Although the casualty data suggests that car occupant fatalities per million registered cars have been falling rapidly in Argentina (see Figure 16), this rate is based on limited data. Information is available on the total number of road accident fatalities recorded in Argentina between 2005 and 2014 (see Figure 7), however, there is limited information on how many of these are car occupants (2010, 2012-14 and 2016 estimates are available). As a result, this trend is based on relatively few data points.

In addition, the review of road safety developments, changes to the economy and changes to vehicle use (Sections 3.3 to 3.5) have not suggested any substantial changes which might be influencing these trends. Therefore, this leads into question the reliability of these forecasts; however, in the absence of contradictory information these have been used for the remainder of the analysis. Alternative assumptions are tested as part of the sensitivity analysis (Appendix D).

Alongside the predictions of the fatality rate, the number of passenger kilometres (for Mexico) and registered cars (for Argentina, Brazil and Chile) is predicted forwards, assuming a linear trend (Figure 19 and Figure 20).
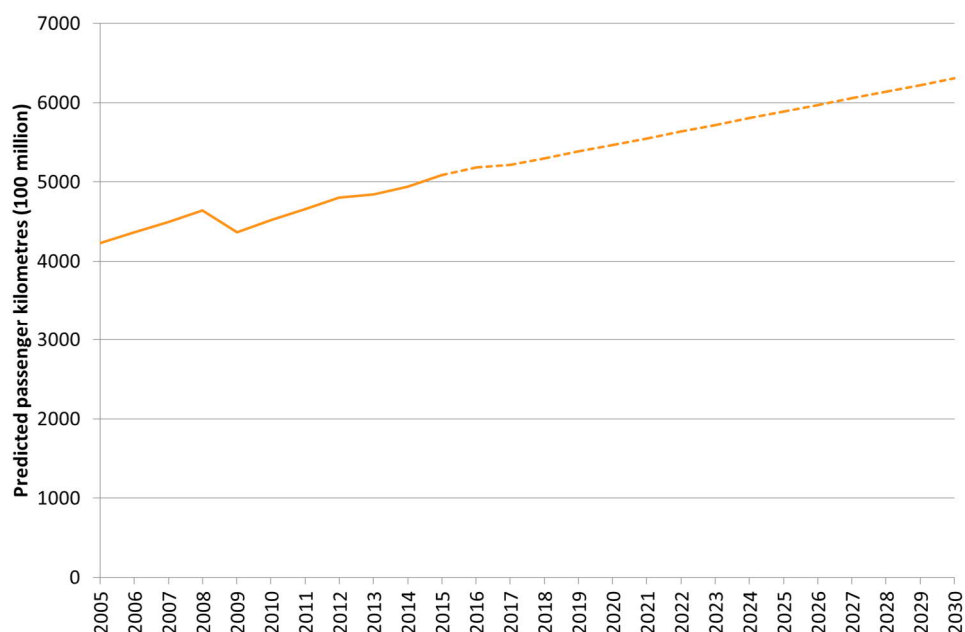
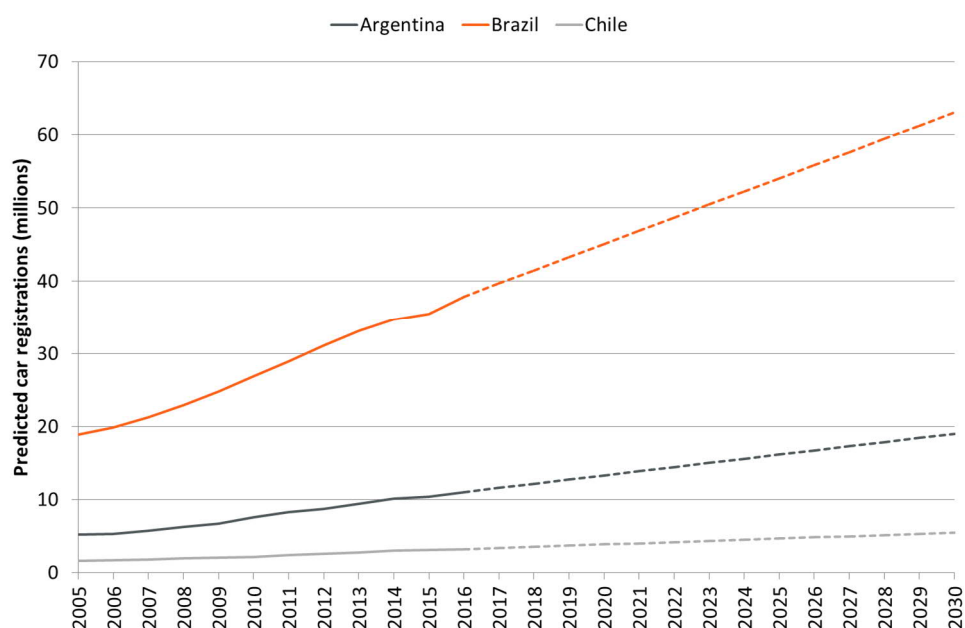Figure 19: Predicted passenger kilometres in Mexico (2005-2030)

Figure 20: Predicted number of registered cars in Argentina, Brazil and Chile (2005-2030)

These forecasts predict that by 2030 the number of cars in Brazil will exceed 60 million. Although there are likely to be limiting factors on vehicle fleet growth (including population and the amount of disposable income, which is related to the state of the economy), these estimates seem realistic given how the population is predicted to change. For example, in Argentina the figure of 19 million cars in use, equates to a motorisation rate (cars per population) of 0.39 if the predictions presented in Figure 6 (Section 3.1) are true; in 2001 in GB the figure was around 0.42 (see Table 6).

The car occupant fatality rate and exposure estimates are then combined to calculate the predicted number of car occupant fatalities up to 2030 (Figure 21). Here it can be noted that whilst the numbers of road traffic fatalities were increasing in all four countries, the number of car occupant fatalities has been, and is predicted to continue, decreasing in Argentina and Mexico throughout the evaluation period. Modal shift with an increased burden of motorcyclist fatalities could go some way to explaining these trends (data from Mexico support this explanation, (INEGI, 2017)).
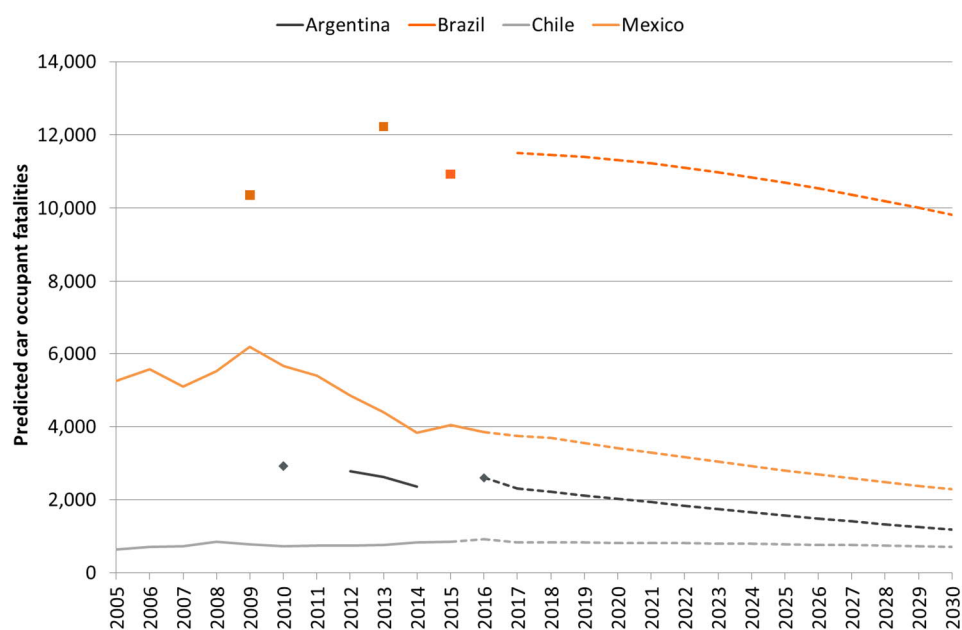
Figure 21: Predicted number of car occupant fatalities in each country (2005-2030)

Finally, adjustments are made to account for the regulations which will be (or have already been) introduced into each country before 2030. These are based on the current timeline of proposed regulations, which differ for each country (see Table 11).

In addition to these regulations, it is also necessary to account for the voluntary uptake of ESC into the fleet through consumer choice (incentivised by Latin NCAP) and implementation by manufacturers. As described in Appendix A, this voluntary uptake is modelled based on the uptake seen in Europe under similar conditions, where it was estimated that it would take 20 years to reach the maximum level of voluntary uptake of all new vehicles fitted with ESC (60% for all four countries).

The effect of this voluntary uptake is modelled by first predicting how many new vehicles enter the fleet with ESC fitted in each year, and then combining this with the effectiveness estimate of ESC (38%) from the literature (Section 2.1.2) and the target population (35%) – this process is described in full in Section 5.1.

Table 11: Vehicle safety regulations for car occupants proposed under the current timelines (year of implementation by country)

Regulation	Argentina	Brazil	Chile	Mexico[28]
Frontal collision testing for new models	2014	2012	n/a	2019
Frontal collision testing for all new cars	2016	2014	2016	2020
Side collision testing for new models	2018	n/a	n/a	2019
Side collision testing for all new cars	2022	n/a	2016	2020
Seat belts & seat belt anchorages	1986 (belts) 1991 (anchorages)[29]	2015	2000 (belts)[30]	2015

Figure 22 shows the final estimate of fatalities for each country, assuming no new regulations (other than those outlined in Table 11) come into regulation before 2030. The 'baseline' estimates replicate those shown in Figure 21 (i.e. are based on assuming the current trends in road safety continue). The 'current timeline' figures represent the additional saving due to the implementation of the secondary safety regulations and the voluntary uptake of ESC.

There is a relatively large difference in the baseline and current timeline estimates for each country, suggesting that the measures which are already being taken to improve vehicle safety are likely to be beneficial towards reducing car occupant casualties. Specifically, the implementation of front and side collision testing regulations in all four countries will likely have a substantial impact on the fatality trends (the results of this analysis are presented in Appendix F). This appendix estimates that approximately 11,000 lives will be saved through implementation of these regulations between now and 2030, demonstrating the substantial benefits that secondary safety regulations will play in these countries.

Voluntary uptake of ESC also has a quantifiable part to play, although there is more that could be done to accelerate the benefits through implementing regulations for ESC – the impact of this is modelled in Section 5.1.

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[28] These are the dates released in the "Norma Oficial Mexicana NOM-194-SCFI-2015, Dispositivos de seguridad esenciales en vehículos nuevos-Especificaciones de seguridad." It is known that the specified requirements have not been implemented yet for frontal and side collision testing; however, alternative dates are not available. Therefore no further adjustment was made to the offset in years between developments in GB road safety and in Mexico.

[29] Norma IRAM 3641/86, PART I and II, Safety Belts for use in Automotive Vehicles (Requirements and Test Methods, Inspection and Reception) and IRAM-AITA Standard IK 15/91, Anchoring for Safety Belts.

[30] DS 26/2000 MTT; The rules that must be met by seat belts are those established by the Federal Code of Regulations, of the United States of America, or by the Community Safety Directives of the European Economic Community or the Security Regulations defined by the European Economic Commission of the Nations, Brazil, Japan or Korea, as determined by the Ministry.
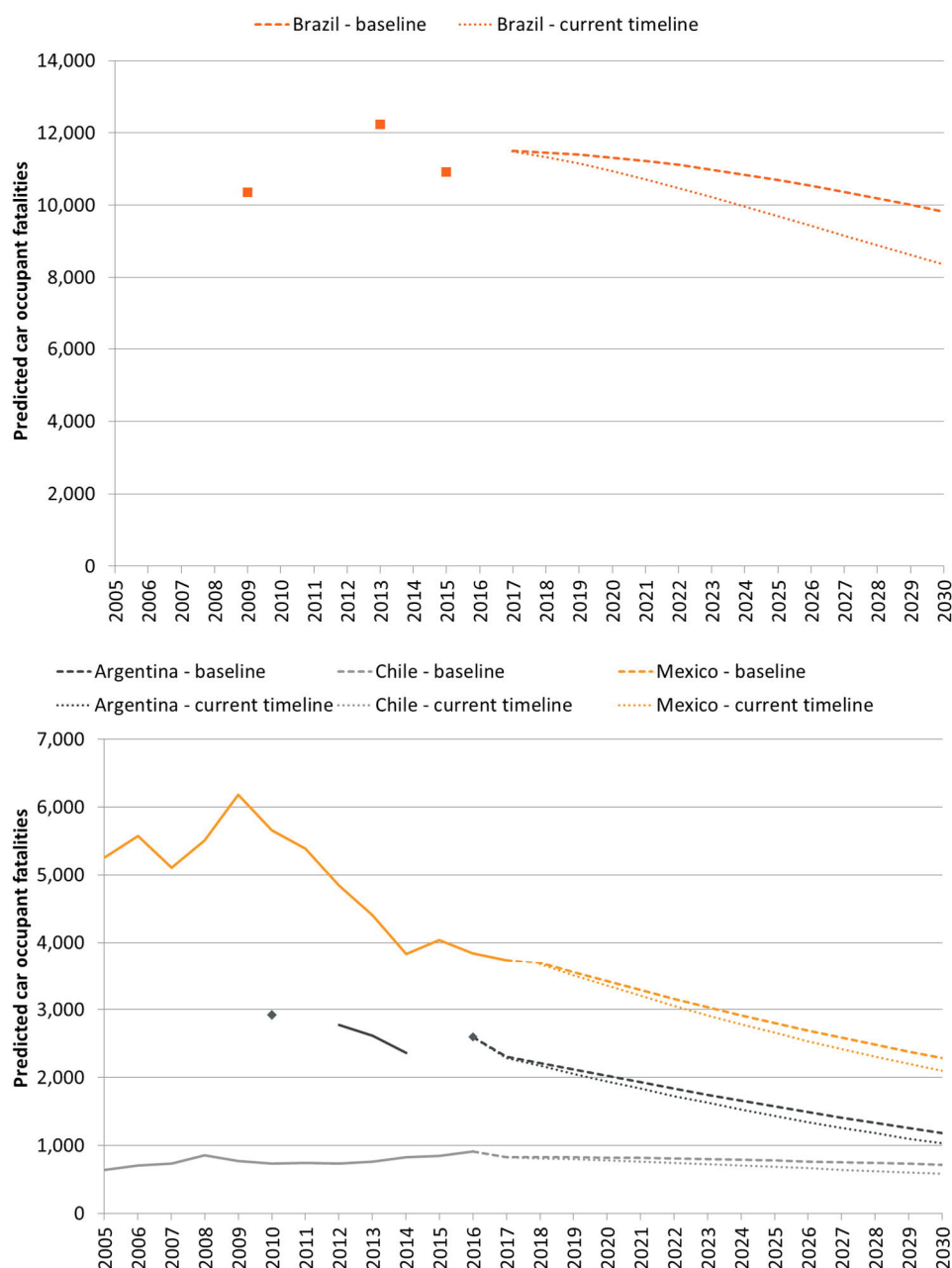
Figure 22: Predicted number of car occupant fatalities in each country adjusted for the current regulation timeline (2005-2030)

4.2   Vulnerable road users

4.2.1   Pedestrians

Figure 23 shows the trend in pedestrian casualties per million population. As with the car occupant fatality trend, an exponential trend line has been fitted to the data from Brazil, Chile and Mexico to show how this rate is decreasing over time. For Argentina, the rate appears to be increasing and hence an exponential trend (which would tend towards infinity) is not appropriate in this case. A logarithmic trend has been assumed instead, although it is recognised there is some uncertainty in this assumption since the trend is based on only four data points, the last of which is from 2014.
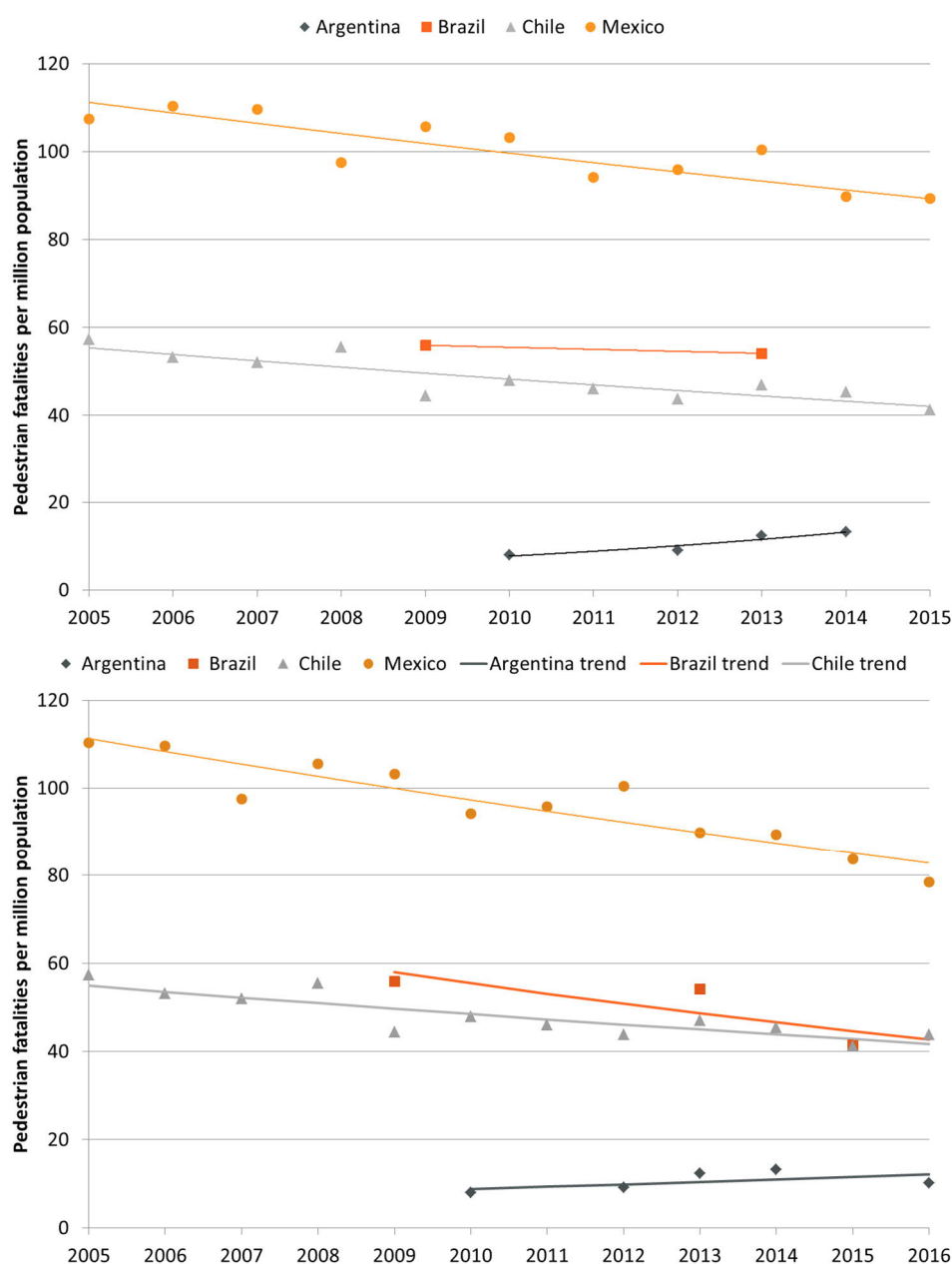

Figure 23: Pedestrian fatality rate (per million population) for each country (2005-2015, latest available data used in each case)

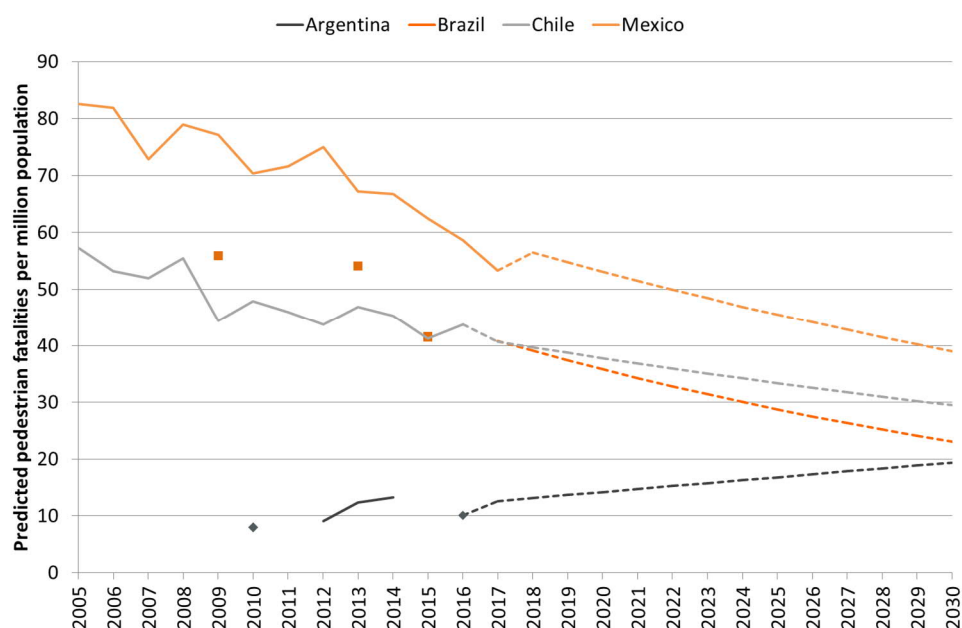This trend is then predicted forwards to 2030 (Figure 24).

Figure 24: Predicted pedestrian fatality rate (per million population) for each country (2005-2030)

In order to calculate the number of baseline fatalities, population projections (generated by the United Nations and shown in Section 3.1, Figure 6) are combined with the predicted pedestrian fatality rate. The results are shown for in each country in Figure 25 – these represent the figures expected if road safety continues to develop as it has done in recent years but no new vehicle safety regulations are implemented.
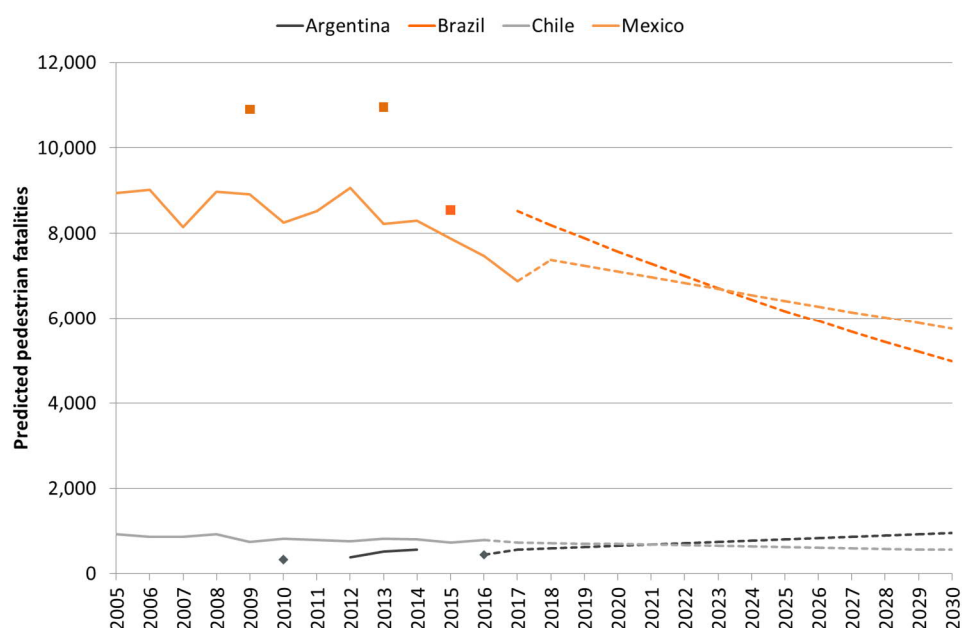

Figure 25: Predicted number of pedestrian fatalities in each country (2005-2030)

Finally, adjustments are made to account for the regulations which will be introduced into each country between 2015 and 2030. There are currently no plans to introduce regulations for VRU-AEB or pedestrian protection in any of the four countries. Hence the baseline fatalities estimates under the current timeline are based solely on voluntary uptake (driven by consumer choice and manufacturers who choose to fit their vehicles as standard). For both technologies it is assumed that under a voluntary scenario it will take 20 years to reach 50% of new cars fitted (see Appendix A for full description of this methodology).

Taking the effect of this voluntary uptake into account (using the predicted fleet fitment and effectiveness estimates from the literature – see Section 2.2.2 and 2.2.3), Figure 26 shows the final estimate of fatalities for each country under the current timeline (note the 'baseline' figures replicate those shown in Figure 25 and are included for comparison purposes only).

Due to the relatively slow uptake of VRU-AEB and pedestrian protection through voluntary uptake alone, there is relatively little difference in the estimates under the 'baseline' and 'current timeline' assumptions.
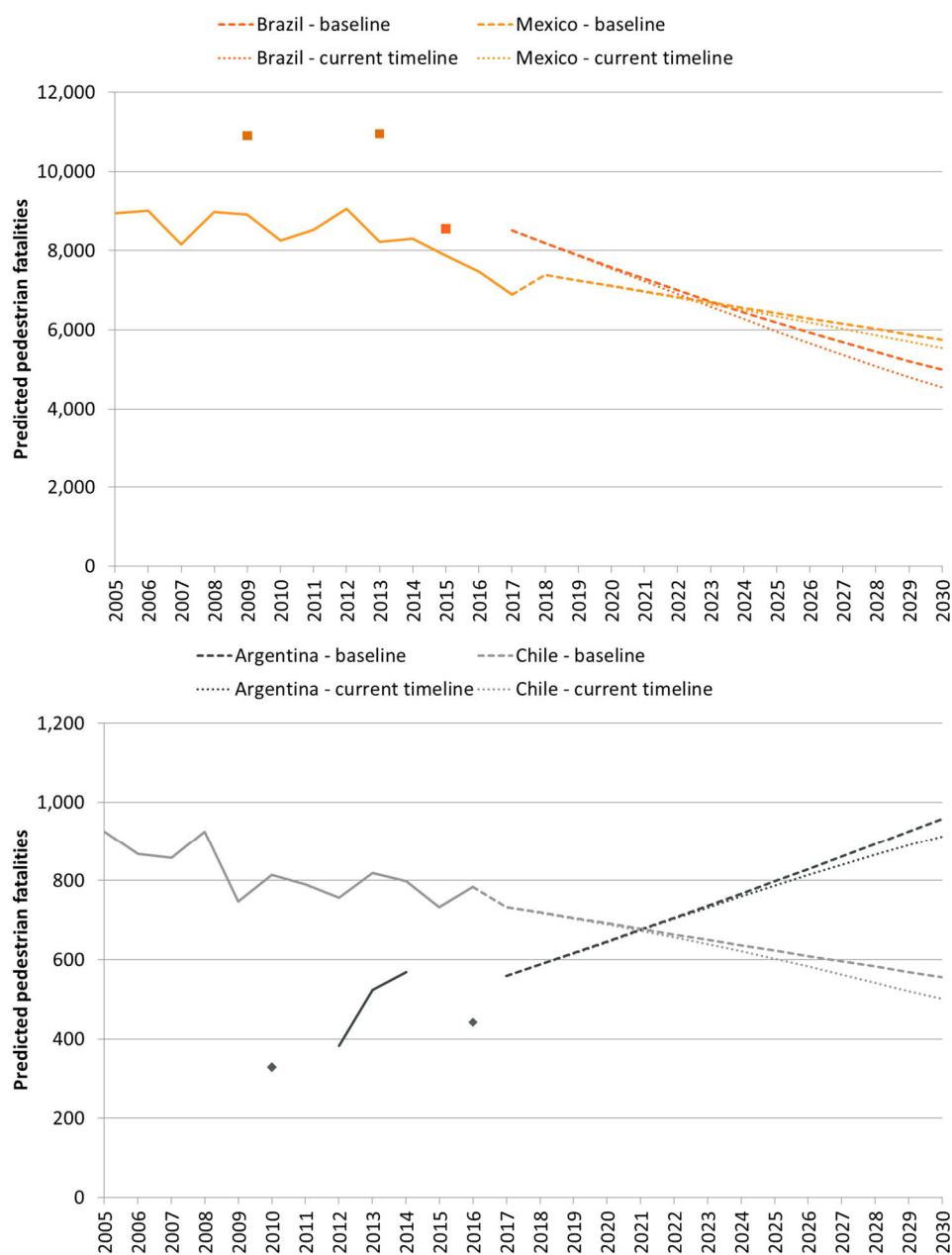
Figure 26: Predicted number of pedestrian fatalities in each country adjusted for the current regulation timeline (2005-2030)

4.2.2   Pedal cyclists

This section presents the equivalent results for pedal cyclists. Figure 27 presents the actual and predicted trend in the fatality rate and Figure 28 presents the predicted 'baseline' and 'current timeline' fatality numbers, assuming the same regulation timeline applies to pedal cyclists as to pedestrians.
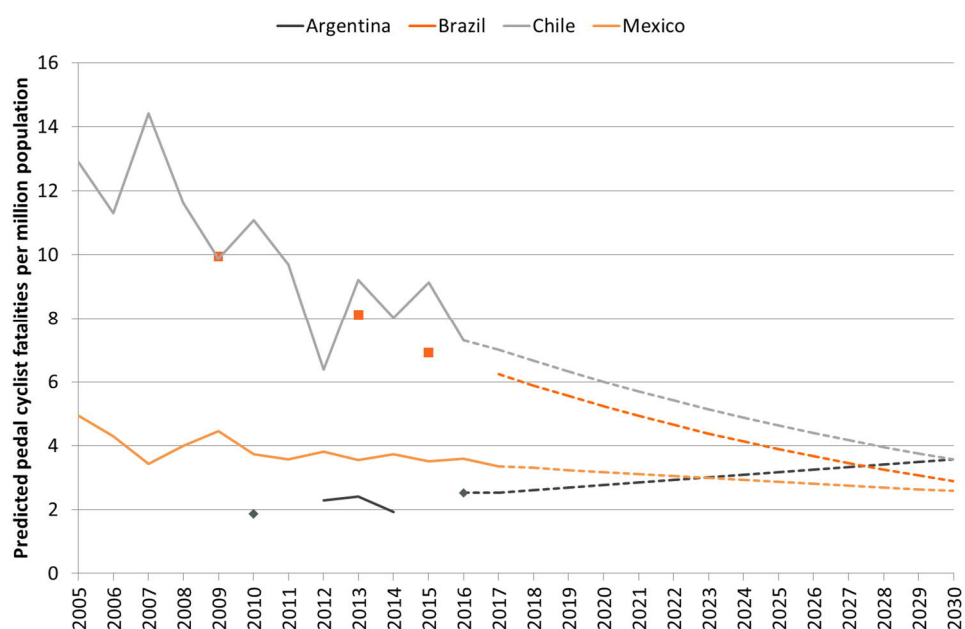

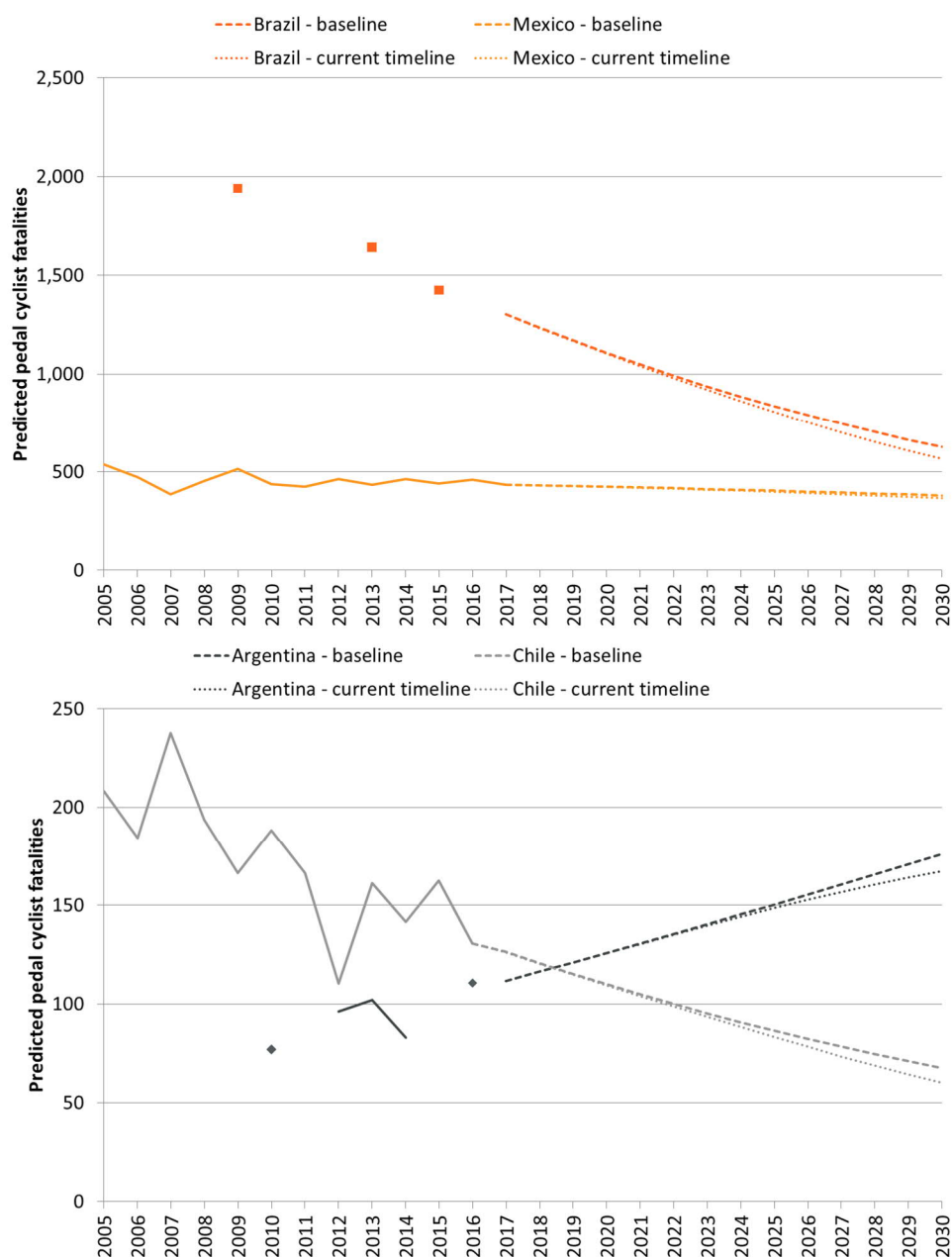Figure 27: Predicted pedal cyclist fatality rate (per million population) for each country (2005-2030)

Figure 28: Predicted number of pedal cyclist fatalities in each country adjusted for the current regulation timeline (2005-2030)

5 Predicting the casualty benefits of regulation

This section presents the results of the benefit estimates. For each casualty type, the assumptions around fleet penetration of each technology are documented, along with the number of casualties saved as a result of the technology (estimated using the effectiveness estimates for the technology and fleet penetration). Casualty benefits are calculated using the VSL approach and these are then discounted to relate the prices presented to present values. Section 5.1 presents the results for car occupants and Section 5.2 for VRUs.

5.1 Car occupants

As discussed in Section 4.1, by 2020 (the implementation date of interest for this study) all four countries will have already implemented or, in the case of Mexico, have stated intentions to implement the secondary safety regulations. In addition, there will have been some voluntary uptake of ESC – the model used in Section 4.1 assumes that it would take approximately 20 years from introduction of ESC to reach 60% of new cars fitted with ESC. The impact of this is already incorporated within the 'current timeline' fatality estimates presented in Section 4.1; this section focuses on the impact that introduction of a regulation for ESC might have on the number of car occupant fatalities up to 2030. For the purpose of this analysis, it is assumed that this regulation would be introduced in 2020 for all four countries.

As discussed in Section 2.1.2, review of the literature has concluded that ESC is 38% effective at reducing the number of fatalities in loss of control collisions. In order to apply this level of effectiveness to the baseline fatality numbers, the numbers of fatalities in these collisions need to be estimated.

There is relatively little data readily available on collision types or causation factors in Latin America: only one study was found which related to data on fatalities in Chile. Data for 2015 are presented in Figure 29 and suggest that 20% of fatalities were a result of loss of control (orange segment).
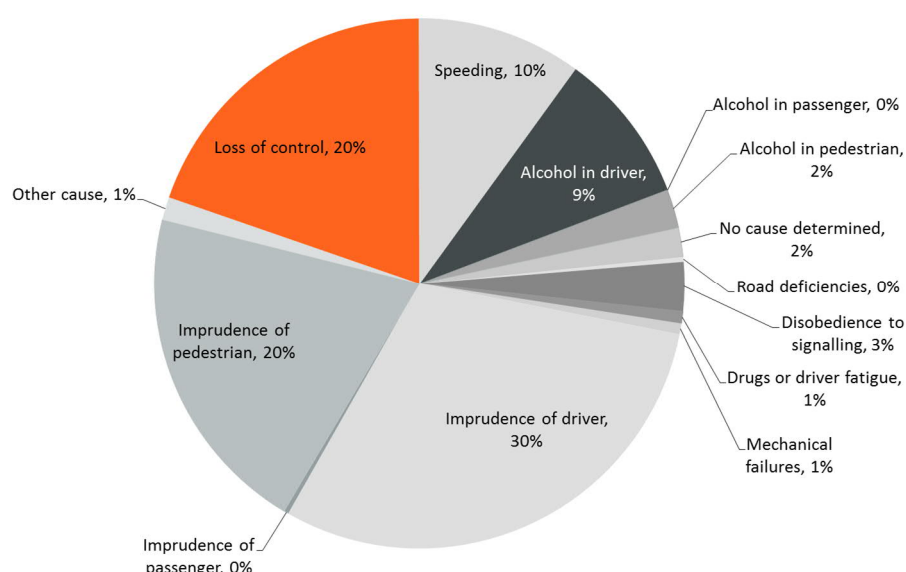
Figure 29: Proportion of fatalities assigned to each causation factor (Chile, 2015) (CONASET, 2017)

However, since this classification only allows one causation factor for each fatality, this is likely to underestimate the true number that are related to loss of control. For example, a collision may involve both speeding and loss of control, but only one cause can be attributed. In addition, these figures relate to all fatalities and not just car occupants and thus might over or underestimate the target population for the car occupant road user group.

Instead, it was decided to analyse collision data from Great Britain and the USA, two regions which publish data of a sufficient level of detail to allow analysis of loss of control and which exhibit very different road characteristics, thereby representing sensible boundaries for a range of the prevalence of loss of control to be expected in different road environments. The STATS19 analysis (GB data) showed that 43.5% of car occupant fatalities occurred in collisions where a car's loss of control was a contributory factor. The FARS analysis (US data) concluded that 26.3% of car occupant fatalities occurred in vehicles which lost control prior to impact. Both of these estimates are based on a 5-year average covering 2011–2015 and corrected for the fact that approximately 55% and 45% of the GB and US fleet in the samples, respectively, were already fitted with ESC. For the overall benefit-cost calculations, the mean value between these boundaries was used, i.e. 34.9% of car occupant fatalities were considered to be within the target population for ESC. The upper and lower boundaries of 43.5% and 26.3% respectively were used for the sensitivity analysis.

By combining the estimated fleet fitment under the regulation assumption (described in Appendix A), estimated effectiveness of ESC (38%) and target population for this measure (35%), the number of lives saved due to implementation of the ESC regulation can be estimated – see Figure 30. Note that figures for Brazil are presented on a separate chart from those for the other three countries since the magnitude of the savings are far greater for this country due to the larger population; this enables clear trends over time to be observed for all four countries.

It should be noted that the estimated benefits are dependent on the rate of adoption of cars with ESC throughout the vehicle fleet. This is incorporated in these estimates through the fleet fitment model. However, this will be subject to market fluctuations in car purchasing and large changes in income or economic growth. Additionally, it is possible for fleet fitment to be influenced via incentives to replace old cars with new cars. The effect of such initiatives would be to increase the benefits soon after implementation of the legislation, giving a corresponding increase in the total number of lives saved and higher benefits (particularly when accounting for the discounting of future benefits).
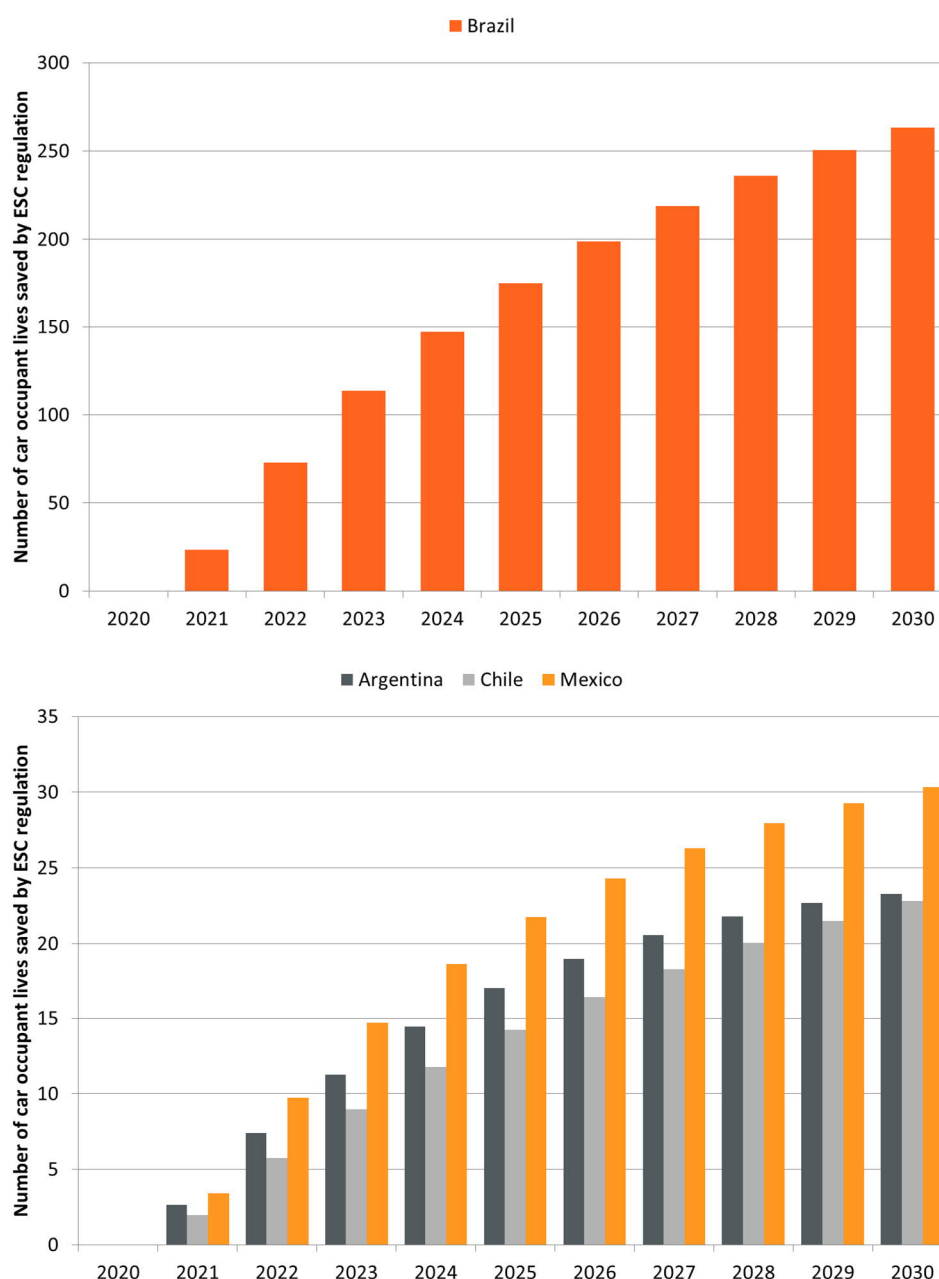

Figure 30: Estimated number of car occupant lives saved due to implementation of ESC regulation in 2020 (2020-2030)

The results show that implementation of the ESC regulation will save around 260 lives each year in Brazil by 2030, and another 75 in the other three countries combined. These figures assume that the minimum standards for crashworthiness have also been implemented by the start of the evaluation period.

Whilst these savings are not substantial, Figure 30 shows that these figures are growing year-on-year. In addition, since this only represents the fatality savings, it is anticipated that considerably more serious casualties will also be prevented, as presented in Table 12.

In addition to the fatality savings predicted above, it is estimated that a further 15,000 lives would have been saved between 2020 and 2030 if earlier regulatory action had ensured that ESC was fitted throughout the whole vehicle fleet by 2020. This additional benefit will not be achieved because of the time it will take for the fleet to turnover and for older cars which don't have ESC fitted to be replaced.

Using the method described in Appendix H, the predicted fatality savings have been used to also estimate the number of serious injuries that could be saved if the ESC regulation is implemented. Following this approach, it is estimated that around 8,000 serious injuries will be saved by the regulation. As is acknowledged in the method, there are some significant limitations with the approach that has been taken, due to a lack of available data on serious injuries in any of the four countries, and as such the results presented here should be treated with some caution.Using the VSL method (Bhalla et al., 2013), which relates the economic loss of each fatality to GDP, the lower and upper limits of a cost of a fatality were obtained from the literature – see Table 7. For the purposes of this analysis, the average of these two estimates was calculated and this mid-estimate was used to estimate the economic benefit of the lives saved by ESC (discounted and presented in 2018 prices – this is explained in Appendix E). The VSL method was also used to relate the economic loss of each serious injury to GDP. The cumulative casualty savings from 2020 to 2030, and the related economic benefit is presented in Table 12 for each country.
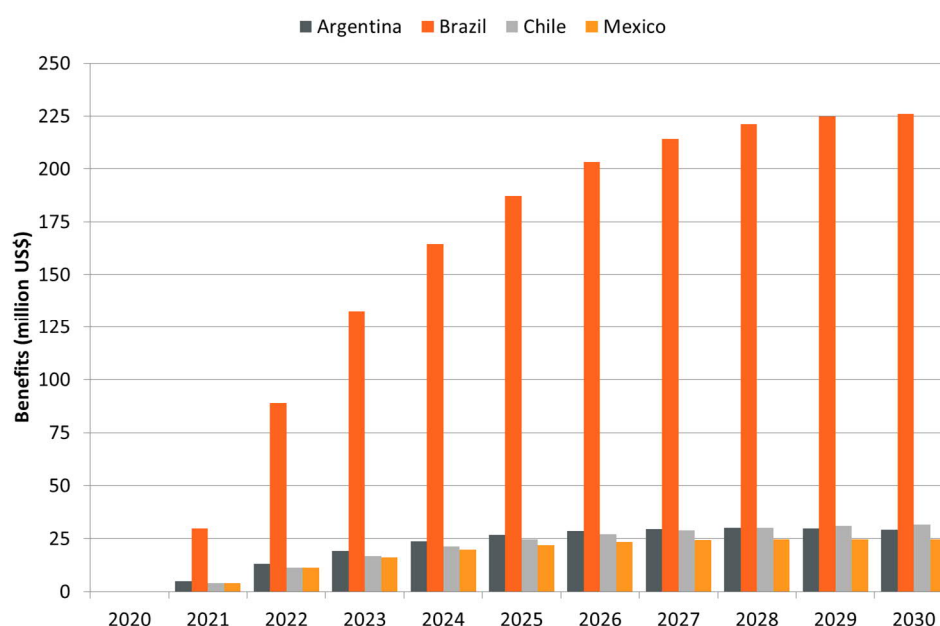
Figure 31: Estimated economic benefit for car occupants due to implementation of ESC regulation in 2020 (2020-2030)

Table 12: Estimated economic benefit for car occupants due to implementation of ESC regulation in 2020 (2020-2030)

	Cumulative lives saved, 2020-2030	Cumulative serious injuries saved, 2020-2030	Mid estimate of economic loss of one death due to traffic collision (2018 US $, thousands)	Estimate of economic loss of one serious injury due to traffic collision (2018 US $, thousands)	Discounted economic benefit, 2020-2030 (2018 US $, millions)
Argentina	160	578	1,342	220	235.11
Brazil	1,699	6,138	914	150	1,693.01
Chile	142	512	1,473	241	226.61
Mexico	206	746	864	141	194.99
Total	2,207	7,975			2,349.72

In total, it is estimated that implementation of the ESC regulation would result in a $2.35 billion economic benefit across the four countries, combining the estimated reduction in fatalities and serious injuries.

5.2 Vulnerable road users

This section presents the estimated benefits of implementation of two regulations for VRUs:

1. VRU-AEB

2. Pedestrian protection

The effectiveness estimates applied for each technology differ for pedestrians and pedal cyclists and hence the results for each are presented in separate sections.

5.2.1 Pedestrians

The effectiveness estimates from the literature suggest that VRU-AEB will be 48% effective at reducing pedestrian fatalities (Section 2.2.2). The equivalent figure for passive pedestrian protection is 3.9% (Section 2.2.3). Combining these estimates with the fleet fitment (described in Appendix A) enables the number of lives saved by VRU-AEB and pedestrian protection to be estimated in Figure 32. Note that this is the combined estimate of both measures. As with the car occupant figures presented in Section 5.1, the savings for Brazil are larger than for the other countries and hence have been presented on a separate chart.

Figure 32: Estimated number of pedestrian lives saved due to implementation of VRU-AEB and pedestrian protection regulations in 2020 (2020-2030)

The model suggests that in excess of 800 pedestrians will be saved in Brazil in 2030, nearly 500 in Mexico, 150 in Argentina and 130 in Chile if VRU-AEB and pedestrian protection regulations are implemented. These savings are larger than those for ESC due to the lower predicted uptake of VRU-AEB and pedestrian protection in the absence of any regulation (Appendix A).

In addition to the pedestrian fatality savings predicted, it is estimated that a further 58,000 lives would be saved between 2020 and 2030 if earlier regulatory action had ensured that VRU-AEB and Pedestrian Protection were already fitted throughout the whole vehicle fleet by 2020. This additional benefit will not be achieved because of the time it will take for the fleet to turnover and for older cars which don't have such protection to be replaced. It is also estimated that 122,000 serious injuries will be saved between 2020 and 2030, using the method described in Appendix H.

Finally, Table 13 presents the discounted economic benefit using the mean estimate of a cost of fatality and the estimate of the cost of a serious injury (shown in Table 12).
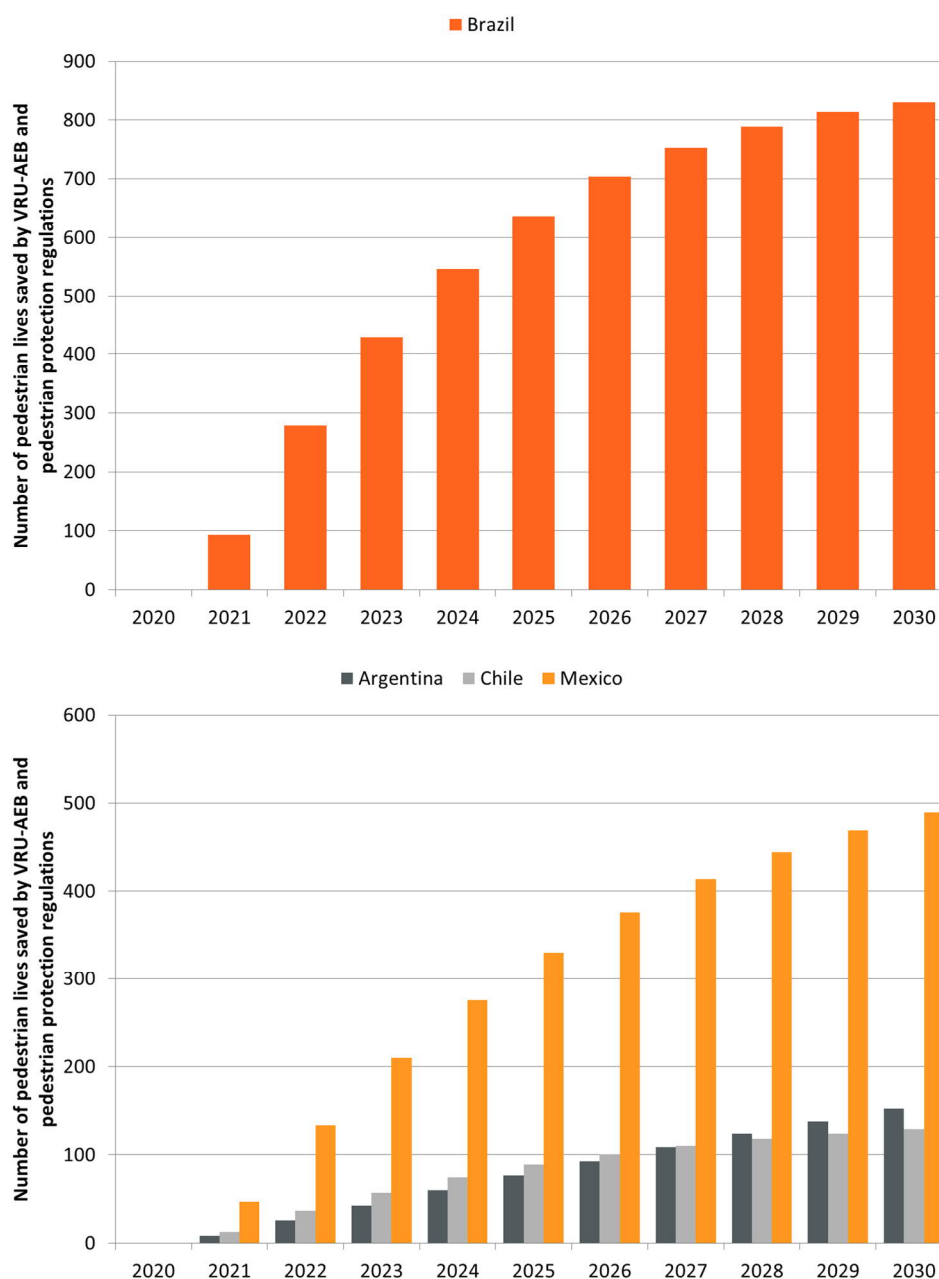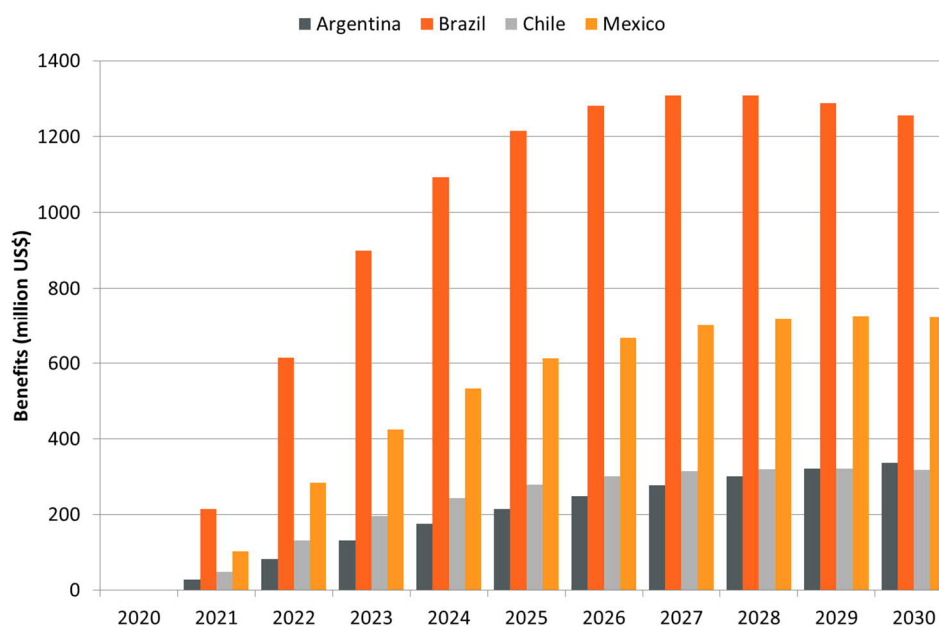

Figure 33: Estimated economic benefit for pedestrians due to implementation of VRU-AEB and pedestrian protection regulations in 2020 (2020-2030)

Table 13: Estimated economic benefit for pedestrians due to implementation of VRU-AEB and pedestrian protection regulations in 2020 (2020-2030)

	Cumulative lives saved, 2020-2030	Cumulative serious injuries saved, 2020-2030	Mid estimate of economic loss of one death due to traffic collision (2018 US $, thousands)	Estimate of economic loss of one death due to traffic collision (2018 US $, thousands)	Discounted economic benefit, 2020-2030 (2018 US $, millions)
Argentina	829	9,207	1,342	220	2,115.13
Brazil	5,871	65,550	914	150	10,482.44
Chile	851	9,751	1,473	241	2,471.10
Mexico	3,187	37,462	864	141	5,500.12
Total	10,738	121,970			20,568.80

In total, it is estimated that implementation of these two regulations would result in a $20.6 billion economic benefit for pedestrians across the four countries.

5.2.2   Pedal cyclists

A similar approach to modelling is used for pedal cyclists, although the effectiveness estimates differ:

- 55% for VRU-AEB

- 1.4% for passive pedestrian protection

Figure 34 presents the number of pedal cyclists saved by these regulations, and Figure 35 and Table 14 estimate the economic benefit.
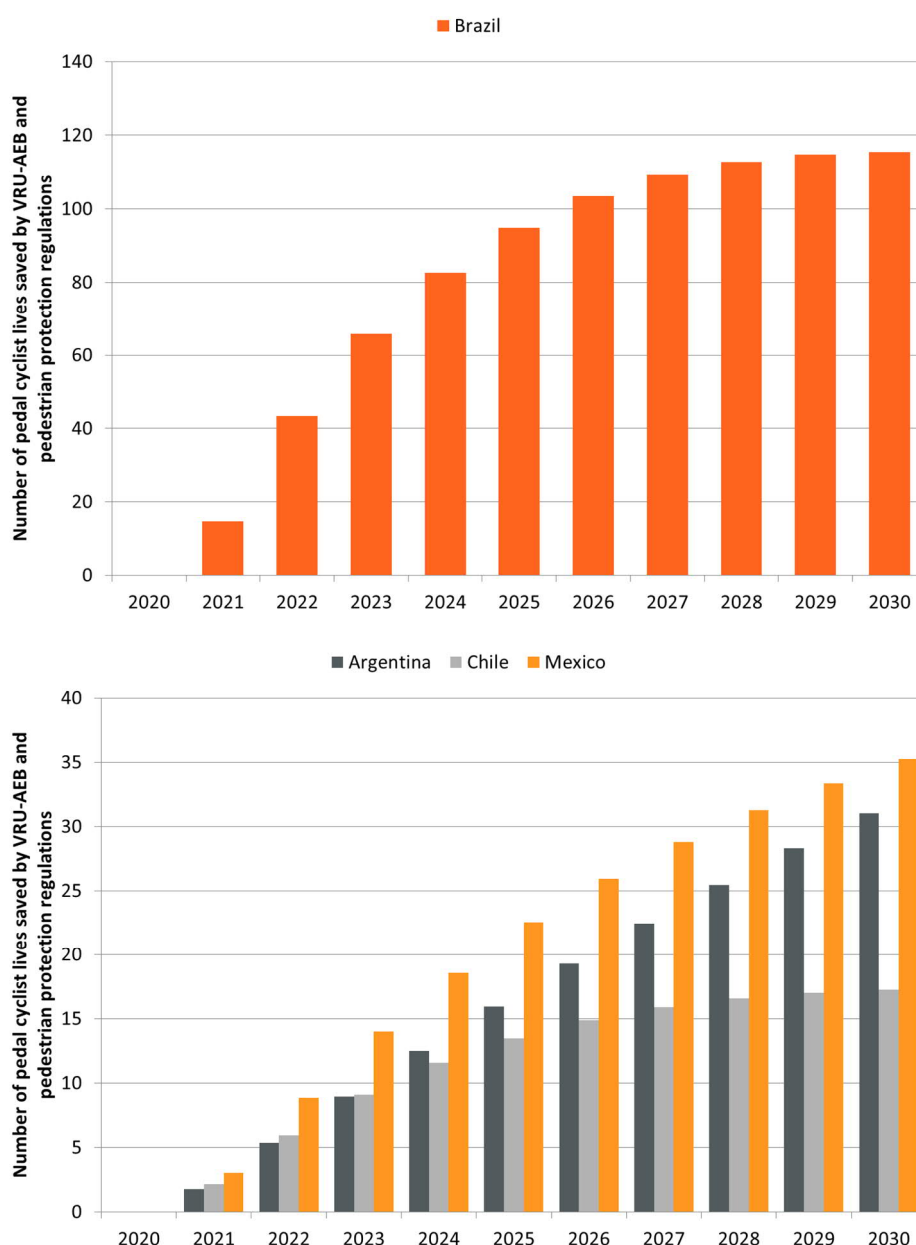

Figure 34: Estimated number of pedal cyclist lives saved due to implementation of VRU-AEB and pedestrian protection regulations in 2020 (2020-2030)

Compared to pedestrians, pedal cyclists make up a relatively small proportion of each fleet (see Figure 9, Section 3.2). As a result, the casualty savings for this mode are much smaller than those presented in Section 5.2.1. The model suggests that around 115 pedal cyclists will be saved in Brazil in 2030, around 35 in Mexico, around 30 in Argentina and around 17 in Chile, if VRU-AEB and pedestrian protection regulations are implemented in 2020.

In addition to the pedal cyclist fatality savings predicted, it is estimated that a further 6,500 lives would be saved between 2020 and 2030 if earlier regulatory action had ensured that VRU-AEB and Pedestrian Protection were already fitted throughout the whole vehicle fleet by 2020. This additional benefit will not be achieved because of the time it will take for the fleet to turnover and for older cars which don't have such protection to be replaced. It is also estimated that 37,500 serious injuries will be saved between 2020 and 2030, using the method described in Appendix H.
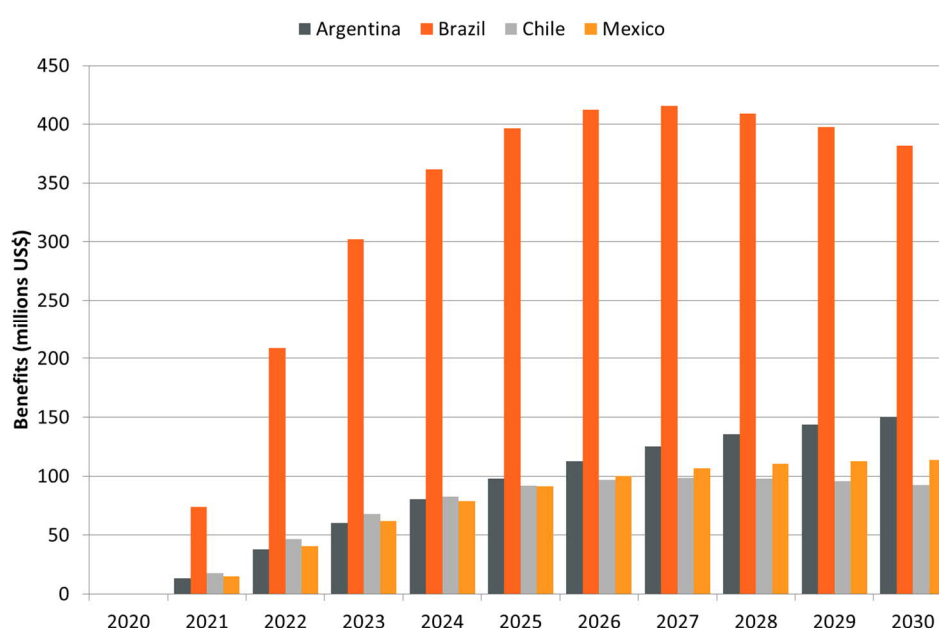

Figure 35: Estimated economic benefit for pedal cyclists due to implementation of VRU AEB and pedestrian protection regulations in 2020 (2020-2030)

Table 14: Estimated economic benefit for pedal cyclists due to implementation of VRU-AEB and pedestrian protection regulations in 2020 (2020-2030)

	Cumulative lives saved, 2020-2030	Cumulative serious injuries saved, 2020-2030	Mid estimate of economic loss of one death due to traffic collision (2018 US $, thousands)	Estimate of economic loss of one death due to traffic collision (2018 US $, thousands)	Discounted economic benefit, 2020-2030 (2018 US $, millions)
Argentina	171	4,428	1,342	220	956.47
Brazil	857	23,515	914	150	3,359.29
Chile	124	3,436	1,473	241	788.54
Mexico	222	6,121	864	141	830.57
Total	1,373	37,500			5,934.87

In total, it is estimated that implementation of these two regulations would result in just over $5.9 billion economic benefit for pedal cyclists across the four countries.

These analyses show that the benefit across the two VRU groups for these two regulations could be just over $26.5 billion.

6   Cost of regulated measures

This section presents the results of the consumer cost estimates. For each technology, estimated costs per vehicle were obtained from a variety of sources. These costs were combined with an estimate of the number of new vehicles equipped with the technology, assuming the regulations are introduced in 2020. The results presented were then discounted to reflect the preference for money to be available now rather than in the future. Section 6.1 presents the results for car occupants, Section 6.2 for VRUs and Section 6.3 discusses other costs which have not been incorporated in this analysis.

The costs obtained for the regulatory measures considered here, have been assumed to be static from the point of first fitment until the end of the evaluation period. However, in practice this is unlikely to be the case. Whilst costs could be constant (or consistent) for a production run (for a complete model) they are unlikely to be consistent from one model to the next. There will be production efficiencies and cost reduction pressures that mean technology costs reduce with time. No evidence was identified to specify a level of cost reduction to use in the modelling tasks to account for these reductions. However, the sensitivity modelling has been used to investigate the effect of a 50% cost reduction over the evaluation period. The implications of this uncertainty in cost estimates are discussed alongside the results from the sensitivity analysis in Section 7.

6.1   Car occupants

At outlined in Section 2.1.5, it is estimated that implementation of the ESC regulation was estimated to cost, on average, $50 per car.

Figure 36 presents the predicted number of newly registered cars in each of the four countries, based on a linear trend from the existing 2005 to 2016 data. Note that for Brazil, the number of newly registered cars has decreased in recent years; this is likely to have been influenced by the economic recession from 2012 to 2017 in this country (see Section 3.4). The upwards trend predicted between 2017 and 2030[31] is based on the assumption that it takes approximately 5 years for new car sales to return to pre-recession levels (based on the trend in GB following the 2007-2010 recession).

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[31] In Figure 36, the downwards trend in new car registrations is expected to continue until 2017 when the recession in Brazil finished, the trend from 2022-2030 is based on the linear trend of data from 2005 to 2016, and a linear assumption is made between 2017 and 2022. In reality, it is unlikely there will be a step change in the rate of new registrations in 2022, that inflexion is an artefact of the two modelled trends coming together in that year.
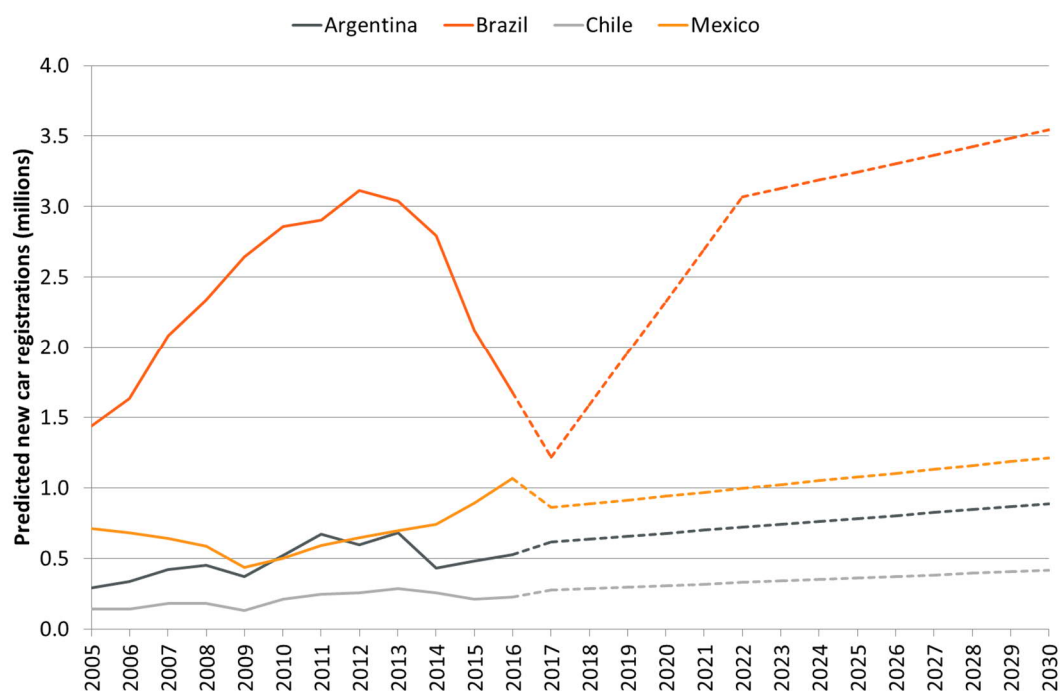
Figure 36: Predicted number of newly registered cars for each country (2005-2030)

To estimate the cost of equipping the fleet due to the introduction of the ESC regulation in 2020, the difference in the number of new vehicles infiltrating the fleet with ESC due to the regulation and the number entering the fleet due to voluntary uptake is calculated. This is then multiplied by the costs for each vehicle ($50 per car). As a result, the figures presented in Table 15 represent the additional cost to each country of introducing the regulation, having removed the effect of any voluntary uptake (similarly to the benefits, these costs are discounted to 2018 prices).

Table 15: Estimated costs associated with implementing ESC regulation in 2020 (2020-2030)

	Predicted additional vehicles equipped, 2020-2030	Discounted economic cost, 2020-2030 (2018 US $, millions)
Argentina	3,086,156	109.87
Brazil	14,363,598	518.25
Chile	1,503,222	53.74
Mexico	4,810,872	173.41
Total	23,763,847	855.27

In total, it is estimated that implementation of the ESC regulation would result in approximately $850 million economic cost across the four countries.

6.2   Vulnerable road users

As explained in Section 2.1.5, the estimated cost of implementation of VRU-AEB and passive pedestrian protection was estimated to be as follows:

- $261 per vehicle for VRU-AEB

- $258 per vehicle for pedestrian protection

Applying the same approach as described in Section 6.1 for these two technologies enables us to calculate the cost associated with implementing the associated regulations in 2020. This estimate removes the cost of voluntary uptake which is anticipated to happen anyway, even in the absence of regulation. Note that although the economic benefit estimates can be split by VRU type (pedestrians and pedal cyclists), it is not possible to distinguish the costs in the same way: if VRU-AEB is installed on a vehicle it will have collision avoidance benefits for both pedestrians and pedal cyclists.

Using the estimates of new vehicles (presented in Figure 36), the number fitted under the voluntary uptake scenario and the estimated costs, Table 16 presents the discounted costs associated with implementing the VRU-AEB and Table 17 presents the equivalent figure for pedestrian protection regulations.

Table 16: Estimated costs associated with implementing VRU-AEB regulation in 2020 (2020-2030)

	Predicted additional vehicles equipped, 2020-2030	Discounted economic cost for VRU-AEB, 2020-2030 (2018 US $, millions)
Argentina	6,016,793	1,136.15
Brazil	20,862,903	3,953.39
Chile	2,494,486	471.75
Mexico	7,400,237	1,401.59
Total	36,774,419	6,962.88

In total, it is estimated that implementation of the VRU-AEB regulation would result in approximately $7 billion economic cost across the four countries.

Table 17: Estimated costs associated with implementing pedestrian protection regulation in 2020 (2020-2030)

	Predicted additional vehicles equipped, 2020-2030	Discounted economic cost for pedestrian protection, 2020-2030 (2018 US $, millions)
Argentina	4,801,373	896.70
Brazil	18,687,545	3,485.98
Chile	2,787,776	519.82
Mexico	8,268,080	1,543.95
Total	34,544,774	6,446.46

In total, it is estimated that implementation of the pedestrian protection regulation would result in approximately $6.5 billion economic cost across the four countries.

These analyses show that the cost across the two VRU groups for these two regulations could be just over $13.4 billion.

6.3 Other costs

The costs we have obtained for vehicle technologies required to meet the regulatory requirements are stated in terms of a price per vehicle. However, these costs are not only intended to represent piece costs, but also to include manufacturing costs which would be a single price per production run. In this case the initial outlay can be large in terms of tooling, but this is amortised over all vehicles produced with that part or parts.

Whilst these piece costs and production costs are captured already, there is the potential for other costs to exist in responding to regulatory changes. An example would be the implementation of assessment centres. Test centres are required to check that new vehicle Types meet the regulations. For frontal impact crash protection, this would include a full-scale crash test laboratory that can undertake the 56 km/h frontal impact test necessary to prove compliance.

In the UK there are several test centres that are capable of undertaking tests of this nature. None of them trades solely in crash testing, but the claimed annual revenue for the whole of one business is about £40 million[32].

In 2013, the Brazilian government announced their intention to install a crash test facility in country[33]. This is reported to have cost $50 million, though there is no news as to the status with the build and installation.

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[32] Rutland Partners (2013) Investment in Millbrook; www.rutlandpartners.com/news-and-media.html?id=90

[33] Automotive World (2013) Government to set up Brazil's first crash test centre; www.automotiveworld.com /analysis/govt-to-set-up-brazils-first-crash-test-centre/

Adding equivalent centres in Argentina, Chile and Mexico might add an additional $50 million in each country. It is likely that sharing of facilities can mitigate the need for each country to have its own dedicated test facility and staff. However, if this cannot be arranged then the costs would have to be modified by this amount. The change for VRU protection would be negligible, but for ESC it could have a bearing on the benefit-to-cost effectiveness of the initiative.

Regarding other areas concerning enforcement of legislation, it has been assumed that the vehicle approval functions operate in the same way as with existing vehicle approvals and that the type approval authorities have existing capacity to deal with any increased processing requirements.

7 Benefit-to-cost estimates

This section takes the benefit estimates presented in Section 5 and the cost estimates in Section 6 and calculates the benefit-to-cost ratio (BCR) for each country. These BCRs allow a comparison of the extent to which the benefits exceed (or fall short of) the costs related to implementation of the equivalent regulation over the period 2020–2030, compared to the baseline scenario (which only includes voluntary uptake of each technology). Values greater than 1 indicate that the benefits are greater than the costs incurred. For example, a BCR of 1.5 can be interpreted as follows: "for every dollar invested by consumers in purchasing vehicles with these technologies, there's a $1.50 return in economic benefit to society".

In addition to the overall results over the period, results for individual years and ranges of uncertainty from the sensitivity analysis are presented. A full description of the methodology used for the sensitivity analysis is presented in Appendix D.

7.1 Car occupants

Table 18 shows the year in which the ESC regulation becomes cost-beneficial (BCR greater than 1) in each of the four countries. The lower and upper bounds from the sensitivity analysis are also presented.

Table 18: Year in which ESC becomes cost-beneficial in each country

Country	First cost-beneficial year	First cost-beneficial year (lower estimate from sensitivity analysis)	First cost-beneficial year (upper estimate from sensitivity analysis)
Argentina	2022	2027	2021
Brazil	2022	2024	2021
Chile	2021	2023	2021
Mexico	2024	>2030	2023
Overall	2022	2025	2021

In each of the four countries studied in this paper, the results suggest that ESC will be cost-beneficial (have a BCR of greater than 1) within a few years of the regulation being introduced. Looking at the individual countries, ESC is predicted to become cost-beneficial very quickly in Chile, Brazil and Argentina, but take longer in Mexico. As shown in Figure 21 and Figure 22, the number of car occupant fatalities in Mexico is predicted to decline substantially up to 2030, even in the absence of specific new regulatory interventions (based on the current trend for the car occupant fatality rate). As mentioned in Section 3.2, this trend aligns with an increase in motorcycle use and fatalities, not just car occupant safety improvements. Additionally, Mexico has the oldest fleet of cars of the four countries. The turnover of the fleet is slow and as a result, the immediate impact that ESC regulation would have on the number of casualties is reduced, compared with the other countries.

The lower estimates for each country relate to Scenario 6 (described in Appendix D) which uses a lower estimate on the effectiveness of ESC. These estimates demonstrate that if ESC is only 15% effective (the 95% lower confidence limit for the light vehicle effectiveness estimate from the literature source (Høye, 2011)) rather than 38% effective, the benefit-to-cost ratio only becomes greater than 1 in Argentina, Brazil and Chile before 2030, but not in Mexico.

In contrast, the upper estimates are based on Scenario 13 which uses an alternative Value of Statistical Life for each country (Viscusi and Masterman, 2017)[34] to those presented in Table 7. These estimates demonstrate that if the VSL estimates for each country are substantially higher ($2.23, $1.47, $2.33, $1.47 million in 2018 USD for Argentina, Brazil, Chile and Mexico respectively, compared to the mid-estimates used in the rest of this report: $1.34, $0.91, $1.47 and $0.86 million), the benefit-to-cost ratio becomes greater than 1 within a year of the regulation being introduced in Argentina, Brazil and Chile, and within three years in Mexico.

Figure 37 shows the trend in the best-estimate BCR over the period 2020 to 2030, reflecting the results in Table 18.
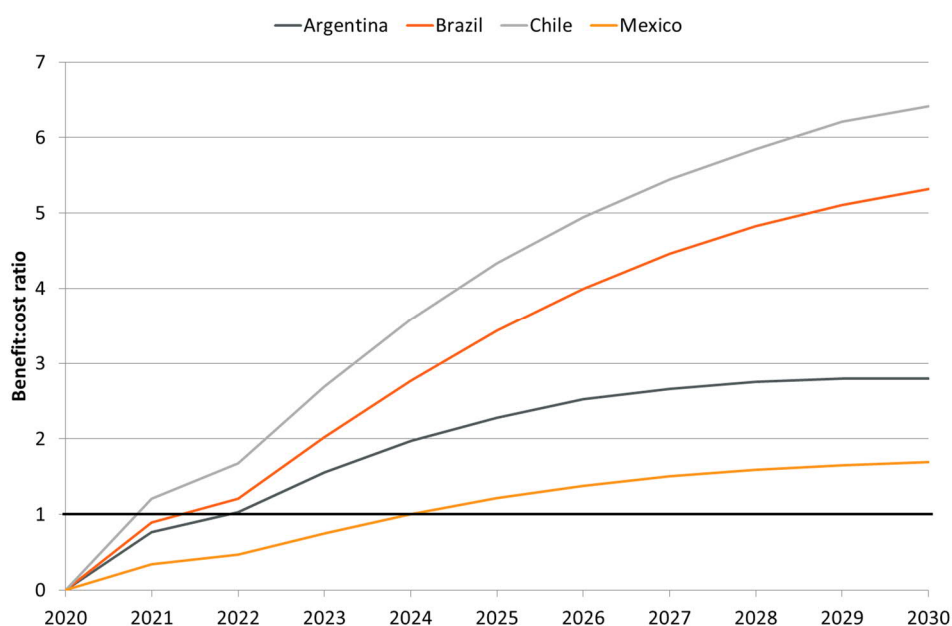
Figure 37: Estimated benefit:cost ratio associated with implementing ESC regulation in 2020 (2020-2030)

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[34] Although the Viscusi & Masterman (2017) estimates are newer than those presented by Bhalla et. al. (2013), the latter were selected as the most appropriate for the project because this paper also estimates the relationship between GDP per capita and serious non-fatal injuries. These estimates are used in the serious injury analysis in 0. In addition, Viscusi & Masterman do acknowledge that their VSLs exceed the values that policy makers in foreign nations have utilized in the past.

The shape of these curves is typical of cost-benefit analysis of new technologies: costs to equip the vehicles are incurred across the whole time period as new vehicles enter the fleet, but the benefits of these vehicles only gradually accumulate as a larger proportion of the fleet is equipped. Eventually, the BCR levels and then tails off, as the target population for the collisions reduced or mitigated by the new technology, reduces towards zero.

7.2 Vulnerable road users

Table 19 shows the cumulative BCR for the combined effect of VRU-AEB and secondary safety (passive) pedestrian protection regulations, taking into account the effect on both pedestrians and pedal cyclists.

Table 19: Year in which VRU-AEB and pedestrian protection become cost-beneficial in each country

Country	First cost-beneficial year	First cost-beneficial year (lower estimate from sensitivity analysis)	First cost-beneficial year (upper estimate from sensitivity analysis)
Argentina	2024	2026	2023
Brazil	2023	2025	2021
Chile	2022	2023	2021
Mexico	2023	2025	2021
Overall	2023	2025	2021

This table suggests that the VRU regulations will become cost-beneficial for all four countries by 2024, and even sooner for Brazil, Chile and Mexico. Figure 38 shows the BCR for each year in the four countries.
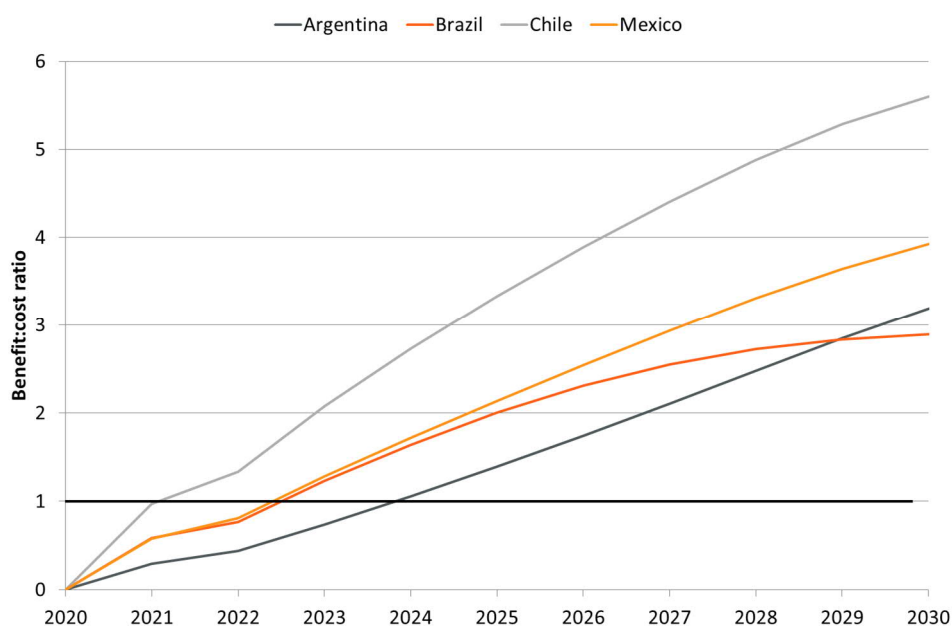
Figure 38: Estimated benefit:cost ratio associated with implementing VRU-AEB and pedestrian protection regulations in 2020 (2020-2030)

As with the car occupants model, the lower BCR estimates presented in Table 19 are based on Scenario 4 for the VRU model where the effectiveness estimate for VRU-AEB is assumed to be lower and the upper estimates are based on Scenario 11 where the costs are halved. The same comments on the likelihood of these scenarios being realised applies as discussed in Section 7.1.

7.3   Overall benefit-to-cost estimates

Table 20 and Figure 39 show the combined results for all three regulations: ESC, VRU-AEB and pedestrian protection.

Table 20: Year in which the combined set of technologies (ESC, VRU-AEB and pedestrian protection) becomes cost-beneficial in each country

Country	First cost-beneficial year	First cost-beneficial year (lower estimate from sensitivity analysis)	First cost-beneficial year (upper estimate from sensitivity analysis)
Argentina	2024	2026	2023
Brazil	2023	2025	2021
Chile	2022	2023	2021
Mexico	2023	2025	2021
Overall	2023	2025	2021

The results show that by 2024, the BCR exceeds the neutral cost-benefit (i.e. 1) for all four countries, and does so even earlier for Chile (2022) and Brazil and Mexico (2023). This indicates that the implementation and harmonisation of these regulations would be a positive move for the region. The BCR for each year is presented for each country in Figure 39, as well as the overall BCR across the region, represented by the black dashed line.
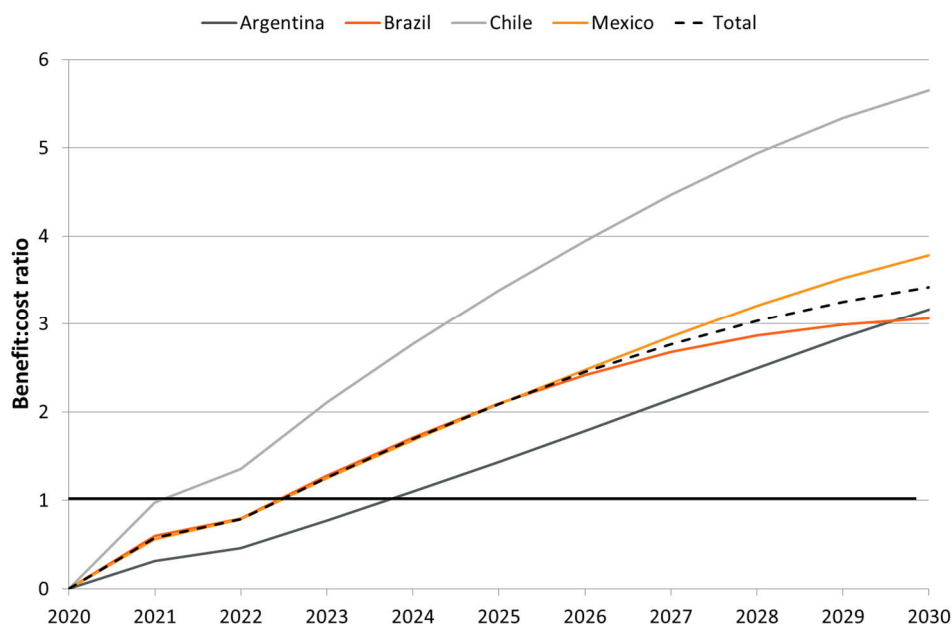

Figure 39: Estimated benefit:cost ratio associated with implementing all three regulations (ESC, VRU-AEB and pedestrian protection) in 2020 (2020-2030)

8   Conclusions

In the EU (and other industrialised regions) vehicle safety standards have improved substantially over the past few decades, resulting in the realisation of substantial casualty savings. These improvements have been driven by regulations (including frontal and side impact regulations) and consumer testing programmes such as Euro NCAP, which have encouraged manufacturers to exceed the minimum requirements set out in the regulations.

The World Health Organization estimates that the number of road traffic deaths has reached 1.35 million per year (WHO, 2018). The Global Status Report on Road Safety (WHO, 2018) highlighted that while vehicles in high-income countries are increasingly safe, less than half of countries implement minimum standards on vehicle safety, and that these standards are absent in many of the major car manufacturing middle-income countries.

Vehicle safety is one of the five pillars of the United Nations Decade of Action for Road Safety (2011-2020), and as a result it is important to ensure it is on the agenda of policy-makers across the world.

8.1   Potential casualty savings

This project aimed to quantify the number of road user fatalities that could be prevented in four of the major geographical regions in Latin America (specifically, Argentina, Brazil, Chile and Mexico) if vehicle safety regulations were applied to passenger cars. It builds on previous analyses which looked at minimum secondary safety regulations and consumer test programmes as reported by Cuerden et al. (2015) and Wallbank et al. (2016). Primary safety systems were not considered in those analyses, and neither was the impact of systems designed to prevent collisions or reduce injuries associated with vulnerable road users.

Therefore, this project estimated the impact of implementing regulations equivalent to these as a minimum:

- Approved seat belts and anchorages for all seating positions (UN Regulations 14 and 16)

- Occupant protection in frontal and lateral collisions (UN Regulations 94 and 95)

- Electronic Stability Control (ESC) (UN Regulation 140 or UN GTR 8)

- Pedestrian protection (UN Regulation 127 or UN GTR 9)

- Autonomous Emergency Braking (AEB) system for Vulnerable Road Users (VRU)

Since there was no evidence of substantial vehicle safety improvements since the last projects, it was concluded that, broadly, today's Latin American cars are still performing approximately 15 years behind cars in Great Britain. Therefore, the car occupant secondary safety modelling was built on the assumption that 2016 model year cars in the four Latin American countries are like those sold in Europe in 2001.

Updating the secondary safety benefit results from those previous projects led to the estimate that over 11,000 car occupant fatalities will be prevented in the four countries included in this study between 2017 and 2030 if minimum vehicle safety standards continue to be implemented as planned. This assumes that UN Regulation 94 (occupant protection in frontal collision), Regulation 95 (occupant protection in lateral collisions) and Regulations 14 & 16 (approved seat belts and anchorages for all seating positions) are mandated for new vehicles in all four countries. This is great news for these countries and, provided the regulations are implemented as planned and enforced, demonstrates the large benefits which they should accrue over the next decade.

On top of these savings, this project has estimated the number of car occupant fatalities which could be saved by the primary safety system ESC: the model estimates that an additional 2,200 fatalities could be prevented between 2020 and 2030 if the appropriate regulation were introduced in 2020 for all new models and 2022 for all new cars. Similarly, when VRU regulations are considered, the models estimate that VRU-AEB and pedestrian protection will save up to 11,000 pedestrians and 1,400 pedal cyclists between 2020 and 2030. Table 21 shows how these figures are broken down by country.

Table 21: Estimated lives saved due to implementation of each vehicle safety regulation in 2020 (2020-2030)

	Cumulative lives saved, 2020-2030		
	ESC for car occupants	VRU-AEB and pedestrian protection for pedestrians	VRU-AEB and pedestrian protection for pedal cyclists
Argentina	160	829	171
Brazil	1,699	5,871	857
Chile	142	851	124
Mexico	206	3,187	222
Total	2,207	10,738	1,373

In addition to the fatality savings predicted above, it is estimated that a further 15,000 lives would have been saved between 2020 and 2030 if earlier regulatory action had ensured that ESC was fitted throughout the whole vehicle fleet by 2020. This additional benefit will not be achieved because of the time it will take for the fleet to turnover and for older cars which don't have ESC fitted to be replaced.

Finally, in addition to the fatality savings, a simplification of the modelling process was also applied to estimate the number of serious injuries prevented. The results estimate that between 2020 and 2030 around:

- 8,000 car occupant serious injuries will be prevented

- 120,000 pedestrian serious injuries will be prevented

- 44,000 pedal cyclist serious injuries will be prevented.

8.2   Economic benefits and costs

The Valuation of Statistical Life (VSL) method estimates the economic loss due to a traffic collision in terms of GDP per capita. This methodology has its limitations, but application to the fatality and serious injury savings (only for those regulations which have not already been implemented in each country) suggests that implementation of the ESC regulation could save up to 2.35 billion USD (2018 $) over the period 2020 to 2030. Adopting AEB for VRUs and secondary (passive) protection for pedestrians and pedal cyclists could save just over 26.5 billion USD over the same period.

Costs were obtained from literature sources to address the vehicle changes that would have to be made to equip all new cars with parts and technological components necessary to comply with these regulations. The corresponding costs for the region are 850 million USD to adopt ESC and 13.4 billion USD to adopt the VRU protection measures.

Comparison of the benefits and costs, taking into account both fatalities and serious injuries leads to the benefit-to-cost ratios for each country becoming greater than 1 by the following years:

Table 22: Years in which benefit-to-cost ratios become greater than 1

Country	Year in which ESC becomes cost-beneficial (fatalities and serious injuries)	Year in which measures to protect VRUs become cost-beneficial (fatalities and serious injuries)
Argentina	2022	2024
Brazil	2022	2023
Chile	2021	2022
Mexico	2024	2023
Overall	2022	2023

The equivalent years in which the measures achieve a benefit-to-cost ratio of greater than one, when considering fatalities only are available in Table 27 and Table 29, in Appendix G.

In addition, comparison of the cumulative fatality and serious injury benefits and costs leads to the following cumulative benefit-to-cost ratios for the region by 2030[35]:

- ESC = 2.75

- Measures to protect VRUs = 1.98

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[35]   Counting the benefits to fatalities only, then the cumulative benefit-to-cost-ratio between 2020 and 2030 for the four countries is: 1.58 for ESC and 0.61 for Measures to protect VRUs.

It should be noted that whilst the aggregated cumulative benefit-to-cost ratio in the region for ESC is expected to rise above 1 by 2022, in Mexico it is expected to take until 2024 for the 'in-year' benefits to exceed the 'in-year' costs. This result for Mexico is because of the recent downward trend in the car occupant fatality rate (number of fatalities per 100 million passenger km, per year) within this country and a slow turnover in the car fleet. It has been suggested that the decline in car occupant fatality rate may be linked with an increase in motorcycle use and motorcyclist fatalities rather than a pure improvement in car occupant safety. Whatever the reason, if the implied car occupant safety improvements in this country slow, then the benefits of ESC could become greater. Equally, if the proportion of the car fleet renewed each year increases then the return on the ESC fitment investment will be greater and realised sooner.

Conversely, ESC is expected to become cost-beneficial very quickly in Brazil and Chile (within 1-2 years of the regulation being introduced), and reasonably quickly in Argentina (3 years after regulation).

For VRU protection measures, the aggregated cumulative benefit-to-cost ratio for the region is expected to rise above 1 by 2023. However, in Argentina it is expected to take until 2024 for the 'in-year' benefit-to-cost ratio to increase above 1. However, the aggregate benefit-to-cost ratio achieves an 'in-year' value of 1 very quickly for Chile (by 2022) and reasonably quickly for Brazil and Mexico (by 2023). Of the four countries, Argentina has the smallest proportion of pedestrians within the road traffic collision fatalities for the country (10%). Car occupants (50%) and motorcyclists (30%) account for most of the road users killed in Argentina. This explains why changes to protect vulnerable road users (pedestrians and bicyclists) would require the longest time before providing a positive return on the investment in vehicle fleet changes.

These results suggest that both ESC and VRU regulations would be cost-beneficial across the four countries if serious injuries are considered as well as fatalities. However, some caution should be applied to these estimates since, as discussed in Appendix H, there are some substantial assumptions made about the casualty figures, which may mean that the estimated number of serious injuries prevented does not truly reflect the numbers observed in each country.

8.3   Model limitations

The modelling presented in this paper has used various input values and assumptions to predict the effects of introducing a range of vehicle safety regulations into four countries in Latin America. Predictions of the future are by definition inherently subject to a degree of uncertainty. This study has used input values based on historical trends and whilst the sensitivity analysis (Appendix D) provides some assessment of the effect that deviations from the expected trend may have on the outcome, it cannot completely account for extreme changes in circumstances. The following important limitations of the simulation model and the input value estimates should be taken into account when interpreting the results.

The predictions are based on the assumption that current trends in road traffic fatalities continue as they have done in recent years. For some countries (Chile and Mexico) these trends are based on 10+ years of data, but for others (Brazil and Argentina) the data are limited. Whilst the fatality numbers used have been verified across a number of sources (where possible), the authors cannot comment on how accurate these figures are. For example, if underreporting levels[36] have changed, or there are inherent biases in the data reported, then these trends may not hold true into the future.

In addition, this approach cannot capture any potential disruptions that might occur in the mobility market in the future, such as autonomous driving radically changing the collision landscape, mobility as a service reducing private car ownership, or a severe economic crisis reducing new vehicle uptake. Disruptions are highly uncertain and impossible to predict as to when, if, and to what extent they will happen and hence their impact could not be captured in the models. If any such changes were to occur then the effect of implementing vehicle safety regulations in Latin America could be vastly different than predicted here.

The effectiveness and cost estimates used are subject to a degree of uncertainty. The level of uncertainty varies between safety measures; there are many studies on the effectiveness of ESC but due to the progress with VRU-AEB (which does not yet have a corresponding regulation, either European or UN – though these are being developed now) there are fewer effectiveness estimates. The passive pedestrian protection regulations are different again, as the formative research assessing European regulation was completed more than ten years ago. The cost estimates were established from relevant literature and are therefore considered to represent the highest level of evidence that could be acquired in the timeframes of this project. However, since they were published, manufacturers have reduced the costs for incorporating the same measures in the latest vehicle models and it seems unrealistic to expect that the full costs obtained from literature sources will ever be translated to consumers in entirety. To treat the remaining uncertainty in these values, upper and lower estimates were employed for the sensitivity analysis.

The results of the cost-benefit analysis should be interpreted with this context in mind and understood as an evidence-based prediction of the cost-effectiveness of the regulations, if historic trends continue within a range of expected uncertainty.

Furthermore, with the implementation of any regulation then appropriate measures will be necessary to enforce compliance. This research has not investigated in detail whether substantive changes would be required to legislative vehicle safety enforcement in any of the four countries to obtain the benefits predicted. However, this need should be recognised alongside the predictions presented.

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[36] Note that there is some evidence from hospital data for Mexico that the number of fatalities reported in the police-reported data (sourced from INEGI) is much lower than reported in the hospital death statistics (STCONAPRA, 2017). Whilst this does suggest some degree of underreporting in the figures used in this report, the trends over the available time period (2011-2015) in the hospital data were similar to those observed in the police report data, and thus there was no evidence to suggest the level of underreporting has changed over time. In order to maximise the number of years of data available for this analysis, and to reflect the reported figures used in the WHO Global Status Report on Road Safety, the decision was made to use the police-reported fatality figures for all countries.

8.4   Summary of key results

This analysis has shown that the four countries included in this study could already have prevented over 11,000 car occupant fatalities between 2017 and 2030 through the implementation of UN Regulations 94 and 95 (occupant protection in frontal and lateral collisions) and UN Regulations 14 and 16 (approved seat belts and anchorages for all seating positions).

On top of this, if ESC, secondary safety pedestrian protection and AEB for VRU regulations were implemented then these were estimated to have the potential to:

- Save around 14,000 lives during the period 2020 to 2030 (and around 290,000 serious injuries)

- Have an economic benefit of $28.9 billion USD through preventing fatal and serious injuries ($9.5 billion USD when considering only fatal injuries)

- Provide an in-year benefit-to-cost ratio greater than 1 by 2023 (2028 for fatal injuries only).

Together the combination of seat belt and seat belt anchorage, frontal and side collision, ESC, secondary safety pedestrian protection and AEB for VRU regulations could save in excess of 25,000 lives in Argentina, Brazil, Chile and Mexico by 2030 and save over 170,000 serious injuries.

8.5   Recommendations

Some recommendations emerging from this research are clear, for instance:

- Fatality figures have been factored to represent a standard 30-day definition (where the death must have occurred within 30 days of the collision). It would be useful to ensure all future data are collected on this basis for all countries.

- It is recommended that Brazil implements with an appropriate timescale UN Regulation 95 for impact protection of car occupants in the event of a side impact, or lateral collision. This has been implemented (or announced for future implementation) in the other three countries included in this study and should be harmonised across Latin America, particularly given the potential for the secondary safety measures to save lives in the region. The consequence of not aligning a timetable for this is not just that the life-saving potential of the countermeasures is not realised, but also that initiatives in other countries are postponed or cancelled. The example here is with ESC implementation in Argentina where implementation has been pushed back to align with other countries. Correspondingly, it is further recommended that Mexico completes the implementation of crashworthiness regulations to fulfil its part in this harmonisation of requirements across the four countries.

- Seat belt wearing is vital to safety for car occupants and is a fundamental requirement to achieve the benefits estimated for secondary safety impact protection measures. In other world regions seat belt reminders have been shown to be effective at increasing seat belt wearing rates. Therefore, to maximise the benefits of the secondary safety impact protection measures, it is recommended that all four countries should ensure that their seat belt requirements include mandatory compliance with UN Regulation 16 (or an equivalent) at a revision level that requires seat belt reminders for the driver's seating position. Enacting the latest revision of UN Regulation 16 would implicitly provide the requirement for seat belt reminders and aid worldwide harmonisation of safety standards.

- The predicted benefit-to-cost ratio for ESC in all four countries recommends it for implementation across the region, with the 'in-year' benefits exceeding the costs within a few years of implementation.

Vulnerable road user impact-friendly vehicle design is particularly important for regions with substantial numbers of vulnerable road user casualties. Adopting the pedestrian protection regulation (UN GTR 9 or UN Regulation 127) ensures a minimum level of protection in the event of a collision with a passenger car. However, there is an opportunity for Latin America to capitalise on Autonomous Emergency Braking systems for Vulnerable Road Users which are emerging and likely to be mandated in Europe

- If implemented in 2020, these vulnerable road user protection measures have the potential to save more than 12,000 lives between 2020 and 2030.

- These vulnerable road user protection measures have an 'in-year' benefit-to-cost ratio that becomes greater than 1 by 2024 in Brazil, Chile and Mexico, and in Argentina by 2029, accounting for the impact of the measures on fatalities and serious injuries.

Other recommendations may also be justified.

- It is noted that initiatives to implement ESC were postponed previously in Argentina due to requirements to harmonise legislation with Brazil. For this reason, and to maximise the stated potential to save lives, matching implementation dates should be set for ESC throughout Latin America. Legislation may be the only way to ensure equal fitment of ESC to all segments of the car market and, hence, equality of protection for all car occupants.

- In Europe, the secondary safety pedestrian protection regulation was complimented with the requirement to fit Brake-Assist Systems (BAS). Adding the mandatory requirement to fit BAS may improve the effectiveness of the regulation for VRU. It may also bring benefits for other road users, injured in other collision events with emergency braking initiated by the driver.

Acknowledgements

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Appendix A   Technology uptake within fleet

There are two aspects to consider when estimating the fleet fitment of ESC, VRU-AEB or pedestrian protection within the fleet:

- Voluntary uptake, where the propagation of technology is led by the willingness of manufacturers to fit the necessary components to vehicles and the willingness of consumers to pay for them.

- Mandatory uptake brought about by a policy intervention. In this case, all vehicles or all vehicle types will be required to meet the regulatory requirements by an implementation date.

In order to model the fleet fitment, data on the number of registered vehicles and the number of newly registered vehicles is combined with information on how these technologies have propagated in other fleets (based on data provided by Bosch from Europe). This appendix outlines the assumptions and data used for this task.

Firstly, the total number of registered cars is predicted up to 2030 by assuming a linear extrapolation using the data from 2005-2015 (see Figure 20 in Section 4.1).

A similar extrapolation is carried out for newly registered cars (see Figure 36 in Section 6.1). Since vehicle safety features will not be retrospectively fitted to the existing car fleet, fitting 100% of these cars with the technology represents the maximum speed at which it is possible for this technology to infiltrate the fleet.

This data demonstrates that the vehicle fleets in the four countries turnover at different rates (for example, only 3% of cars in the Mexico fleet are new each year, but this figure is much higher for Chile at 7%). These differences need to be incorporated in the estimate of fitment across the whole fleet. As described above, Information on the total number of cars and new cars in the fleet was available for each country, but limited information was available on the number or age of those vehicles dropping out (due to being scrapped). Evidence from the literature suggests that the average age of the vehicle fleet in Latin America is typically at least 10 years (see Section 3.5.3). As a result, for the purposes of this analysis, we have assumed that no cars fitted with the technologies drop out of the fleet during the timeframe of interest (2020-2030). In reality there will be new cars dropping out of the fleet due to collision damage; cars which may be fitted with new technology or safety measures. However, for this rate of fleet turnover and the uncertainties over forward projections of new car numbers and whole fleet size, this omission of new car drop out is thought to be reasonable.

The assumptions used in this project around fleet fitment were based on evidence gained from a similar cost-benefit analysis for the European Commission (Seidl et al., 2017). Specifically, voluntary uptake is modelled based on the uptake seen in Europe under similar conditions, where it was estimated that it would take 10 years to reach 80% of all new vehicles fitted with ESC. This uptake is modelled using an S-shaped curve[37].

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[37] Estimated using a sigmoid function

The launch date for a technology was used to define the x-axis (time) start point for S-shaped curves of fitment. This relates to the first time a system was released with the characteristics likely to be required in order to meet the regulatory requirements. The assumed launch dates for each technology in each country are documented in Table 23.

- The launch dates for ESC were based on fitment information received from a Tier 1 supplier provided via the Stop the Crash partnership. They indicated the years in which the fitment in car production processes or new vehicle sales stepped up beyond a negligible level. Adjustments were made to match the subsequent fitment information from this source or from recent sales literature (i.e. manufacturers' websites).

- The launch dates for AEB for VRUs were estimated on the basis of the technology available on the top 20 best-selling cars in each country, based on internet searches of manufacturer's internet sites. The rate of fitment, as standard, was found to be 0% for Mexico, 3% for Argentina and Chile, and 5% in Brazil.

- The launch dates for pedestrian protection were based on the expected fitment levels for the best-selling cars again. Although, with pedestrian protection standard fitment was judged by the cars receiving a Latin NCAP Advanced Award for pedestrian protection. Despite many cars having European counterparts, which already have to meet the requirements of UN Regulation 127, no new cars received this award in Chile or Mexico. In Brazil and Argentina, the Toyota Corolla features in the top 20 best-selling cars, and the Corolla received this Advanced Award from Latin NCAP when assessed in 2017. The launch date for these two countries was then adjusted so that the S-shaped curve of new car fitment matched the proportion of new car sales represented by the Corolla in 2017.

Table 23: Assumed launch dates of ESC, VRU-AEB and pedestrian protection in each Latin American country

	ESC	VRU-AEB	Pedestrian protection
Argentina	2005	2017	2013
Brazil	2010	2014	2012
Chile	2008	2015	2017
Mexico	2010	2015	2017

The year that full voluntary implementation is achieved dictates the slope of the S-shaped curve and represents the time necessary for the measure to reach maturity in terms of full voluntary adoption into new vehicle registrations. For all three technologies, it is assumed that a long voluntary implementation phase of 20 years is required to reach full voluntary adoption. This length of time was necessary to match the recent data on ESC fitment in Argentina, Brazil and Chile more closely than would be provided by the evidence on European uptake period, of 10 years.

The maximum voluntary take up of technologies within the fleet was as follows:

- 60% voluntary propagation for ESC, leaving the 40% of vehicles which wouldn't be equipped without regulatory action (as supported by the Tier 1 fitment data)

- 50% voluntary propagation for VRU-AEB and pedestrian protection (indicating a slightly lower willingness for consumers to adopt the technology on a voluntary basis)

These values represent point estimates for the resulting final take up in the fleet. The S-shaped curve for percentage of newly registered cars equipped is modelled to form a plateau at this value.

Examples of model outputs for uptake and fleet dispersion of each technology are shown in Figure 40 for the voluntary uptake scenario only (i.e. the baseline scenario – see Section 4). The charts on the left represent the proportion of new cars equipped with the technology each year (these charts level off at the maximum uptake levels defined above) and the charts on the right show how this translates to the uptake within the whole car fleet. The points on the ESC chart show the data provided by Bosch for each country – these were used to define the launch dates documented in Table 23.
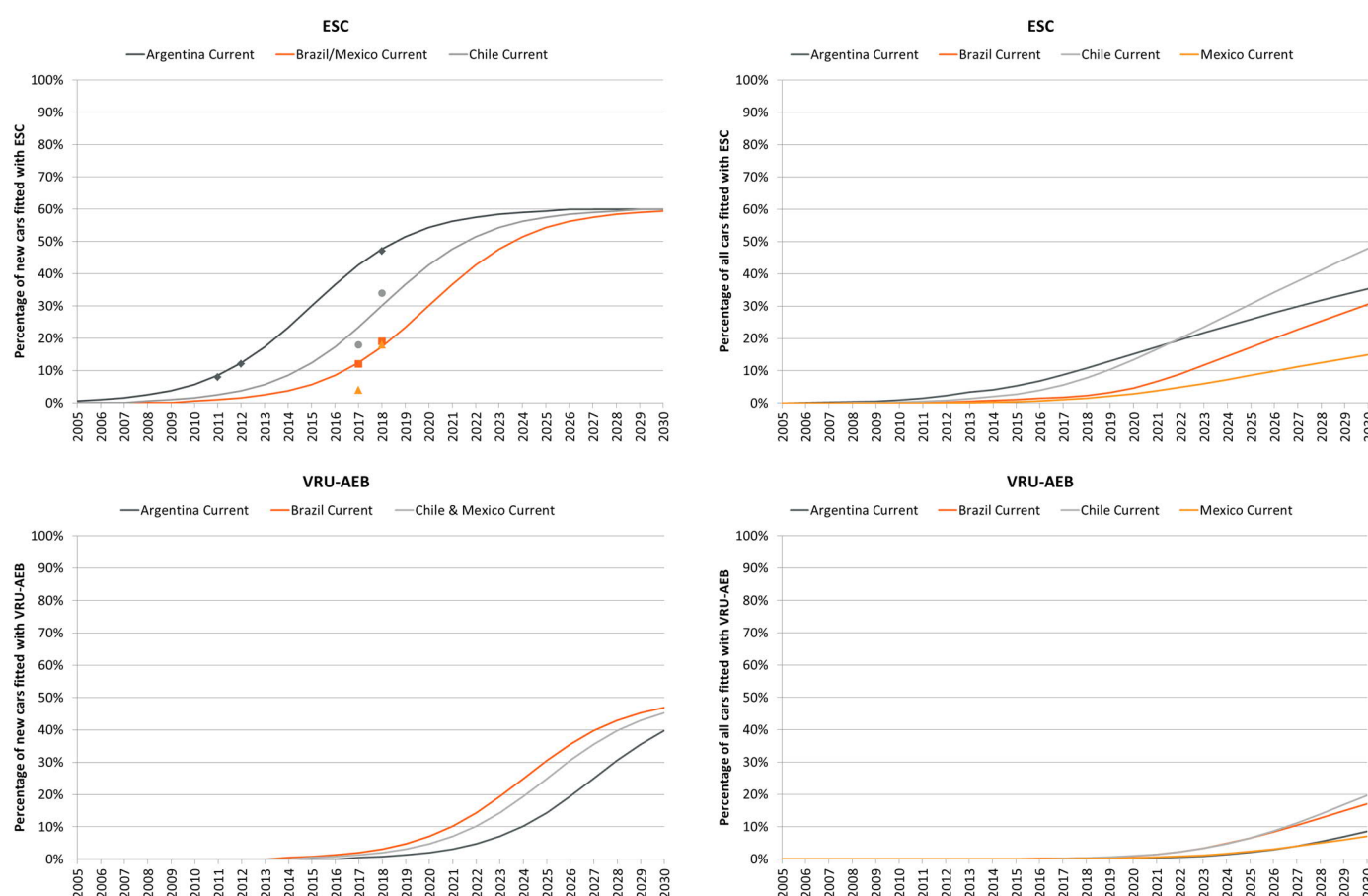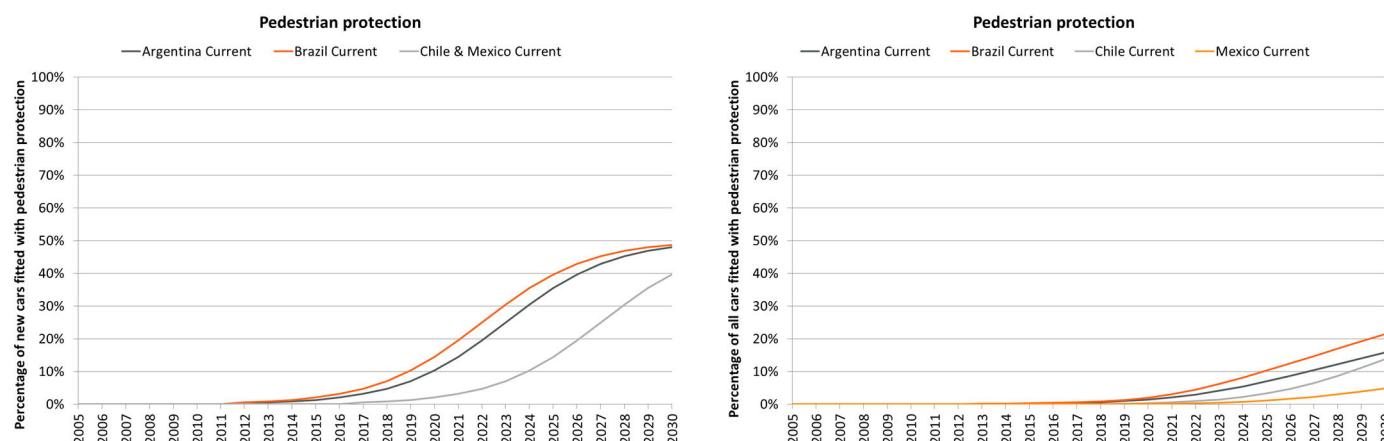
Figure 40: Left hand side: percentage of newly registered cars equipped with each technology in voluntary uptake scenario

Right hand side: percentage of all registered cars equipped with each technology in voluntary uptake scenario

Using the assumption of revised regulation timelines (i.e. assuming that all three technologies are introduced into regulation in 2020), the fitment curves can be adjusted.

In practise, regulation typically comes in in two phases:

1. All new models (Types) are required to have ESC and VRU-AEB and pedestrian protection measures fitted

2. Two years later, all new cars are required to have ESC and VRU-AEB and pedestrian protection measures fitted

In order to replicate this, the regulation dates have been chosen as 2020 (all new models) and 2022 (all new cars). In order to model this, the mandatory uptake scenario follows the voluntary uptake curve up until 2020 and elevates the new vehicle fitment rates from then onward gradually over two years to 100% (see uptake between dotted vertical lines on the charts on the left side of Figure 41).

Even with full fitment in new vehicles, it still takes time for those vehicles to replace existing vehicles on the road (charts on the right hand side of Figure 41). The difference between the curves in Figure 41 and Figure 40 is responsible for the fatalities prevented of a regulation option compared to the baseline option. These fatality savings are presented in Section 5.

The implementation dates of 2020 for new models and 2022 for all new cars are extremely aggressive. This gives manufacturers between two and four years to respond to the requirements even if these requirements could be published and applied in legislation immediately. The reasons for discussing such short phase-in periods are twofold. Firstly, it shows the maximum effectiveness of the regulations, given that there is some transition to voluntary uptake and underlying road safety changes occurring in Latin America. Secondly, it provides a nominal ten year evaluation period between 2020 and 2030. From a political point of view, this is helpful alongside discussions about safety goals for the next decade. Realistically, it may be that political decisions and feasibility arguments prevent such a timescale from being implemented, but consideration of those negotiations are beyond the scope of this analysis.
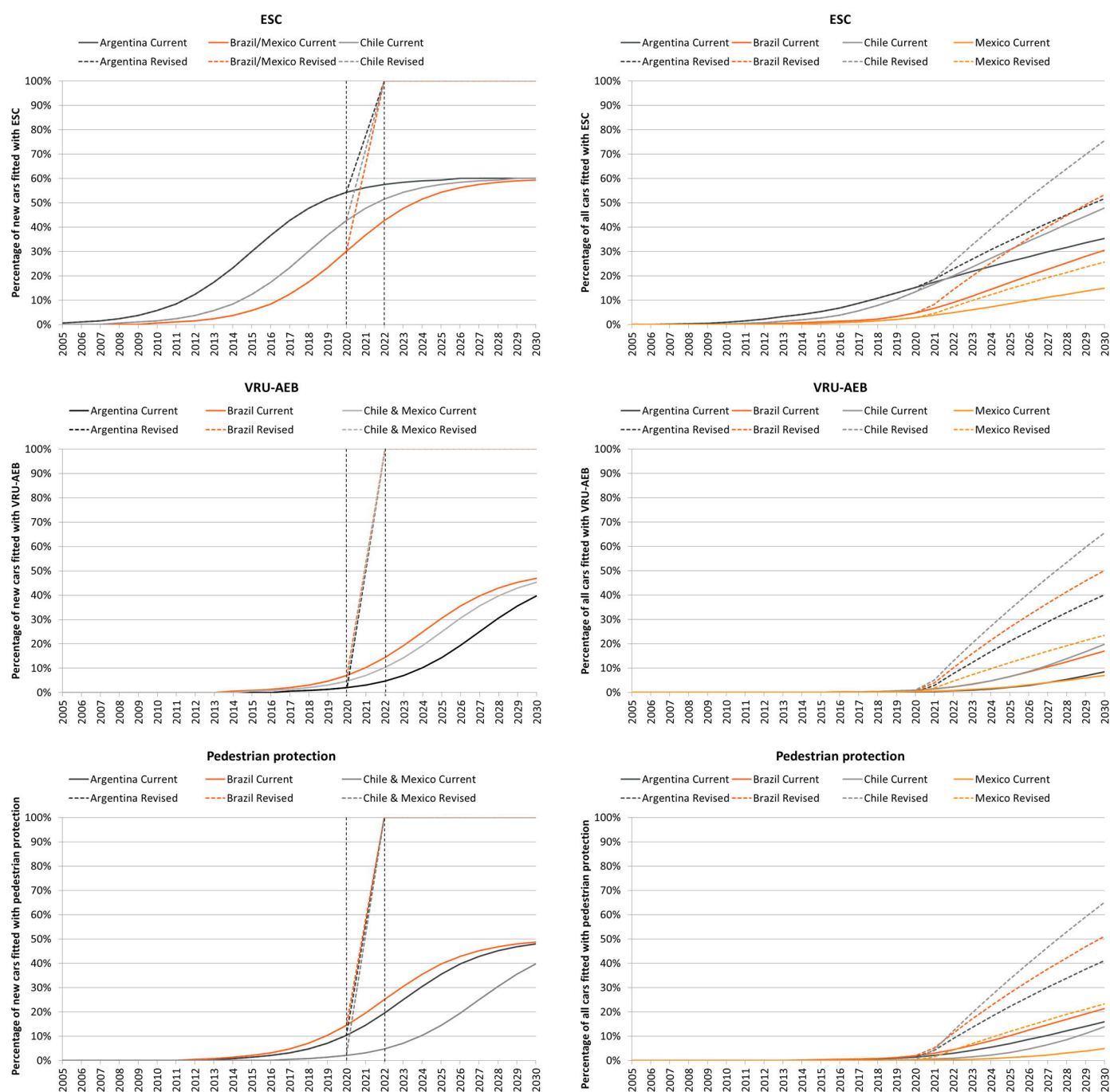
Figure 41: Left hand side: percentage of newly registered cars equipped with each technology in the voluntary and mandatory uptake scenarios

Right hand side: percentage of all registered cars equipped with each technology in the voluntary and mandatory uptake scenarios

In order to treat the inherent uncertainty in these fitment predictions, the input numbers were varied, along with other inputs, as part of the sensitivity analysis (see Appendix D). A lower estimate of the voluntary uptake for ESC was modelled to represent a scenario where voluntary uptake did not reach the 60% quoted above, but instead only reached 45%. For the pedestrian protection measures an increased uptake of 90% was modelled to represent a scenario of maximum voluntary uptake. Though this latter increase in voluntary uptake of VRU protection measures is considered by the authors to be unlikely, experience in Europe suggests that consumer information can be powerful in advocating the adoption of such technologies; this therefore reflects, to some extent, the potential influence the Latin NCAP Advanced Awards could have in driving improvements in vehicle safety.

Appendix B   Literature review – VRU AEB

This project systematically identified, interpreted and appraised research relevant to establishing the target populations, effectiveness and costs associated with two vehicle safety options for preventing deaths and injuries in Latin America.

1. Adopting the mandatory fitment to new cars of Autonomous Emergency Braking (AEB) systems for the detection and avoidance or mitigation of potential collisions with Vulnerable Road Users (VRU).

2. Adopting secondary safety (typically passive) pedestrian protection requirements for new cars according to UN Global Technical Regulation No. 9 or UN Regulation No. 127.

A standardised framework was utilised to identify and assess the quality of pertinent information sources in order to extract relevant data in an unbiased and replicable manner.

This appendix describes the processes of source selection, critical appraisal and analysis employed to extract relevant data from the selected articles for the first bullet point (AEB for VRUs). Appendix C describes a similar process for pedestrian protection requirements.

B.1   Method

This systematic literature review was conducted following the core principles and methods described by Seidl et al. (2017). Following these predefined processes, this literature review was completed in the four key steps outlined below in Figure 42.

Step 1: Scoping Study
- Scoping study to perform high-level review of key sources
- Collation of key sources
- Collation of other key sources identified by technical experts

Step 2: Source Selection
- Process to identify and select sources for critical appraisal
- Establish research questions, search strategy, selection criteria and the source identification and selection process

Step 3: Critical Appraisal
- Critical appraisal of sources
- Assessment of methods adopted by selected sources
- Final selection criteria applied to exclude low quality sources

Step 4: Review
- Review and extraction of relevant information from included sources
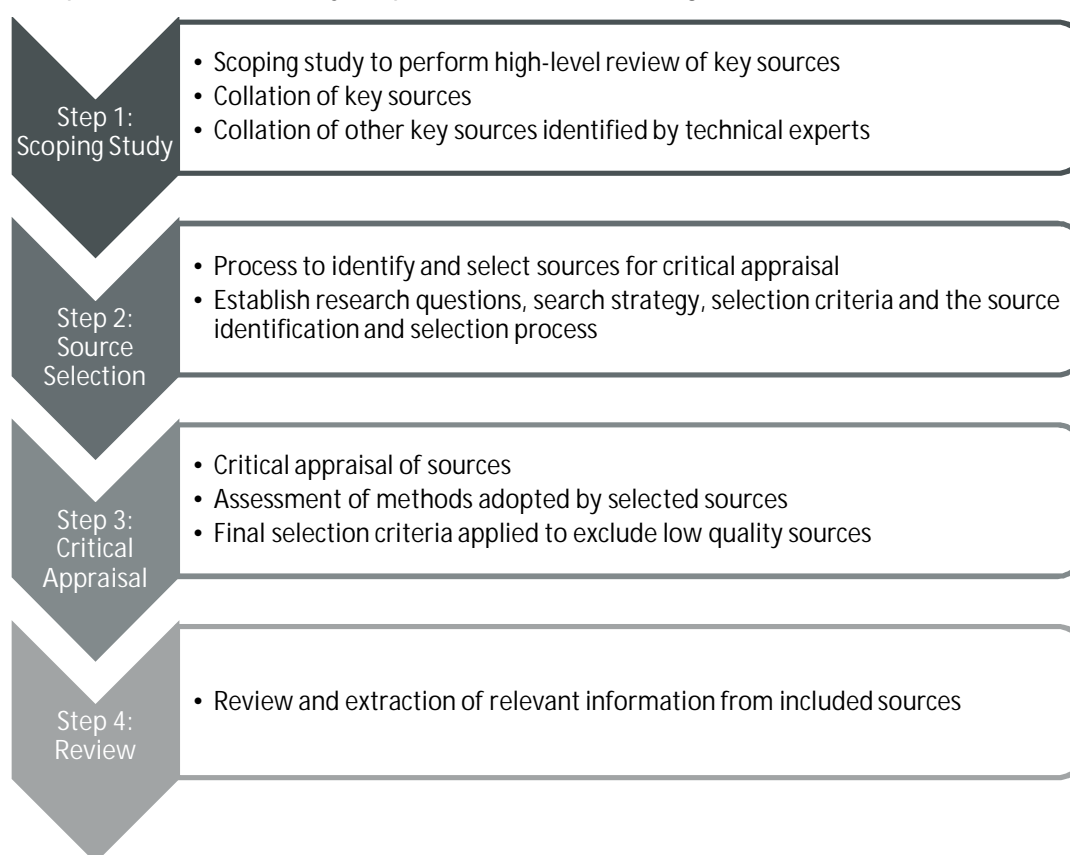
Figure 42: Top-level overview of systematic literature review process

B.2   Scoping study

This scoping study identified studies that were collated during previous research (preamble to UN GTR 9 and the European ASPECSS Project[38]) and that were deemed relevant to the safety measures in the scope of this project. These sources were further supplemented by several other key sources that were identified by technical experts.

Sources were selected for critical appraisal if they met one of the following inclusion criteria:

- The source contained quantitative primary data on the impacts of safety measure implementation (e.g. casualty benefits, etc.)

- The source contained evidence that could be used to indirectly calculate the impacts of safety measure implementation (e.g. reduction in injury risks due to improved pedestrian crashworthiness structures, etc.)

- The sources contained evidence that could be used to assess the potential maximum effectiveness relevant to each safety measure

It is this final point that was critical for direct use of a source within the project. Effectiveness values were sought that could be applied to the fatal VRU casualty population in the four countries included in this study.

In addition to being selected for critical appraisal, the bibliographies of these sources were reviewed to identify any further studies cited by these sources that were deemed relevant to the safety measures investigated in the scope of this project. Finally, all sources identified during this scoping study were used to establish the inputs for the source selection process.

B.3   Source selection

The source selection process adopted a standardised approach for systematically searching for, and selecting, the sources relevant to the investigated safety measures. This approach required the development of four key research questions to establish a search strategy for several literature databases. This search strategy was implemented, in combination with predefined selection criteria, to identify and select sources for critical appraisal. The following sections summarise the approaches taken for each of these steps.

B.3.1   Research questions

For each safety measure investigated by this project, a number of research questions were designed to query literature databases for the purposes of locating and identifying relevant research. These questions used the TIO (Target group [T], Intervention [I] and Outcome [O]) approach to structure and formulate each research question.

- How many Vulnerable Road User [T] lives [O] would AEB for VRU [I] save?

- What is the value added [O] that AEB for Vulnerable Road Users [I] would have on the state of the economy [T]

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[38] http://www.aspecss-project.eu/

- What effect does AEB for VRU [I] have on the severity [O] of car collisions with vulnerable road users [T]?

B.3.2   Search strategy

The main key search word combinations used for the journals, databases and reports included "Safer car fronts for pedestrians and cyclists", "vulnerable road users", "Design for pedestrian impact", "Pedestrian protection", "Protection of pedestrians", "Pedestrian safety", "Pedestrian impact requirements", "Vehicle-pedestrian accidents", "Pedestrian-car-collision", "Protection of vulnerable road users", "Protection of cyclists", "Safer car fronts for pedestrians, cyclists and vulnerable road users", "Passive safety systems", "Secondary safety systems", "Active safety systems", "Autonomous Emergency Braking (AEB)".

Target group [T] keyword options for search strategy

Vulnerable road users, Pedestrian Motorcyclist, Cyclist, Rider, Economy, Manufacturer

Intervention [I] keyword options for search strategy

Autonomous Emergency Braking for Vulnerable Road Users, VRU protection, Pedestrian safety performance,

Outcome [O] keyword list for search strategy

Severity, Fatal or Fatality, Killed, Value of life saved, Cost

B.3.3   Literature databases

The main journals and databases subscribed by TRL found to have relevant information to the study were Accident Analysis and Prevention Journal, Journal of Safety Research and Traffic Injury Prevention Journal. The databases searched on behalf of this literature review are outlined below.

TRID (Transport Research International Documentation): a database that combines ITRD (OECD's International Transport Research Documentation database) and the US-based database TRIS (Transport Research Information Service). Together they form one of the most comprehensive transport research databases available today.

https://trid.trb.org/

ScienceDirect: a leading full-text scientific database offering journal articles and book chapters from more than 2,500 peer-reviewed journals and over 11,000 books.

https://www.sciencedirect.com/

PubMed: a public version of MEDLINE, arguably the world's largest medical database. Its records contain many levels of medical research from meta-analyses and systematic reviews to case studies. It includes accident studies, safety, human factors, psychology etc.

https://www.ncbi.nlm.nih.gov/pubmed/

Google Scholar: a freely accessible web search engine that indexes the full text or metadata of scholarly literature across an array of publishing formats and disciplines. Released in beta in November 2004, the Google Scholar index includes most peer-reviewed online journals of

Europe and America's largest scholarly publishers, plus scholarly books and other non-peer reviewed journals.

https://scholar.google.co.uk/

B.3.4   Source selection criteria

This search first excluded all English language sources published before the 1st January 2006, based on a hypothesis that all relevant sources published prior to this date would have been identified by the scoping study. Duplicate sources were excluded. Source titles and abstracts were then screened for relevance based upon the criteria previously specified in B.2, with identified sources included for the detailed review of the full manuscript. Finally, the bibliographies of all the sources that were selected for full text review were recursively searched for further relevant sources.

B.4   Critical appraisal

To ensure only high quality sources were selected for inclusion, the source assessment process first developed by Seidl et al. (2017) was adopted by this project. This allowed for an objective assessment of the relevance and methodological quality of each source.

The source assessment process developed by Seidl et al. (2017) grades the selected sources such that an objective judgement can be made as to whether the quality of data is sufficient to be included in the review. Each source was appraised and graded against standardised criteria for the parameters described in Figure 43 (a full description of these standardised criteria is provided in Annex 1 of Seidl et al. (2017)).

Reviewers were trained in applying the process and the consistency of reviews was assured via a system of spot checks and individual feedback. Each of these parameters was assessed and assigned a standardised score determined based on the reviewer's assessment of the source against each of these criteria. Scores were combined to provide a rating score that ranged between 0 and 100%, with 100% denoting the highest possible quality rating a source could achieve. A minimum rating score of 50% was adopted as the methodological quality exclusion criteria, with sources failing to achieve this excluded from the literature review.
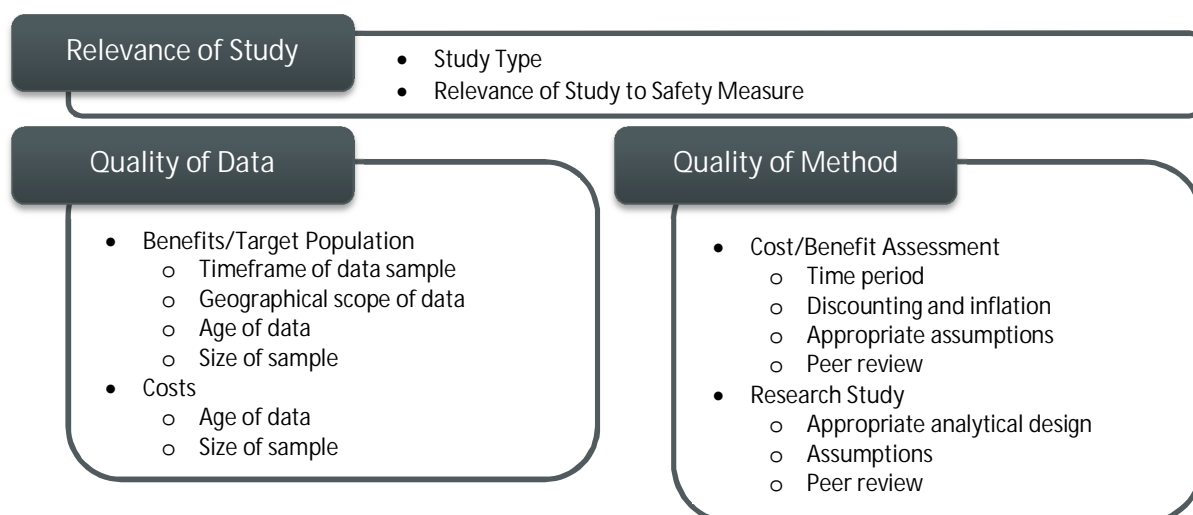
Figure 43: Standardised criteria used for assessing and grading sources during the source assessment process (Seidl et al., 2017)

B.5   Included sources

The flow of sources through the source selection process can be seen in the flow diagram in Figure 44. A total of 193 sources were returned from the source selection process, of which 165 were excluded based on the criteria. Of the 28 articles selected for the source assessment, a total of eight met the selection criteria and were included for full evaluation.

Figure 44: Source selection process flow diagram

B.6   Findings

Amongst the 28 sources included within this review, four sources contained relevant information on the safety measure and also provided effectiveness estimates. The findings from these papers are described in more detail below.

B.6.1   Source 1: Autonomous Emergency Braking for Vulnerable Road Users

Rosén (2013) used available pre-collision data to re-create 543 car-to-pedestrian collisions and 607 car-to-cyclist collisions. These collisions were re-created using information from 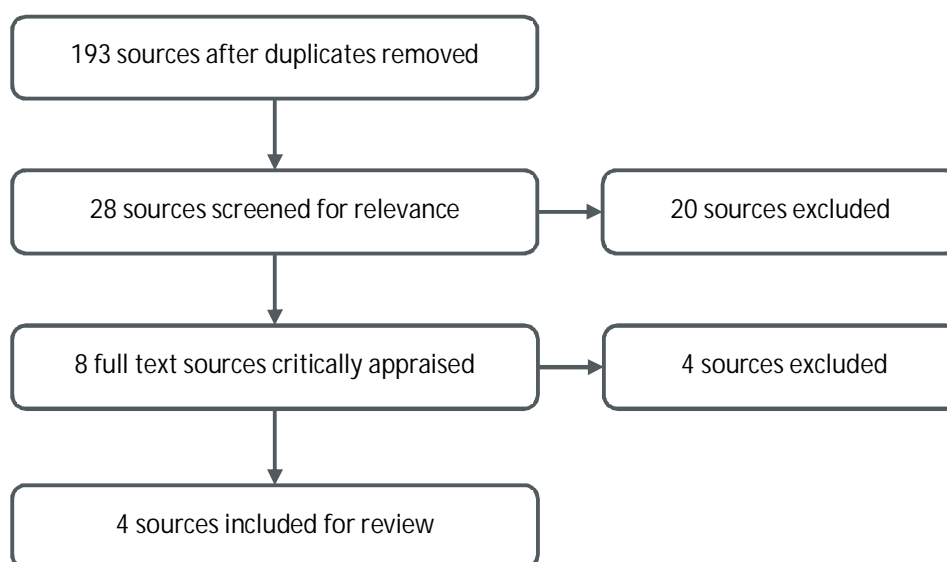the GIDAS database. GIDAS collects data from Hanover and Dresden and provides a representative sample of German collisions with pedestrian injuries. A subset of GIDAS accidents were re-analysed (by GIDAS' own experts) to provide a detailed and quantitative description of trajectories of both car and VRU during the final seconds prior to collision. This subset was used to constitute a representative subset of the GIDAS database.

Rosen discusses 6 different AEB systems in his study with each system having at least one different parameter. The systems range from "minimal" (minimum level of AEB) to "max brake" (highly functional AEB system) and systems in between. While no regulation currently exists for AEB for VRU, the "reference" AEB system stated by Rosen seems like a reasonable expectation for a standard system performance. Systems with greater braking potential and with no operating speed limitation (beyond a nominal minimum speed and extremely high maximum speed, e.g. 180 km/h) are already being encouraged by Euro NCAP and are being fitted to new vehicles sold in Europe. As a result, the reference AEB system was used as an estimate of effectiveness.

These results must be considered carefully as Rosen has assumed that the AEB system has full functionality in rain and other adverse conditions, assumes pedestrian detection rates are at 100% and tracking accuracy is perfect which may not always be the case in a contemporary AEB system. The reference system, has the following parameters: 1 second maximum predicted time to collision, for an unbraked car, when the brake decision was taken; 1 metre of trigger width – the maximum lateral distance from car path to VRU at which braking was activated; 40° Field of View of the AEB system; 0.7 g as the maximum brake acceleration provided by the AEB system; No limit on the cut-off speed of the car. Based on these parameters, AEB for pedestrians is 48% effective in reducing fatal injuries and 42% effective in reducing severe injuries. AEB for cyclists is 55% effective in reducing fatal injuries and 33% effective in reducing severe injuries.

If the assumption that AEB systems can function with the same efficiency in darkness was removed and replaced with the assumption that the AEB system did not work at all in the dark, the effectiveness of AEB significantly drops to 21% for both fatally and severely injured pedestrians and 42% and 24% effective for fatally and severely injured cyclists respectively. As this demonstrates, Rosén sets out certain assumptions for the theoretical AEB systems he considered. Some of these assumptions are seemingly optimistic for production-ready systems. Therefore, given the high quality of the research, it makes sense to adopt the values but recognise and use these effectiveness values as the upper limit for AEB effectiveness for VRU's.

On the other end of the spectrum, Rosen has also formulated a "minimal" (minimum level of AEB) system which has the following parameters: 0.5 seconds maximum predicted time to collision for an unbraked car, when the brake decision was taken; 0 metres of trigger width; 40° Field of View of the AEB system; 0.5 g as the maximum brake acceleration provided by the AEB system; 60 km/h cut off speed limit for the AEB system and the AEB system does not work in the dark. For pedestrians, the "minimal" AEB system was 3% effective is reducing fatal and serious injuries. For cyclists, the AEB system's effectiveness was 6% for fatal injuries and 5% for serious injuries.

B.6.2 Source 2: Benefits assessment of autonomous emergency braking pedestrian systems based on real world accident reconstruction

Paez et al. (2015) simulated 50 car-to-pedestrian collision cases using PC-Crash software. AEB effectiveness was emulated in this paper through computer simulation based on DaimlerChrysler's PROTECTOR system. In 42% of cases, the collision was predicted to be avoided due to the PROTECTOR system. There is no evidence to suggest that the 50 collisions considered are a representative sample of all car-to-pedestrian collisions.

B.6.3 Source 3: Issues and challenges for pedestrian active safety systems based on real world accidents

Hamdane et al. (2015) reconstructed 100 real car-to-pedestrian collisions, providing a comprehensive set of data describing the interaction between the vehicles, the environment and the pedestrian all along the scenario of the collision. A generic AEB system was modelled to determine its impact on pedestrian safety. They estimated that 50% of car-to-pedestrian collisions could be avoided if systems were able to trigger 1 second before impact with a Field of View greater than 35°. One criticism of this system is that it does not consider weather or lighting conditions and assumes perfect visibility. Once again, there is no evidence to suggest that the 100 reconstructed collisions are a representative sample of all car-to-pedestrian collisions.

B.6.4 Source 4: Pedestrian injury mitigation by autonomous braking

Rosén et al. (2010) reconstructed 243 car-to-pedestrian collisions where sufficient information was available to estimate the pedestrian location relative to the car 1 second prior to impact. From GIDAS, 755 cases were gathered, and due to the history of project and the time frame of project, 243 cases provided sufficient information. All 755 cases were assessed through the normal GIDAS reconstruction process though. The GIDAS database contains a fairly representative sample of German accidents with pedestrian injuries, though it is not clear if the subset of 243 cases with sufficient information remains representative. A certain bias towards severe and fatal collisions is present and a method to adjust for that was used by Rosen and Sander (2009). Rosén et al. estimated that the AEB system had an effectiveness of 51% for fatal injuries and 39% for severe injuries for pedestrians. The system considered had a 40° field of view.

If the driver could not see the pedestrian (due to obstacles in the environment) in time to be able to react and avoid the crash, the pedestrian was coded by Rosén et al. as being "not visible". However, there is no accounting for environmental conditions and performance of the AEB system. As such, these estimates are considered to be optimistic given the likely real-world performance of production-ready technology.

B.7   Summary and recommendation

From these 4 papers, the following ranges of effectiveness of AEB for VRUs are provided:

- AEB for Fatal pedestrian injuries: 21% - 51% effective
- AEB for Serious pedestrian injuries: 39% - 50% effective
- AEB for Fatal cyclist injuries: 42% - 55% effective
- AEB for Serious cyclist injuries: 24% - 33% effective

However, given the quality of the primary research and the fullness of the stated assumptions, the primary effectiveness numbers to be used with fatality reduction estimates are:

- AEB for Fatal pedestrian injuries: 48% effective
- AEB for Fatal cyclist injuries: 55% effective
- AEB for Serious pedestrian injuries: 42% effective
- AEB for Serious cyclist injuries: 33% effective

The implication of this recommendation is that, for the example of pedestrians, 48 percent of pedestrian collisions leading to a fatal injury would be either avoided or mitigated in severity. The fatal injury would no longer occur, though a serious or slight injury may still occur where the collision severity is only mitigated.

Within this modelling only fatal injuries are counted, therefore assuming all fatal injuries have been avoided in 48 percent of cases is an overestimation of the potential benefits. However, as we are not accounting for serious injuries being prevented, then in general the estimates will remain conservative.

Appendix C   Literature review – pedestrian protection

Every year around the world, 270,000 pedestrians are struck and killed by vehicles (WHO/FIA/GRSP/WB, 2013). There will be even more road traffic fatalities resulting from vehicle collisions if other vulnerable road users, such as pedal cyclists and motorcyclists, are included. The UN Global Technical Regulation (GTR) No.9 (UN, 2008) seeks to lower appreciably the levels of injury suffered by pedestrians involved in frontal impacts with motor vehicles. The GTR aims to improve pedestrian safety by demanding vehicle bonnets and bumpers absorb energy in a more effective manner when impacted at a 40 kilometres per hour (km/h) vehicle-to-pedestrian speed. Collisions with an impact speed up to 40 km/h account for more than 75 percent of the pedestrian injured collisions (AIS 1+) published by IHRA/PS (International Harmonised Research Activities/ Pedestrian Safety working group).

UN Regulation No. 127 (UN, 2015) also states requirements relating to the Type approval of a vehicle with regard to pedestrian protection. It is intended to offer precisely the same requirements as GTR No. 9 so that the two can be used together to generate harmonised pedestrian protection requirements around the world.

A methodical identification, explanation and evaluation of all applicable research relating to the target group of pedestrian and pedal cyclist casualties and pedestrian protection systems was carried out in this project. A systematic structure was used to find and evaluate the quality of applicable sources of information so as to obtain suitable data in an impartial way.

This section of the report will describe the processes of source selection, critical appraisal and data analysis used to obtain relevant literature.

The report also describes the methodical review used to establish the target populations and effectiveness of pedestrian protection systems. The report goes on to describe and discuss four studies found useful to this report. Finally there is a discussion and a proposed estimated effectiveness value for pedestrian protection systems is given.

C.1   Method

The systematic literature review principles and methods described in Figure 42 (Appendix B.1) were also used for this review.

C.2   Scoping study

This aspect of the report identified studies that were previously used that referred to the UN Global Technical Regulation (GTR) No. 9 and the UN Regulation No. 127 and were identified to be suitable for providing the safety outcomes required by the project scope. This study also found studies that were obtained from former research (Hardy et al., 2006) (Lawrence et al., 2004). Data obtained was complemented with other suitable references identified by technical experts.

The identified material was chosen for review if they satisfied one of the following requirements:

- The source contained quantitative primary data on the impacts of safety measure implementation of pedestrian protection systems (e.g. casualty benefits, etc.)

- The source contained evidence that could be used to indirectly calculate the impacts of safety measure implementation of pedestrian protection systems (e.g. reduction in injury risks due to improved pedestrian protection systems, etc.)

- The sources contained evidence that could be used to assess the potential maximum effectiveness relevant to pedestrian protection systems

The bibliographies of the identified literature were also queried to identify other relevant referenced literature.

C.3 Source selection

A systematic approach was used for selecting the appropriate literature.

C.3.1 Research questions

In an attempt to obtain relevant information in an unbiased way a number of key words were used. The questions were constructed using the TIO (Target Group [T], Intervention [I] and Outcome [O]) approach.

The key questions asked included:

- Do pedestrian protection [I] systems reduce the risk of pedestrian [T] injury severity [O]?

- How many lives [T] will be saved [O] with the use of pedestrian protection [I] systems?

- What is the level of protection [O] to pedestrians [T] obtained from using pedestrian protection [I] systems (i.e. percentage reduction in fatal and serious injuries)?

C.3.2 Search strategy

The main key search word combinations used for the journals, databases and reports included "pedestrian protection effect and injury severity", "Pedestrian protection", "Pedestrian Protection and injury severity", "Pedestrian protection and injury risk", "Bicyclist protection and injury severity", "Pedestrian protection and lives saved", "Pedestrian protection and lives saved", "Vulnerable road user protection and injury severity", "Vulnerable road user protection and injury risk", "VRU and injury severity" and "pedestrian passive safety measures and injury severity".

Target group [T] keyword options for search strategy

Pedestrian, Bicyclist, VRU, Vulnerable road user

Intervention [I] keyword options for search strategy

Protection, Protection effect, Protection System, Passive Safety Measure

Outcome [O] keyword list for search strategy

Injury Severity, Injury Risk, Lives Saved, Frequency of Fatal Accidents, Frequency of Serious Accidents, Seriously Injured, Fatally Injured, Fatality, Killed, Road Traffic Accidents, Road Traffic Collision

C.3.3 Literature databases

The same databases described in Appendix B.3.3 were used for this search.

C.3.4 Source selection criteria

The search excluded all literature published before the year 2003. The choice of the year 2003 as a cut off for the literature search was based on the assumption that all applicable sources dated before 2003 would have been included in the reports (Hardy et al., 2006) (Lawrence et al., 2004). Duplicate sources were rejected. Titles and abstracts were then examined to determine their applicability on the basis of the set criteria outlined earlier in this report. Bibliographies from relevant identified sources chosen for final review were further searched for more applicable sources. The effectiveness to be obtained from these sources must make reference to the UN Regulation 127 and Global Technical Regulation No. 9 or their precursors, in order to be useful.

C.4 Critical appraisal

The same process described in Appendix B.4 was used for this review.

C.5 Included sources

Figure 45 provides a flow chart of the source selection process. A total of 538 sources were obtained from the source selection process of which 161 were removed based on the criteria. Subsequently, 40 literature sources were chosen for further assessment, of which only a total of 4 met the selection criteria and were used for full evaluation.
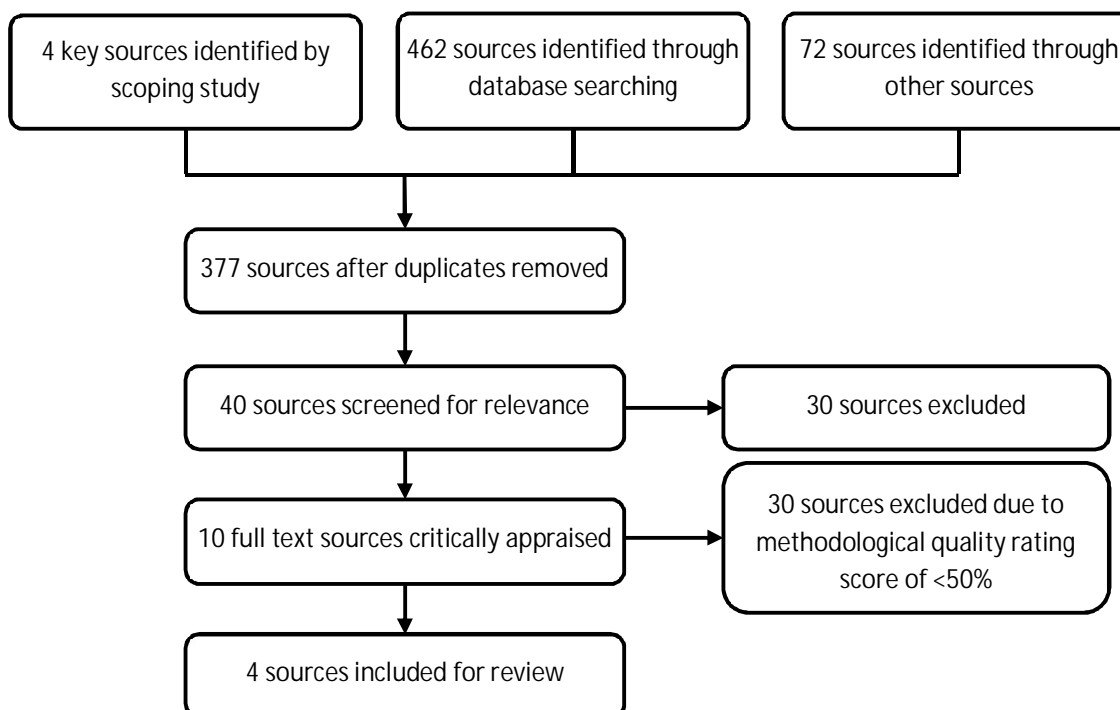

Figure 45: Source selection process flow diagram

C.6 Findings

This review commenced with the identification of literature showing the effectiveness of pedestrian protection systems referring to UN Regulation 127 and Global Technical Regulation No. 9.

Three studies (as well as the GTR itself) were finally identified with relevant effectiveness values making reference to the desired regulations on pedestrian protection. The studies (Moran et al., 2017), (Lawrence et al., 2004), (Hardy et al., 2006) in addition to UN Global Technical Regulation No. 9 (UN, 2008) are summarised below. The first is described in most detail given that this is the only journal paper identified with stated effectiveness values as well as making reference to UN Regulation 127. A brief summary of the other three sources (including the GTR) is also provided. This is provided to form a basis for discussion and sound justification on which to draw conclusions.

C.6.1 Source 1: Impact of improving vehicle front design on the burden of pedestrian injuries in Germany, the United States, and India by Moran et al. (2017)

Moran et al. (2017) investigated the impact of improving vehicle front design on the burden of pedestrian injuries in Germany, the United States and India using 2013 data. In this study pedestrians account for 37% of DALYs (Disability Adjusted Life Years) lost in India, 11% in the United States and 10% in Germany. In Germany and the United States, most pedestrians are struck by cars whereas in India, pedestrians are normally involved in crashes with heavy motor vehicles (HMVs, buses and trucks) and motorised 2-wheelers. In India and the United States, the DALYs lost by pedestrians hit by cars was 3 times and 2.6 times that in Germany respectively.

The data was from the International Road Traffic Accident Database and the Global Burden of Disease project to estimate baseline pedestrian deaths and non-fatal injuries for each country. At the time of the study there was limited knowledge about the pedestrian safety performance of cars sold in the United States and India as these countries did not perform pedestrian NCAP (New Car Assessment Program) tests and there was no implementation of pedestrian safety regulations to mandate a minimum standard. The effectiveness of improved passenger car star ratings (which go beyond the requirements of the regulation with regard to testing) on the probability of pedestrian injury was thus based on current assessment of pedestrian crash data from Germany. In Germany new cars are required to meet pedestrian safety regulations and common models are tested by an NCAP programme.

There was consequently an estimation of the reduction in injury burden under various scenarios of the pedestrian safety performance of the current vehicle fleet. In a similar process to that used by Wallbank et al. (2016) and in the current study, it was assumed that the pedestrian star ratings of the vehicle fleet in the United States in 2013 were similar to that in Germany in 1997 (pre-regulation and pre-NCAP) assuming that the development of pedestrian friendly vehicle designs is guided mainly by design regulations and consumer testing. For India, it was assumed that all cars sold had a 0-star rating for pedestrian safety considering the poor results from occupant crash testing for selected cars in India (Global NCAP, 2015).

For passenger cars, the study intended to estimate the decrease in the pedestrian injury burden in each country that would occur if all passenger cars achieved at least 3 stars in

Euro NCAP pedestrian protection testing. Even though the star rating used in NCAP cannot be directly related to the regulatory minimum requirements (UN, 2015) it gives some assurance that the vehicles are being designed to ensure protection to pedestrians.

In 1997 no cars in Germany received a 3-star rating but by 2013, following the start of crash testing and regulations on pedestrian protection, 97% of cars obtained the equivalent of at least a 3-star rating (Strandroth et al., 2014), noting that procedures had changed and that stars were no longer awarded for pedestrian protection. These advancements in vehicle design were pushed by competition triggered by pedestrian testing from Euro NCAP beginning in 1997 and the pedestrian protection regulation that had a higher tier compliance needed for cars with a maximum mass under 2,500 kg by 2013.

The study used the registration data from Germany (2012) and the United States (2010) to establish the number of pedestrians fatally injured by passenger cars and heavy motor vehicles (HMVs). For India the scale of pedestrians fatally injured by passenger cars and heavy motor vehicles (HMVs) was estimated using a province in India.

A sensitivity analysis to investigate the effect of changing the assumed star rating distributions of the vehicle fleet in the United States and India in 2013 was performed. The following scenarios were used: all cars have a pedestrian star rating of zero stars; pedestrian star ratings of the vehicle fleet similar to the situation in Germany in 1997; a pedestrian star rating distribution that is midway between Germany in 1997 and Germany in 2013; and pedestrian star ratings comparable to the situation in Germany in 2013. The study also estimated the deaths that would have happened in Germany in 2013 had cars not improved with regards to passive pedestrian protection. Due to the unreliability of baseline estimates for pedestrian deaths and injuries in India, an estimate of the impact of applying the lower bound and upper bound of the unpredictability interval of the Global Burden of Disease (GBD) estimates for pedestrian deaths was done. Finally the study estimated the impact of improving car design to make all cars achieve a 4-star rating.

Moran et al. (2017) reported that by improving car designs to at least a 3-star pedestrian safety rating in India, assuming all cars at the time of the study have a 0-star rating, would result in a 46% decrease in pedestrian deaths. In the United States where an assumption was made that at the time of the study there were 30% of cars with a 0-star rating and 70% with a 1-star rating, improvements will result in a 27% decrease in deaths to pedestrians hit by cars. Motorised 2-wheelers are the impacting vehicle in a large proportion (22%) of pedestrian deaths in India. In Germany, where 97% of cars had a 3-star or better rating, additional improvement is expected to result in a smaller decrease (2% in deaths) in the health loss of pedestrians hit by cars. Even though improving the design of the front of HMVs is estimated to result in a 16% reduction in deaths of pedestrians in HMV collisions in all three countries, heavy vehicles are excluded from the scope of application of the GTR.

C.6.2 Source 2: Global Technical Regulation No. 9 (2008) by the UN

The scope of application of the GTR (UN, 2008) is limited to passenger cars, sports utility vehicles (SUV), light trucks and other light commercial vehicles. These represent the vast majority of vehicles presently in use, giving the proposed measures the widest effect in reducing pedestrian injuries. Data used in developing the GTR was obtained from Australia, Germany, Japan, United States, Italy, Spain, Canada, the Netherlands, Sweden and Korea.

The GTR is based on the scenario that in the most representative pedestrian to car collision the pedestrian is in normal walking posture, meaning the pedestrian is standing sideways to the vehicle and is struck by the vehicle front.

Cumulative frequencies of crash speeds up to 40 km/h obtained from pedestrian collision data describe more than 75% of total pedestrian injuries (AIS 1+) in all regions between vehicles and pedestrians.

The GTR is expected to reduce the number of pedestrian fatalities and injuries resulting from head impacts against the bonnet and leg impacts with the bumper. The target population was 24% of child pedestrian head injuries, 8% of adult pedestrian head injuries (fatal and serious head injuries) and 32% of adult leg injuries for AIS2+ injuries for the proposed GTR. The head of a child/adult and the adult leg body regions cover more than 30% of the total fatal and serious injuries.

From information prepared during its development, it is estimated that the GTR will prevent 1% to 5% of pedestrian fatalities depending on the region. The GTR acknowledges that there will be many variables affecting the likely advantages of the GTR and these include region-to-region differences in the composition of the vehicle fleet, driver behaviour, extent to which existing vehicles currently satisfy the conditions for pedestrian protection of the GTR or are equipped with safety features useful to pedestrians, and in the prevalence of pedestrian-friendly infrastructure.

C.6.3   Source 3: A study on the feasibility of measures relating to the protection of pedestrians and other vulnerable road users – Final Report (2004)

This study (Lawrence et al., 2004) investigated the feasibility of measures relating to the protection of pedestrians and other vulnerable road users. The pedestrian collision dataset used was from IHRA (the International Harmonised Research Activities) and contained 1535 casualties of which 155 were fatalities, 732 were serious casualties and 648 were slight casualties. The country split was 782 casualties from Germany, 242 casualties for Japan and 511 casualties for USA from 1985 to 1998. The number of pedestrians and pedal cyclists hit by cars and car fronts from 1997 to 2001 were obtained for Great Britain.

A proposal was made in the report to improve upon the phase two requirements and test methods of EC Directive 2003/102/EC and also to take account of feasibility issues when moving to these requirements from the less stringent phase one. This proposal was used when evaluating the effectiveness of pedestrian protection systems on vulnerable road users. The estimated pedestrian casualty severity reductions from fatal to serious were either 9.6% or 16.9% depending on the risk reduction estimation method used. For the estimated pedestrian casualty reductions from serious to slight, these values were 17.5% and 13.3%.

C.6.4   Source 4: A study on the feasibility of measures relating to the protection of pedestrians and vulnerable road users - Final Report (2006)

This study (Hardy et al., 2006) is an update of that carried out in Source 3. The scope of the study update included taking account of the draft GTR and as far as possible more recent collision data. This led to three 'options' for protecting vulnerable road users to be considered:

1. The first option was that specified in phase two of EC Directive 2003/102/EC, as considered within Source 3 (Lawrence et al., 2004);

2. The second option was that offered by the industry for replacing phase two. The intention was to maintain (the less stringent) phase one test procedures with the addition of brake assist systems (BAS) to provide additional benefits;

3. The third option was a package of measures proposed to harmonise with the (then draft) GTR, but with a wider scope of application to vehicles.

The updated cost-benefit analysis compared the benefits of the three options. Further work led to the conclusion that the proposal for revising phase two and adding the active measure of brake assist, achieves and is likely to exceed by a considerable margin the requirements of 'at least the same level of protection' of the Directive. A number of other recommendations were made in this study.

The study identified new technologies that might be used to avoid pedestrian collisions or mitigate their effects in terms of injuries, it investigated brake assist and provided an updated cost-benefit analysis. There was an assumption that BAS (brake assist system) will result in a reduction in pedestrian fatalities of more than zero and less than 12%. The estimated proportional reductions in numbers of pedestrian and pedal cyclist casualties hit by car fronts that would be obtained by implementation of various options is given in Table 24.

Table 24: Estimated proportional reductions in numbers of those pedestrian and pedal cyclist casualties hit by car fronts that would be obtained by implementation of the various options by severity

Estimation method	Road user type	Option 1 = Phase 2 of 2003/102/EC		Option 2 = Industry proposal plus BAS		Option 3 = GTR (draft form) plus BAS	
		Fatal	Serious	Fatal	Serious	Fatal	Serious
Those hit by cars	Pedestrians	9.5%	18.9%	15.7%	24.9%	16.4%	26.3%
	Pedal Cyclists	4.5%	7.9%	9.8%	12.1%	10.2%	12.8%
Those hit by car front	Pedestrians	11.1%	28.2%	18.4%	37.2%	19.3%	39.2%
	Pedal Cyclists	5.6%	14.3%	12.1%	22.0%	12.7%	23.3%

EEVC (European Enhanced Vehicle-safety Committee)   BAS (Brake Assist Systems)

Arguably, Option 3 provides the closest link to the GTR in its current form noting that the effect of BAS is added to the values in Table 24, whereas this is not present in the GTR. Only benefits to pedestrians and pedal cyclists were considered with respect to these effectiveness values due to the fact that benefits to motorcyclists were not given even though the report states that it is expected that there will be some added benefits for motorcyclists.

C.7   Discussion and conclusions

This section provides a brief discussion of the four studies summarised above in order to draw a conclusion about the range to be considered for the effectiveness of pedestrian protection systems for the four Latin American countries (Argentina, Brazil, Chile and Mexico). All the studies which have been summarised above made assumptions which differ so that direct comparison between the studies is difficult.

One of the limitations identified by Moran et al. (2017), was that the risks related to the vehicle fleet in India and the United States at the time of the study were poorly comprehended. It was anticipated that for the United States, the car fleet in 2013 was similar to that in Germany in 1997. This assumption was validated by a study of seven small cars (2002–2007 model years) in the United States which were subjected to Euro NCAP-style pedestrian headform tests (Mueller et al., 2013). The other limitation stated in the study was that the only proof of effectiveness of pedestrian safety design was obtained from reasonably small studies that discuss correlation between star ratings and injury outcomes (Strandroth et al., 2014) (Pastor, 2013). Small studies are likely to result in large standard error, wide confidence intervals with imprecise estimate of effects. The study claimed to overcome the risk of effectiveness overestimation as it did not assess impact on other vulnerable road users such as cyclists who may be faced with a decreased injury risk from softer vehicle fronts and their lesser involvement in road collisions compared with pedestrians (Bhalla et al., 2011). Care must be taken in generalising the results obtained from this study noting this implicit incorporation of benefits to cyclists.

The GTR focusses on protecting particular body regions and injury severities which are head injuries (AIS2+) of children and adults as well as AIS2+ adult leg injuries, whereas the study by Moran et al. (2017) purely focused on the proportion of pedestrians fatally injured by passenger cars and heavy motor vehicles. The Moran et al. study may overestimate benefits given that the GTR intends to addresses only the specific body regions of leg and head whereas Euro NCAP testing includes procedures to represent contacts with other pedestrian body regions and over a wider area of the vehicle. Nevertheless, the target population of the GTR covers more than 30 percent of total fatal and severe injuries with no upper boundary estimated for this target population.

It is also worth discussing that the GTR has a scope of application restricted to passenger cars, sport utility vehicles (SUV), light trucks and other light commercial vehicles. These vehicle classes constitute most of the vehicles currently in use in most countries, but not all vehicles that account for pedestrian fatalities. The study by Moran et al. considered cars and heavy motor vehicles (HMVs) which is more inclusive. However, in the preamble to the GTR it is recognised that its application to heavier vehicles (large trucks and buses) as well as to very small and light vehicles could be of minimal value and may not be practically applicable in the current form. Another issue worth discussing is the type of vehicle fleet in the four Latin American countries. Vehicles in Brazil have tended to be smaller in size, lighter and less powerful than that in countries like Argentina, Mexico, China, South Korea, U.S. and Japan (Posada and Facanha, 2015).

The Moran et al. (2017) study estimates that improving car designs to at least a Euro NCAP 3-star pedestrian safety rating in India, assuming all cars at the time of the study had a 0-star rating will result in a 46% decrease in road traffic pedestrian deaths. In the United States where an assumption is made that at the time of the study, there were 30% of cars with a 0-star rating and 70% having a 1-star rating, it was estimated that improvements will result in a 27% decrease in deaths to pedestrians hit by cars. There is, however, no direct relationship between NCAP ratings and the safety performance required by the Regulations. Therefore, the equivalent improvements between those stated in this study and the implementation of the pedestrian protection regulations remains unclear.

Effectiveness estimates given in the GTR (UN, 2008) are in the range of 1% to 5% of pedestrian fatalities depending on the region considered.

For the 2006 study by Hardy et al. (2006) for pedestrians hit by cars a proposal with brake assist systems (BAS) was approximated to result in a 16.4% and 26.3% reduction in fatal and serious casualties, respectively. For those hit by a car front an 19.3% and 39.2% reduction in fatal and serious casualties respectively was estimated to be achieved for pedestrians. Without BAS, the proportional reductions were estimated to be about 3.9% and 11.8% for fatal and serious casualties, respectively. The corresponding numbers for pedal cyclists were 1.4% and 4.7% for fatal and serious casualties, respectively.

From the effectiveness values listed for the four studies, the minimum value obtained was 1% from the GTR (UN, 2008) with the maximum value being 46% obtained for India from the Moran et al. (2017) study. There is an effectiveness value that can be derived from these two boundary figures. The 1% obtained from the GTR (UN, 2008) is on the lower side given that the study by Moran et al., which stated that in Germany where 97% of cars already have a 3-star or better rating, improvement due to consumer information programme encouragement can still result in about a further 2% reduction in deaths. It is also worth discussing that the 46% estimated effectiveness value obtained for India by Moran et al. is on the high side for application of the regulation given that it relates to vehicles achieving a 3-star NCAP rating. Even for the United States where a 27% reduction in deaths is estimated based on the assumption that 30% of cars had a 0-star rating and 70% a 1-star rating, this figure may be on the high side, as the regulation will not enforce 3-star performance. The effectiveness values estimated in the two studies by TRL, Lawrence et al. (2004) and (Hardy et al., 2006) show values within the two extreme figures (1% and 46%) discussed so far. In the 2006 study, the estimated proportional reduction in the numbers of pedestrian fatal casualties was 16.4% for those hit by cars. The effectiveness value obtained from the study by Hardy et al. included the effect of Brake Assist Systems (BAS) which are active safety systems and therefore goes beyond the effectiveness which can be expected from the passive protection alone. Considering that the GTR does not include the provision of BAS, and focusses on passive systems, the effectiveness value will be lower than the 16.4% figure. The estimated proportional reduction to be achieved for pedestrian fatal casualties without BAS was 3.9% from the study (Hardy et al., 2006). Given that this estimated reduction of pedestrian fatalities (3.9%) is within that estimated in the GTR (1 to 5%), it is reasonable to assume this figure as a central or best estimate. However, if the application of BAS is considered in addition to pedestrian protection systems, 16.4% effectiveness may be achievable. This value was used within one of the sensitivity analysis model runs, as noted in Appendix D.

There is a difficulty in relating the Moran et al. study to the Lawrence et al. study because the former focusses on NCAP star ratings whilst the latter focusses on the GTR. However, the focus of the study by Hardy et al. (2006) is in line with that in the GTR making them comparable and hence recommended for benefit estimates.

Based on these findings and discussions, it is therefore suggested that an effectiveness value within the range of 1% to 5% be considered for pedestrian fatalities. Recommended values for fatal and serious injuries, all taken from the same source, are:

- 3.9% for pedestrian fatalities

- 1.4% for pedal cyclist fatalities

- 11.8% for pedestrian serious injuries

- 4.7% for pedal cyclist serious injuries (Hardy et al., 2006).

It should be remembered that factors influencing how much benefit is to be derived by a country from vehicle front end design for pedestrian safety will include the frequency with which pedestrians are hit by vehicles and the vehicle types that hit pedestrians. Other variables affecting the likely benefits of the GTR include region-to-region differences in the composition of the vehicle fleet, driver behaviour, extent to which existing vehicles currently satisfy the conditions for pedestrian protection of the GTR or are equipped with safety features useful to pedestrians and the prevalence of pedestrian-friendly infrastructure.

Appendix D   Sensitivity analysis

The best-estimate benefit-to-cost ratios (BCRs) presented in Section 7, represent the most likely outcome if road safety trends continue as they have done in recent years. However, there is inherent uncertainty in many of the predictions made and thus sensitivity analysis is required to determine what impact changes to the assumed input values could have on the resulting ratios.

In order to quantify the range of uncertainty around the BCR values, scenario analysis was carried out to reflect the bounds of variation that could be expected if the input values were varied from low to high estimates, or if different assumptions were made at each stage. Specifically, the effect of changing the following inputs/assumptions was investigated[39]:

- The general road safety trend

- Vehicle registration data and extrapolation

- Population predictions from WHO

- Baseline years for vehicles in secondary safety modelling

- Effectiveness estimates

- Target population for ESC

- Voluntary uptake of safety measures

- VSL for benefits estimation

- Safety measure costs

For each analysis, one of these was varied, whilst the other input values/assumptions remained the same. Table 25 outlines the scenarios tested for the car occupant model and Table 26 for the VRU model. Blank cells show where the best-estimate value (see column 2) is used in the model.

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[39] Note that the effect of changing the discounting rates was not investigated since this would affect both the cost and benefit calculations in the same way, resulting in no change to the BCRs presented.

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Table 25: Varied input parameter values for the scenario analysis for car occupants

Input/assumption	Best-estimate	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Casualty rate trend	Exponential trend	Logarithmic trend							
Vehicle registration data	Data from OICA for all countries		Uplift data for Brazil, Argentina and Chile to match IRTAD estimates						
Vehicle registration extrapolation	Linear trend for both all cars and new cars			Logarithmic trend					
Baseline year for secondary safety modelling	2001 in 2016 i.e. 15 years behind				Change to 1996 in 2016 i.e. 20 years behind				
ESC effectiveness estimate	38%					Higher estimate (55%)	Lower estimate (15%)		
Target population for ESC	Loss of control = 34.9% of fatalities							Higher estimate (43.5%)	Lower estimate (26.3%)

Input/assumption	Best-estimate	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Scenario 14	Scenario 15
Uptake of ESC	Uptake takes 20 years, voluntary uptake reaches maximum of 60% in Argentina, Brazil and Chile, and 45% in Mexico	Uptake takes 20 years, voluntary uptake reaches maximum of 45% in all four countries	Uptake takes 20 years, voluntary uptake reaches maximum of 60% in all four countries					
VSL for benefits estimation	Mid estimate for each country			Low estimate for each country	High estimate for each country	Alternative estimates from Viscusi & Masterman (2017)		
Costs	ESC = $50						$36.46	$102

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Table 26: Varied input parameter values for the scenario analysis for VRUs

Input/ assumption	Best-estimate	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Casualty rate trend	Exponential trend for Brazil, Chile and Mexico. Logarithmic for Argentina	Logarithmic trend for all countries							
Population extrapolation	WHO low or medium population projections		Use low projection for all countries	Use medium projection for all countries					
VRU-AEB effectiveness estimate	55% for cyclists 48% for pedestrians				Lower estimate: 21% for pedestrians and 42% for pedal cyclists				
Pedestrian protection effectiveness estimate	1.4% for cyclists 3.9% for pedestrians					Higher estimate: 16.4%, for pedestrians and 10.2% for pedal cyclists	Lower estimate: 1%, for pedestrians and pedal cyclists		
Uptake of VRU-AEB	Uptake takes 20 years, voluntary uptake reaches 50%							Higher uptake: voluntary uptake reaches 90%	
Uptake of pedestrian protection	Uptake takes 20 years, voluntary uptake reaches 50%								Higher uptake: voluntary uptake reaches 90%

Input/ assumption	Best-estimate	Scenario 9	Scenario 10	Scenario 11
VSL for benefits estimation	Mid estimate for each country	Low estimate for each country	High estimate for each country	
Costs	VRU-AEB = $261 Pedestrian protection = $258			Multiply costs by 50%

Appendix E   Discounting

In this paper a discount rate is applied to both the costs and benefits (presented in today's terms). The application of a discount rate reflects that benefits and costs further into future are valued less highly than present benefits and costs.

For private sector project evaluation it is usual to use the return that an investor could get in the open market as a discount rate (the Opportunity Cost of Capital). Projects are then evaluated more worthwhile if they can offer a better return than would be gained from investing elsewhere. For projects with a social benefit a lower rate is normally used to reflect the difference in people's expectations of returns on social projects versus private ones. A social discount rate was chosen with reference to Lopez et al, who calculated social discount rates for Latin American countries (Lopez, 2008).

Lower social discount rates are used for projects with longer time-horizons. As we are evaluating the costs and benefits from 2020 to 2030 a social discount rate of 4.5%, for projects with a 10 year time horizon, has been used (figure 2, Lopez, 2008).

While these rates were calculated a number of years ago, in other parts of the world social discount rates have stayed relatively stable over the same period. For example the social discount rate used by the UK treasury in 2003 was 3.5%, and the same rate has been used in subsequent updates up to the most recent (HM Treasury, 2003;HM Treasury, 2013). Similarly the EU rate for poorer regions of Europe has fluctuated only slightly between 2002 and today (in 2002 the recommended social discount rate was 5%, in 2008 it was 5.5% and it has since reverted to 5%) (European Commission, 2008;European Commission, 2014;European Commission, 2002).

Appendix F   Secondary safety benefits

As outlined in Table 11 (Section 4.1), by 2020 the secondary safety regulations for frontal collision testing, seat belts and seat belt anchorages will have been implemented in all new cars in all four countries. Side collision testing will also be in place (or planned in the near future) for three of the four countries (Brazil being the only exception where the proposed timeline for this regulation is currently unclear).

As a result, the analysis presented in Sections 5-7 of this report does not include any benefit or cost predictions for UN Regulation 94 (occupant protection in frontal collision), Reg. 95 (Occupant protection in side or lateral collisions) or Reg.s 14 & 16 (Approved seat belts and anchorages for all seating positions) since the current timeline predictions (Section 4) already incorporate the impact of these changes.

Although these regulations are already in place, it is useful to provide some additional context to the results presented in the report, specifically to outline how many car occupant lives will likely be saved in these countries as a result of these regulations. This appendix presents an estimate of the number of lives saved due to the implementation of these secondary safety regulations, improving on the model used in previous work (Cuerden et al., 2015 and Wallbank et al., 2016). The model presented here offers two improvements over the previous work in this area:

1. The model accounts for the impact that voluntary uptake of other regulations (namely ESC) will have on the baseline casualty estimates. Primary safety regulations, such as ESC, reduce the size of the target population which secondary safety measures can influence. The model used in this work first takes into account the casualty savings which primary measures can achieve, and then applies the secondary safety modelling methodology to the fatalities which still occur. As a result, the secondary safety savings presented here are marginally smaller than seen in previous work.

2. The fatality numbers presented in this paper have been factored to ensure that the results for all four countries are comparable, and represent the number of fatalities within 30 days of the collision. As discussed in Section 3.2, Brazil and Mexico figures are factored down (using a factor of 0.97) from those used in previous papers, and those from Chile are factored up (using a factor of 1.30). As a result, the Chile figures are marginally larger than the lower estimates presented in Wallbank et al., 2016.

As described in Section 2.1.3, the secondary safety modelling in this paper assumes that vehicle secondary safety in Latin America is generally 15 years behind that in Great Britain; in 2016 the standards in Latin America are at approximately the same level as in Great Britain in 2001. Using this assumption, Figure 46 presents the estimated number of lives saved in each year between 2017 and 2030 due to these regulations.
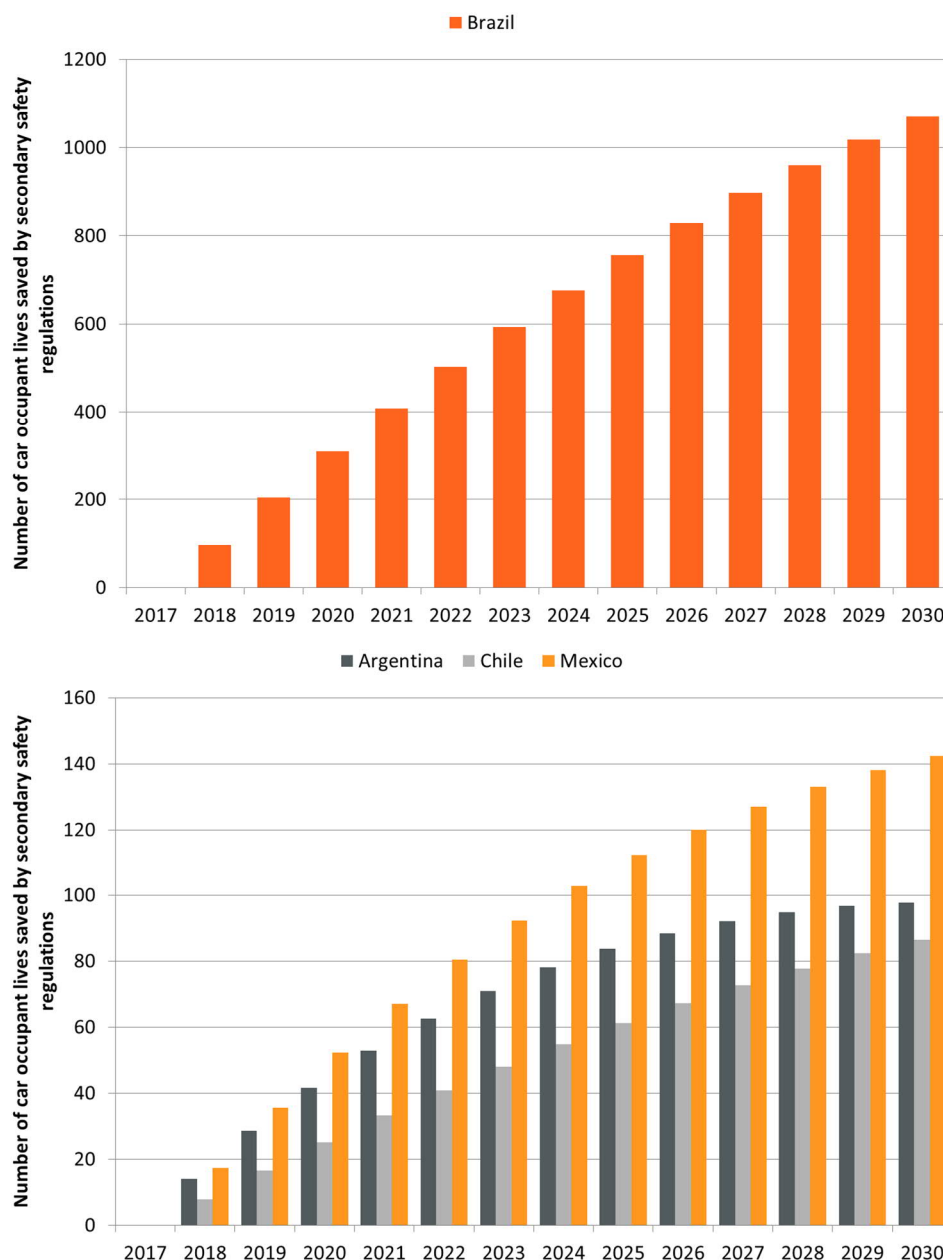
Figure 46: Estimated number of car occupant lives saved due to implementation of secondary safety regulations (2017-2030)

The results show that by 2030, around 1,100 fatalities will be saved each year in Brazil and between 80-140 fatalities will be saved in each of the other three countries. This results in a cumulative saving in the four Latin American countries of over 11,000 fatalities between 2017 and 2030, equivalent to a monetary saving of approximately 7.4 billion USD (2018 $).

This is a good news story for Latin America: the vehicle safety regulations already being implemented will have a significant impact on the fatality trends in future years. However, as evidenced by the rest of the results presented in this report, more can be done to reduce

the fatality numbers even further and other regulations such as ESC, VRU-AEB and pedestrian protection could offer a cost-beneficial solution.

Appendix G   Fatality benefit-to-cost ratios

This section presents the results of the cost-benefit analysis when just the impact of the safety measures on fatalities is considered. Figure 47 presents the year-by-year benefit-to-cost ratio of implementing ESC in each of the four countries from 2020-2030, just focusing on car occupant fatalities. Table 27 presents the year in which the benefit-to-cost ratio becomes greater than 1 in each country, and Table 28 presents the cumulative benefit-to-cost ratios over the full period.
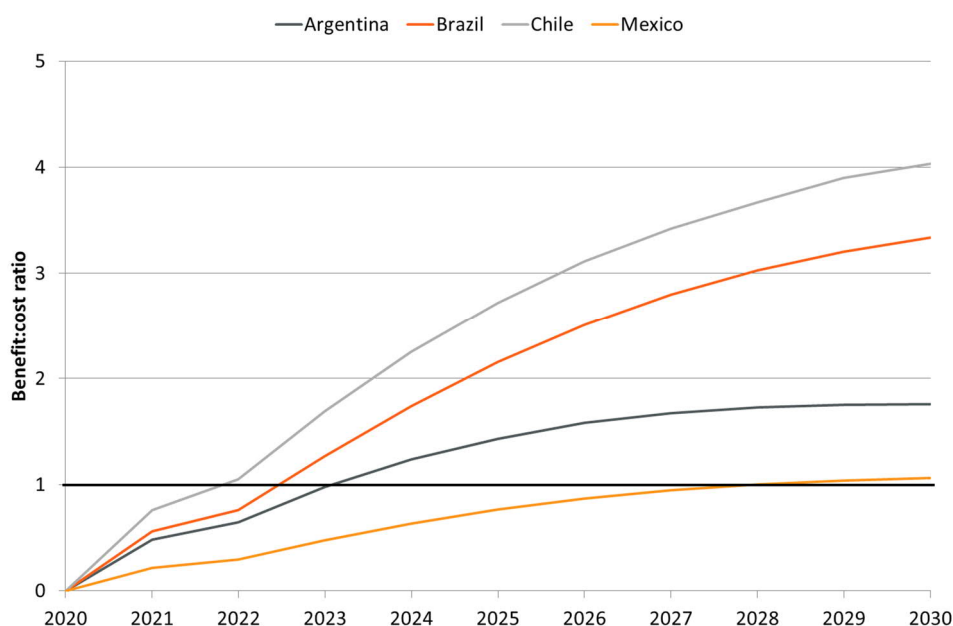

Figure 47: Estimated benefit:cost ratio associated with implementing ESC regulation in 2020, just considering impact on fatalities (2020-2030)

Table 27: Year in which the BCR for ESC becomes greater than 1 in each country, just considering impact on fatalities

Country	First cost-beneficial year	First cost-beneficial year (lower estimate from sensitivity analysis)	First cost-beneficial year (upper estimate from sensitivity analysis)
Argentina	2024	>2030	2022
Brazil	2023	2027	2022
Chile	2022	2025	2021
Mexico	2028	>2030	2024
Overall	2023	2029	2022

Table 28: Cumulative BCR for ESC over the period 2020-2030 by country, just considering impact on fatalities

Country	BCR (2020-2030)	BCR (lower estimate from sensitivity analysis)	BCR (upper estimate from sensitivity analysis)
Argentina	1.34	0.53	2.23
Brazil	2.05	0.81	3.29
Chile	2.65	1.05	4.19
Mexico	0.71	0.28	1.21
Total	1.58	0.68	2.79

These results show that the benefit-to-cost ratio for ESC becomes greater than 1 in the region within 3 years of implementation, although it takes 8 years for this to happen in Mexico. Over the full period from 2020-2030, the regulation is cost-beneficial in Argentina, Brazil and Chile, but not in Mexico.

Figure 48 presents the year-by-year benefit-to-cost ratio of implementing VRU-AEB and pedestrian protection in each of the four countries from 2020-2030, just focusing on VRU fatalities. Table 29 presents the year in which the benefit-to-cost ratio becomes greater than 1 in each country, and Table 30 presents the cumulative benefit-to-cost ratios over the full period.
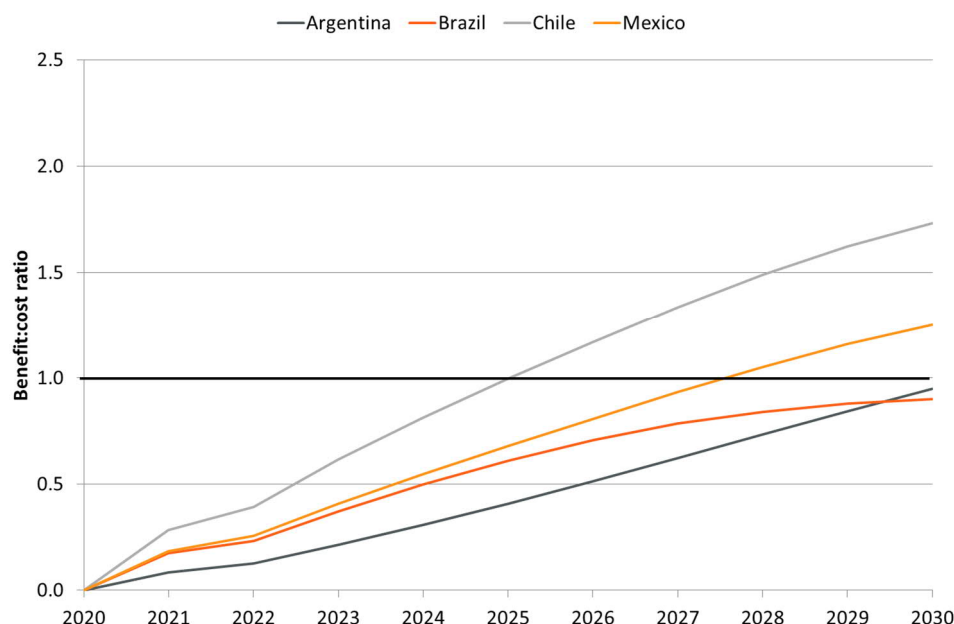

Figure 48: Estimated benefit:cost ratio associated with implementing VRU-AEB and pedestrian protection regulations in 2020, just considering impact on fatalities (2020-2030)

Table 29: Year in which the BCR for VRU-AEB and pedestrian protection becomes greater than 1 in each country, just considering impact on fatalities

Country	First cost-beneficial year	First cost-beneficial year (lower estimate from sensitivity analysis)	First cost-beneficial year (upper estimate from sensitivity analysis)
Argentina	>2030	>2030	2026
Brazil	>2030	>2030	2025
Chile	2026	>2030	2023
Mexico	2028	>2030	2024
Overall	2030	>2030	2024

Table 30: Cumulative BCR for VRU-AEB and pedestrian protection over the period 2020-2030 by country

Country	BCR (2020-2030)	BCR (lower estimate from sensitivity analysis)	BCR (upper estimate from sensitivity analysis)
Argentina	0.44	0.23	0.89
Brazil	0.57	0.29	1.14
Chile	0.99	0.52	1.99
Mexico	0.68	0.34	1.37
Total	0.61	0.31	1.21

These results show that the 'in-year' benefit-to-cost ratio for VRU-AEB and pedestrian protection will have increased above 1 in Chile and Mexico by 2028, if only the impact on fatalities is considered. However, the ratio for Argentina and Brazil will still be below 1 in 2030, although in Argentina it would be expected to rise above 1 by 2031, if the analysis was extended to that time point. The results also show that over the whole period (2020-2030), the measures to protect VRUs would not be cost-beneficial if only fatalities were considered. This is a consequence of the fact that a substantial proportion of the benefits presented in section 5 (41%) come from reductions in serious injuries.

Figure 49 presents the year-by-year benefit-to-cost ratio of implementing (ESC, VRU-AEB and pedestrian protection) in each of the four countries from 2020-2030, focusing on the overall impact on car occupant and VRU fatalities. Table 31 presents the year in which the benefit-to-cost ratio becomes greater than 1 in each country, and Table 32 presents the cumulative benefit-to-cost ratios over the full period.
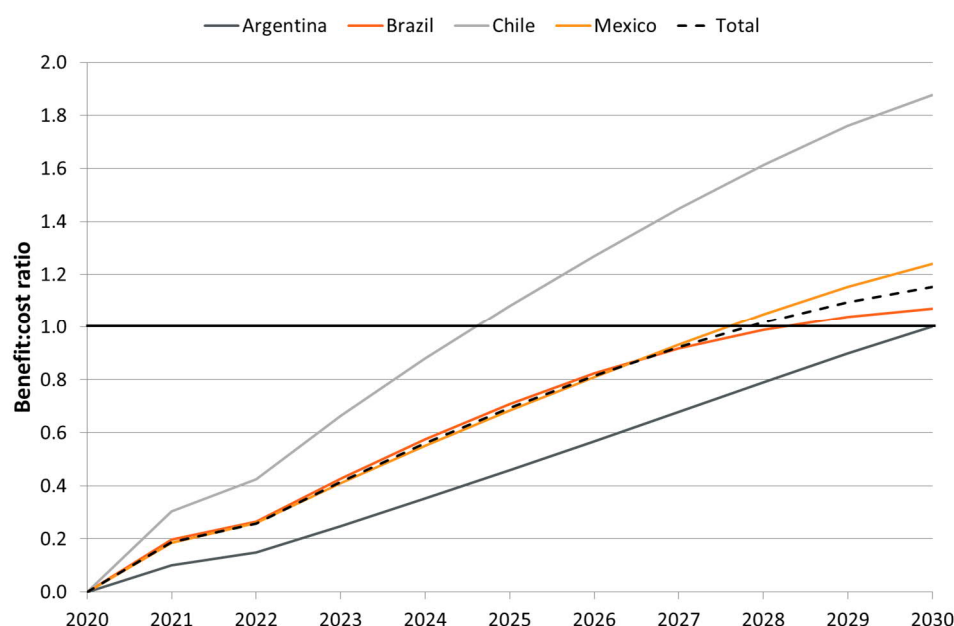
Figure 49: Estimated benefit:cost ratio associated with implementing all three regulations (ESC, VRU-AEB and pedestrian protection) in 2020, just considering impact on fatalities (2020-2030)

Table 31: Year in which the BCR for ESC, VRU-AEB and pedestrian protection becomes greater than 1 in each country, just considering impact on fatalities

Country	First cost-beneficial year	First cost-beneficial year (lower estimate from sensitivity analysis)	First cost-beneficial year (upper estimate from sensitivity analysis)
Argentina	2030	>2030	2026
Brazil	2029	>2030	2024
Chile	2025	>2030	2023
Mexico	2028	>2030	2024
Overall	2028	>2030	2024

Table 32: Combined cumulative BCR for ESC, VRU-AEB and pedestrian protection over the period 2020-2030 by country

Country	BCR (2020-2030)	BCR (lower estimate from sensitivity analysis)	BCR (upper estimate from sensitivity analysis)
Argentina	0.49	0.25	1.02
Brazil	0.67	0.33	1.40
Chile	1.08	0.54	2.20
Mexico	0.65	0.34	1.35
Total	0.67	0.33	1.39

These results show that in each country, the combined set of safety measures reach an 'in-year' benefit-to-cost ratio of greater than 1 by 2030 at the latest (and as early as 2025 in Chile). However, over the full period (2020-2030), the measures would not be cost-beneficial if only fatalities were considered, for the same reasons explained above for VRUs.

Appendix H   Serious injury benefits

In addition to the fatality benefits estimated in Section 5 of this report, the regulations implemented in this study are also likely to have an impact on the number of serious injuries. This appendix presents the results of analysis to estimate the serious injury savings, and resulting BCRs, which could be obtained on top of the fatality estimates presented in the main body of the report.

It should be noted that this methodology is a simplification of that applied to the fatality savings and as a result, substantial caution should be applied to the results since additional assumptions are required. These are documented in Appendix H.1.

H.1   Methodology and assumptions

There is limited information available on the number of serious injuries in each country, and so some assumptions are required to estimate the baseline number of these casualties. For the purposes of this analysis, we have assumed that a simple factoring process can be applied, using data from STATS19 to estimate the ratio of fatal to serious casualties in each of the relevant scenarios.

For car occupants in ESC collisions (i.e. those involving loss of control), we estimate that in GB there are approximately 6.5 serious injuries for every fatality. For pedestrians struck by a car the figure is 11.3 and for pedal cyclists in a collision with a car 49.1. This factoring assumes that the ratio of fatal to serious casualties is the same in each of the four countries included in this study as observed in Great Britain: a substantial assumption given the likely differences in collision types and severity definitions.

In addition to factoring the baseline casualties, the effectiveness estimates for each regulation are likely to be different for serious injuries than fatalities. A review of the literature (documented in Appendix B, Appendix C and equivalent information for ESC) shows that the relevant effectiveness estimates for serious injuries are:

- Car occupants:
    - ESC serious injury effectiveness = 21%
- Pedestrians:
    - VRU-AEB serious injury effectiveness = 42%
    - Pedestrian protection serious injury effectiveness = 11.8%
- Pedal cyclists:
    - VRU-AEB serious injury effectiveness = 33%
    - Pedestrian protection serious injury effectiveness = 4.7%

Using these factors, the number of serious injuries prevented by regulation can be estimated and a VSL estimate then applied to estimate the economic benefit. Bhalla et al. (2013) reviewed a number of relevant VSL studies and showed that the economic loss due to a serious non-fatal injury was equivalent to 17 times GDP per capita (Table 33).

Table 33: Economic loss of serious injury using VSL method

	Forecast GDP per capita (2018) (2018 USD) – see Figure 11	Economic loss of one serious injury due to traffic collision (2018 USD, thousands)
Argentina	12,924	220
Brazil	8,807	150
Chile	14,186	241
Mexico	8,321	141

Finally, this economic benefit can be combined with the economic benefit for fatalities prevented (from Section 5) to estimate the total benefit of the casualty savings. This is then compared to costs (from Section 6) to generate new BCRs accounting for both fatalities and serious injuries combined. Appendix H.2 presents the casualty savings and H.3 the revised BCRs.

H.2   Casualty savings

H.2.1   Car occupants

Figure 50 presents the estimated number of car occupant serious injuries saved each year through the implementation of the regulation for ESC.
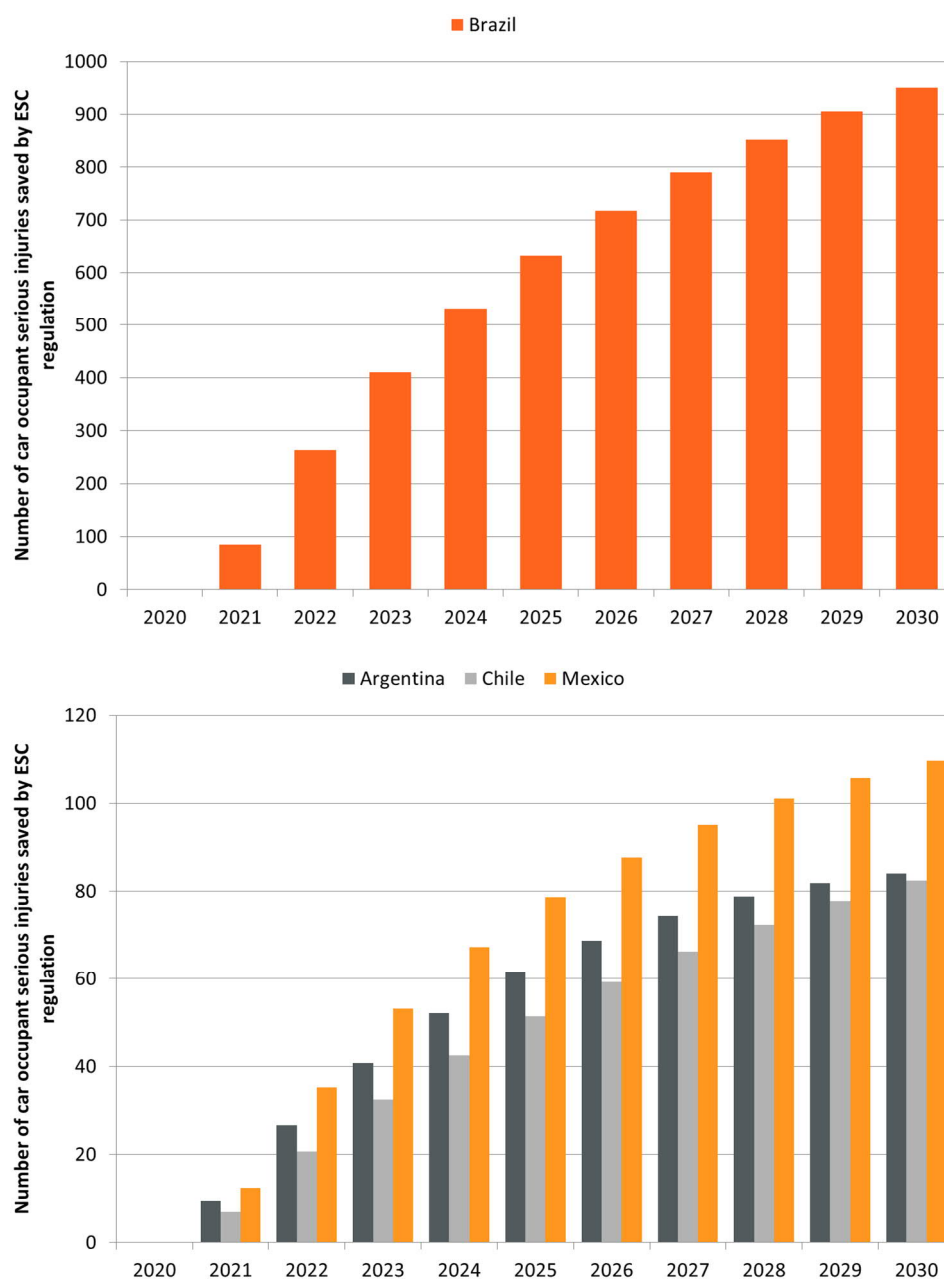

Figure 50: Estimated number of car occupant serious injuries saved due to implementation of ESC regulations in 2020 (2020-2030)

The cumulative results are presented in Table 34.

Table 34: Lives and serious injuries saved and economic benefit for car occupants due to implementation of ESC regulation in 2020 (2020-2030)

	Cumulative lives saved, 2020-2030	Cumulative serious injuries saved, 2020-2030	Discounted economic benefit, fatalities 2020-2030 (2018 US $, millions)	Discounted economic benefit, serious injuries 2020-2030 (2018 US $, millions)	Total economic benefit 2020-2030 (2018 US $, millions)
Argentina	160	578	147.64	87.47	235.11
Brazil	1,699	6,138	1,062.90	630.11	1,693.01
Chile	142	512	142.41	84.21	226.61
Mexico	206	746	122.66	72.34	194.99
Total	2,207	7,975	1,352.94	874.12	2,349.72

This demonstrates that by 2030, almost 8,000 serious injuries could be saved in total due to ESC regulations. The majority of these savings are found in Brazil with just over 6,000 serious injuries saved over the period of study. This is the equivalent to a monetary saving of around 870 million USD, resulting in a total benefit of around 2.35 billion USD when fatalities are also added.

H.2.2   Vulnerable road users

Figure 51 presents the estimated number of pedestrian serious injuries saved each year through the implementation of regulations for VRU-AEB and pedestrian protection. Table 35 presents the cumulative figures.
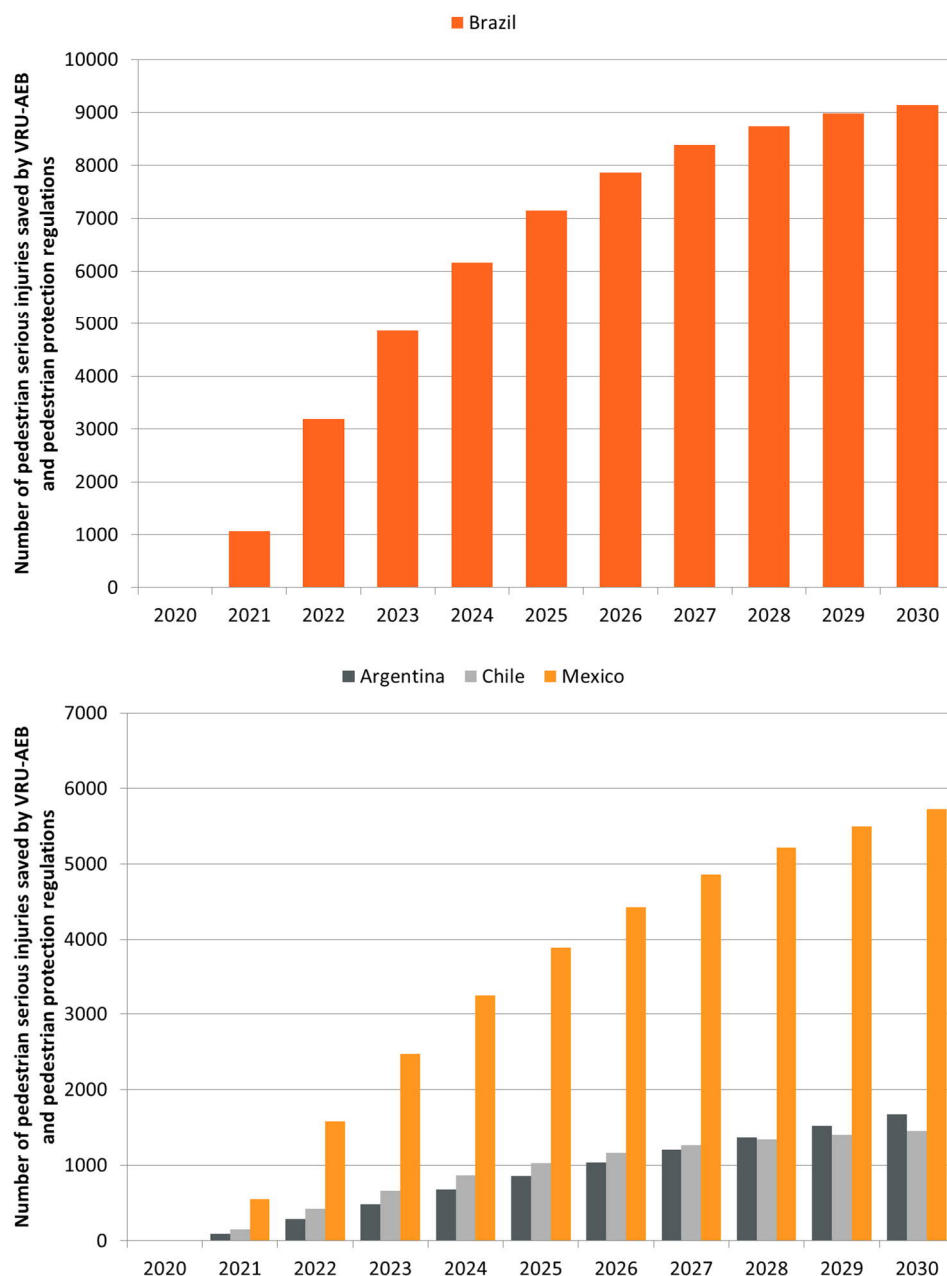
Figure 51: Estimated number of pedestrian serious injuries saved due to implementation of VRU-AEB and pedestrian protection regulations in 2020 (2020-2030)

Table 35: Lives and serious injuries saved and economic benefit for pedestrians due to implementation of VRU-AEB and pedestrian protection regulations in 2020 (2020-2030)

	Cumulative lives saved, 2020-2030	Cumulative serious injuries saved, 2020-2030	Discounted economic benefit, fatalities 2020-2030 (2018 US $, millions)	Discounted economic benefit, serious injuries 2020-2030 (2018 US $, millions)	Total economic benefit 2020-2030 (2018 US $, millions)
Argentina	829	9,207	749.01	1,366.12	2,115.13
Brazil	5,871	65,550	3,698.33	6,784.12	10,482.44
Chile	851	9,751	858.84	1,612.26	2,471.10
Mexico	3,187	37,462	1,884.06	3,616.06	5,500.12
Total	10,738	121,970	7,190.23	13,378.57	20,568.80

Regulations targeted at VRUs have the potential to prevent serious injuries to around 120,000 pedestrians between 2020 and 2030. This is the equivalent to a monetary saving of 13.4 billion USD, resulting in estimated total economic savings of 20.6 billion USD for this casualty group.

Figure 52 presents the estimated number of pedal cyclist serious injuries saved each year by the VRU regulations. Table 36 presents the cumulative figures.
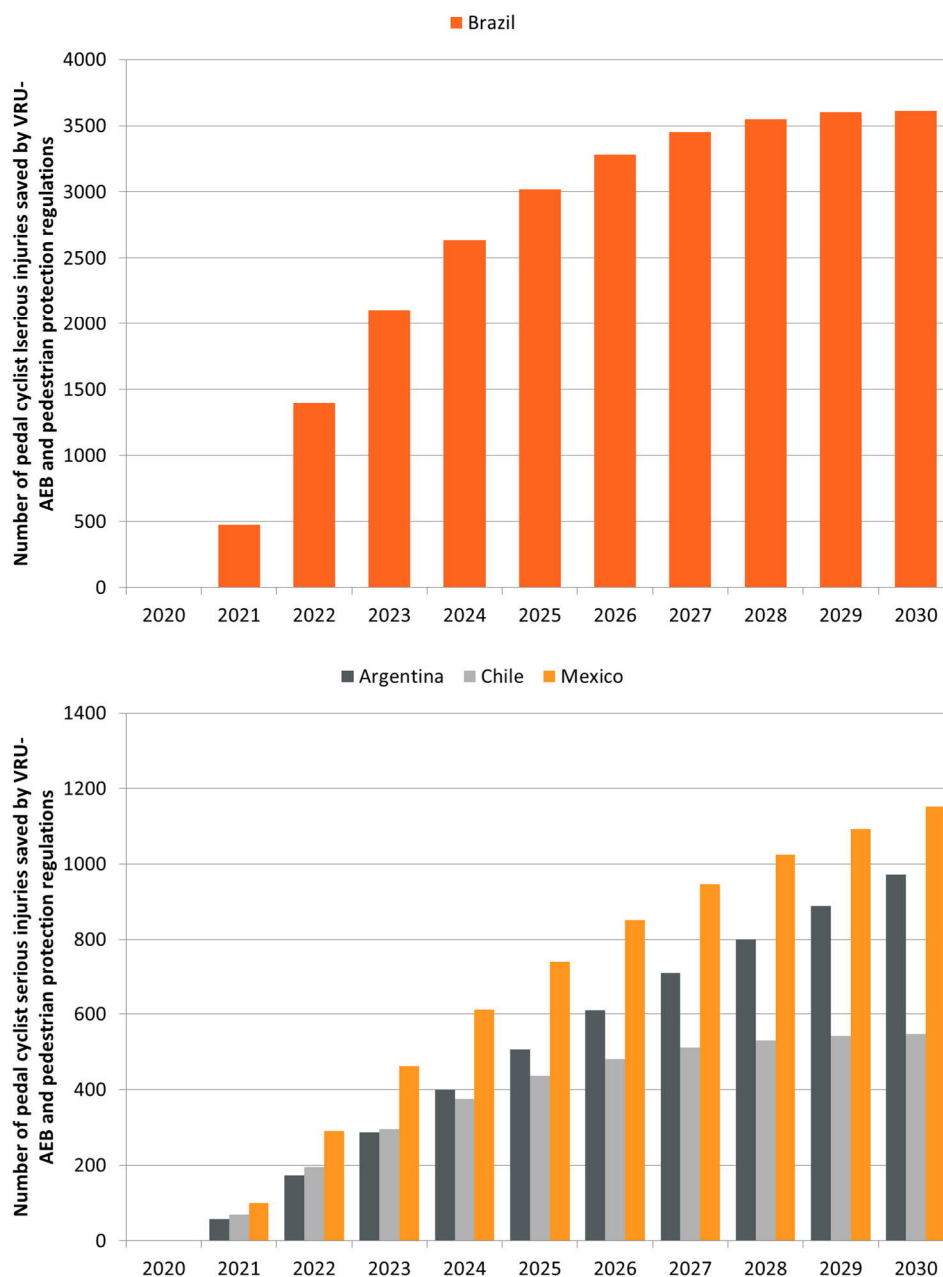

Figure 52: Estimated number of pedal cyclist serious injuries saved due to implementation of VRU-AEB and pedestrian protection regulations in 2020 (2020-2030)

Regulations targeted at VRUs will also save pedal cyclist serious injuries; between 2020 and 2030 over 43,000 could be saved. This is the equivalent to a monetary saving of almost 5 billion USD, making the total saving for all pedal cyclist casualties around 5.9 billion USD.

Table 36: Lives and serious injuries saved and economic benefit for pedal cyclists due to implementation of ESC regulation in 2020 (2020-2030)

	Cumulative lives saved, 2020-2030	Cumulative serious injuries saved, 2020-2030	Discounted economic benefit, fatalities 2020-2030 (2018 US $, millions)	Discounted economic benefit, serious injuries 2020-2030 (2018 US $, millions)	Total economic benefit 2020-2030 (2018 US $, millions)
Argentina	171	5,400	154.71	801.77	956.47
Brazil	857	27,127	541.75	2.817.54	3,359.29
Chile	124	3,983	125.66	662.88	788.54
Mexico	222	7,273	130.58	699.99	830.57
Total	1,373	43,782	952.70	4,982.17	5,934.87

H.3   Benefit-to-cost estimates

H.3.1   Car occupants

The addition of serious injuries to the benefit estimates improves the benefit-to-cost ratio (BCR) of ESC regulations for the countries studied. Table 37 presents the cumulative BCR for car occupants, including both fatalities and serious injuries, over the period 2020 to 2030.

Table 37: BCR including fatalities and serious injuries for car occupants over the period 2020-2030 by country

Country	BCR (2020-2030)
Argentina	2.14
Brazil	3.27
Chile	4.22
Mexico	1.12
Total	2.75

The inclusion of the serious injury benefits means that the ESC regulations are cost-beneficial in all four of the individual countries and for the region in total.

H.3.2   Vulnerable road users

Table 38 presents the cumulative BCR for VRUs over the period 2020 to 2030.

Table 38: BCR including fatalities and serious injuries for VRUs over the period 2020-2030 by country

Country	BCR (2020-2030)
Argentina	1.51
Brazil	1.86
Chile	3.29
Mexico	2.15
Total	1.98

The inclusion of the serious injury benefits means that the VRU-AEB and pedestrian protection regulations are also cost-beneficial in all four countries; both individually, and also for the region in total.

The potential for vehicle safety standards to prevent deaths and injuries in Argentina, Brazil, Chile and Mexico: a 2018 update

The World Health Organization estimates that the number of road traffic deaths has reached 1.35 million per year, with the highest road traffic fatality rates in low-income countries. The overall aim of this research is to support the adoption of priority vehicle safety standards for all new vehicles globally. Four countries (Argentina, Brazil, Chile and Mexico) are used as a case study.

The three highest priority vehicle safety standards (applicable to cars) are considered to be:

1. Minimum standards for crashworthiness (seat belts and frontal and side collision protection);

2. Electronic Stability Control (ESC) for crash avoidance;

3. Pedestrian protection measures to improve safety for Vulnerable Road Users (VRUs).

The report estimates the lives and serious injuries that could be saved over ten years if Argentina, Brazil, Chile, and Mexico adopted the full set of priority vehicle safety standards from 2020.

Other titles from this subject area

PPR766   The potential for vehicle safety standards to prevent road deaths and injuries in Brazil. Cuerden, Lloyd, Wallbank & Seidl. 2015

PPR797   The potential for vehicle safety standards to prevent deaths and injuries in Latin America. Wallbank, McRae-McKee, Durrell & Hynd. 2016.