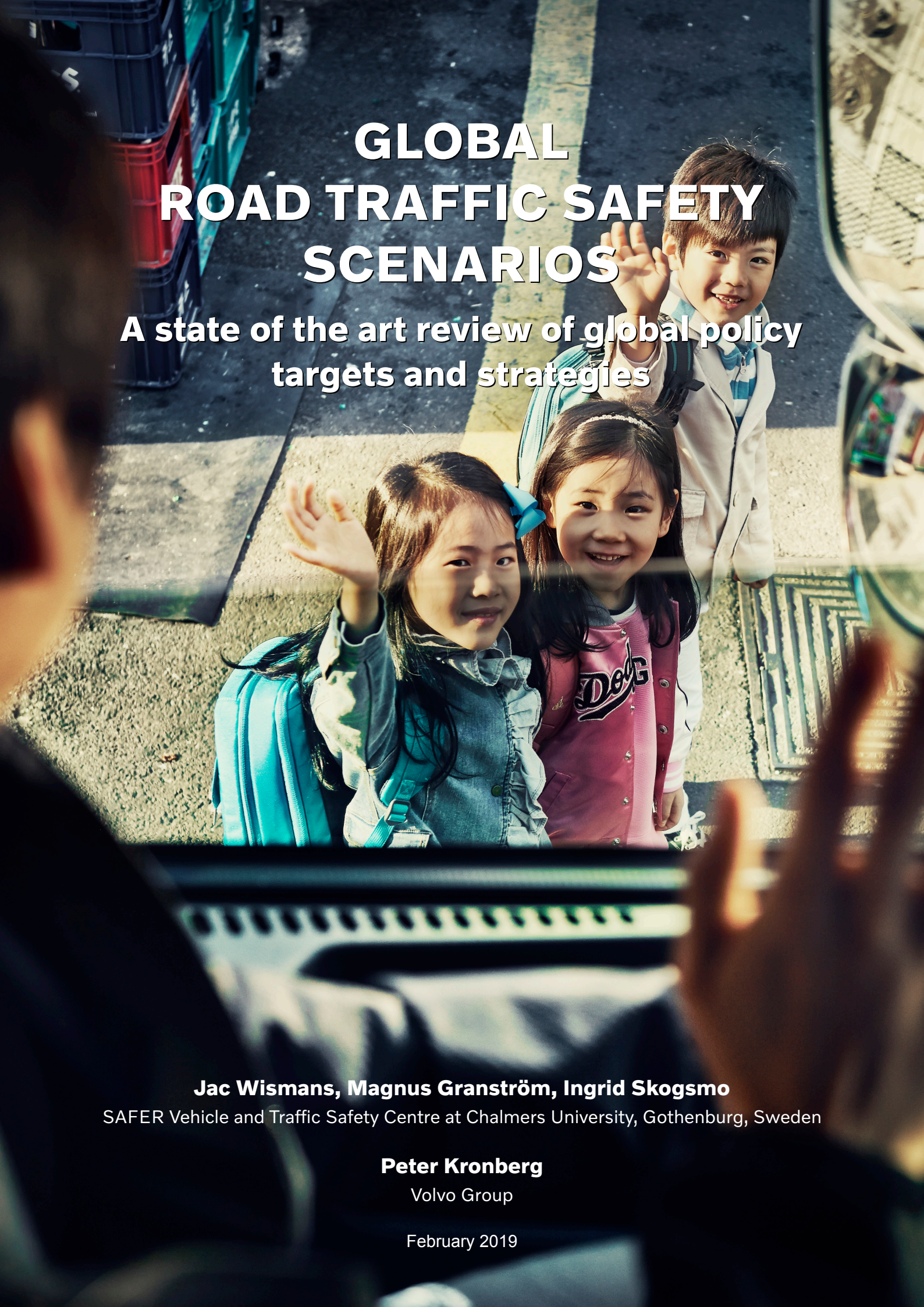

GLOBAL ROAD TRAFFIC SAFETY SCENARIOS

A state of the art review of global policy targets and strategies

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Forewords

Dear reader, it is disheartening to consider how far we are from cutting the rise in road fatalities, as revealed by the most recent WHO status report on road safety, despite being quite aware of the tools at our disposal, as demonstrated by the relative success of countries like Sweden, Norway, the UK, and the Netherlands.

Is the lack of progress due to a lack of funds, vehicle safety standards, enforcement, political commitment, or something else – and is the present situation of stagnation inescapable?

The authors of this report believe that what may be lacking to mobilize fully, both public and private stakeholders, is a convincing narrative for what to achieve and how to get there and what decisions to take in the intermediate steps to ensure progress.

This report serves as a review of the state of the art of the methods and frameworks used in road safety strategy and policy work today. It is meant as a pre-cursor to a larger effort aiming to create a robust model of road safety progress, which will allow the definition of possible scenarios for how to reach regional and global road safety targets.

I wish to express a particular thanks to Prof. Dr Jac Wismans for shouldering the role of main author in such a prodigious manner.

I hope you will find this report useful in your work.

Peter Kronberg
Safety Director
Volvo Group

Even though a lot of effort has been spent, and many steps forward have been taken over the years, this report shows that there is still a lot of work ahead of us if we want to fulfil the goals set both on a global scale and regionally and nationally.

As a national research centre for vehicle and traffic safety, the work on this report has given us an opportunity to delve deeper into certain aspects than we often do, especially in terms of policy issues and deployment of legislation and other means of influencing behaviour, vehicle features, and infrastructure. This, combined with the latest research results from national and international projects should provide a solid foundation for the next step of this project. At SAFER we are happy to be part of this endeavour and hope that you as a reader find a lot of useful information and also get inspiration for future common work in this area.

Magnus Granström
Director, SAFER

Executive Summary

The objective of this study is to establish a foundation for development of future scenarios that can help implement and identify true road safety improvements. It contains a state-of-the-art review of available papers and reports dealing with:

- **future regional and global road safety plans**
- **prediction models and information for the development of future road safety scenarios**

In **Chapter 2** an overview of general global trends in our society is given, focusing on the use of scenarios to predict future trends as function of measures taken. It is shown that the use of scenario modelling is quite common in transport energy forecasts, but in the field of road safety, scientifically based road safety forecasts are rare.

The global road safety problem is briefly reviewed in **Chapter 3**. In 2016 worldwide around 1.35 million people died due to road accidents and this number is still increasing. Vulnerable Road Users (pedestrians, cyclists and motor cyclists combined) are particularly at risk. More than half of all global fatalities are in Asia and almost 20% in Africa. The number of road fatalities per 100.000 inhabitants is much higher in some parts of the world than in Europe. Fatalities are just the top of the iceberg: in 2010 almost 80 million persons needed medical care due to a road accident, of which more than 9 million were requiring hospital admission.

Road safety plans on a global and regional level are summarized in **Chapter 4**, including the UN Decade of Action for Road Safety (2011-2020) and the adoption of the sustainable development goals (SDGs) by the United Nations in 2015, with the target to reduce, by 2020, half of the number of global deaths and injuries from road traffic accidents. In the meantime, this target has appeared to be much too ambitious. Most regions and countries in the world have adopted similar targets as the SDG target 3.6. Chapter 4 includes an overview of the status of implementation of road safety measures in Africa and Asia and shows that there is a lack of good accident data in many developing countries.

The key part of this report is **Chapter 5**, that summarizes prediction models and other sources that can help to develop future scenarios of countermeasures to more effectively improve the road safety situation in a country. The reviewed sources contain a lot of useful information and elements that can be used for the development of future road safety scenarios, but none of them offer in their current status an integrated, unique and ready to use framework/methodology for such scenario development. It is recommended that some of the prediction models like the SafetyCube DSS and SafeFITS, are analysed in more detail in order to assess their appropriateness as a basis for a future framework/methodology for the development of road safety scenarios.

Table of Contents

1 Introduction

The objective of this study is to perform a state-of-the-art review of available papers and reports dealing with

1) future regional and global road safety plans and
2) prediction models and other tools and data

for the development of future road safety scenarios for the whole safety system (infrastructure, vehicles, human behaviour, policy etc.) as well as different geographical and/or economical regions.

This report is organised in 6 Chapters. In Chapter 2, first some global trends in the next 20-30 years in our society will be discussed with the focus on transport and mobility, followed in Chapter 3 by a y short summary of the global road safety problem. Chapter 4 deals with future road safety plans on a global and regional level and Chapter 5 with prediction models and other tools and data that can help developing future road safety scenarios. The conclusions of this study are presented in Chapter 6 together with suggestions for next steps.

2 Global trends until 2050

The key drivers for the growing demand for transportation are population growth and increase in income per person (economic growth). The world population is projected to increase from 7.6 billion in 2017, to 8.6 billion in 2030, 9.8 billion in 2050 and 11.2 billion in 2100 according to the 2017 Revision of UN World Population Prospects [1]. The world economy is expected to almost double over the next 20 years, where a large part of the expected growth is taken place in emerging economies [2]. Africa accounts for almost half of the increase in the world population till 2035 [2].

Other important trends are:

- an aging population
- increasing urbanization and congested megacities
- increase in motorization in low- and middle-income countries
- climate change and due to this the urgent need to reduce CO2 and emissions due to transportation
- many new technology developments including vehicle automation
- government policy to promote more liveable cities.

Through scenario modelling several organisations have made predictions for future transport demand, vehicle mix and transport energy usage. Figure 1 shows predictions from the World Energy Council for transport energy demand for Light Duty Vehicles (LDV's) and the predicted changes in technology mix of LDV's until 2050, according to 2 scenarios: the so-called Freeway and Tollway scenarios. The "Freeway" scenario describes a world where pure market forces prevail (open global competition) and the "Tollway" scenario a more regulated world where governments regulate markets to promote technology and infrastructure developments among others aimed to minimize climate change. In the Tollway scenario the energy demand after some initial increase returns to a 2005 level, whereas in the Freeway scenario the energy demand almost increases by 70% from 2005-2050. The share of Gasoline and Diesel engines has decreased significantly in the Tollway scenario in favour of Electric, Hybrid and Fuel cell vehicles [3].

According to the International Energy Agency (IEA) - Global EV Outlook 2018 [4] in 2017 more than 1 million electric cars were sold worldwide, of which 50% in China [4]. Also for other transport modes electrification is developing rapidly. In 2017, sales of electric buses were estimated about 100 000 and sales of two-wheelers (mainly e-bikes) at 30 million [4]. Figure 2 shows predictions for the global growth in electric vehicles till 2030 according to 2 scenarios: The New Policies Scenario and the EV30@30 Scenario for different types of vehicles (excluding electrified 2-3 wheelers) [4]. In the New Policies Scenario, which is business as usual, but taking existing and announced policies into account, the number of electric vehicles on the road reaches more than 125 million by 2030. In the EV30@30 scenario with higher policy ambitions to meet the climate goals and other sustainable targets, the number of EV's on the road reaches more than 220 million.

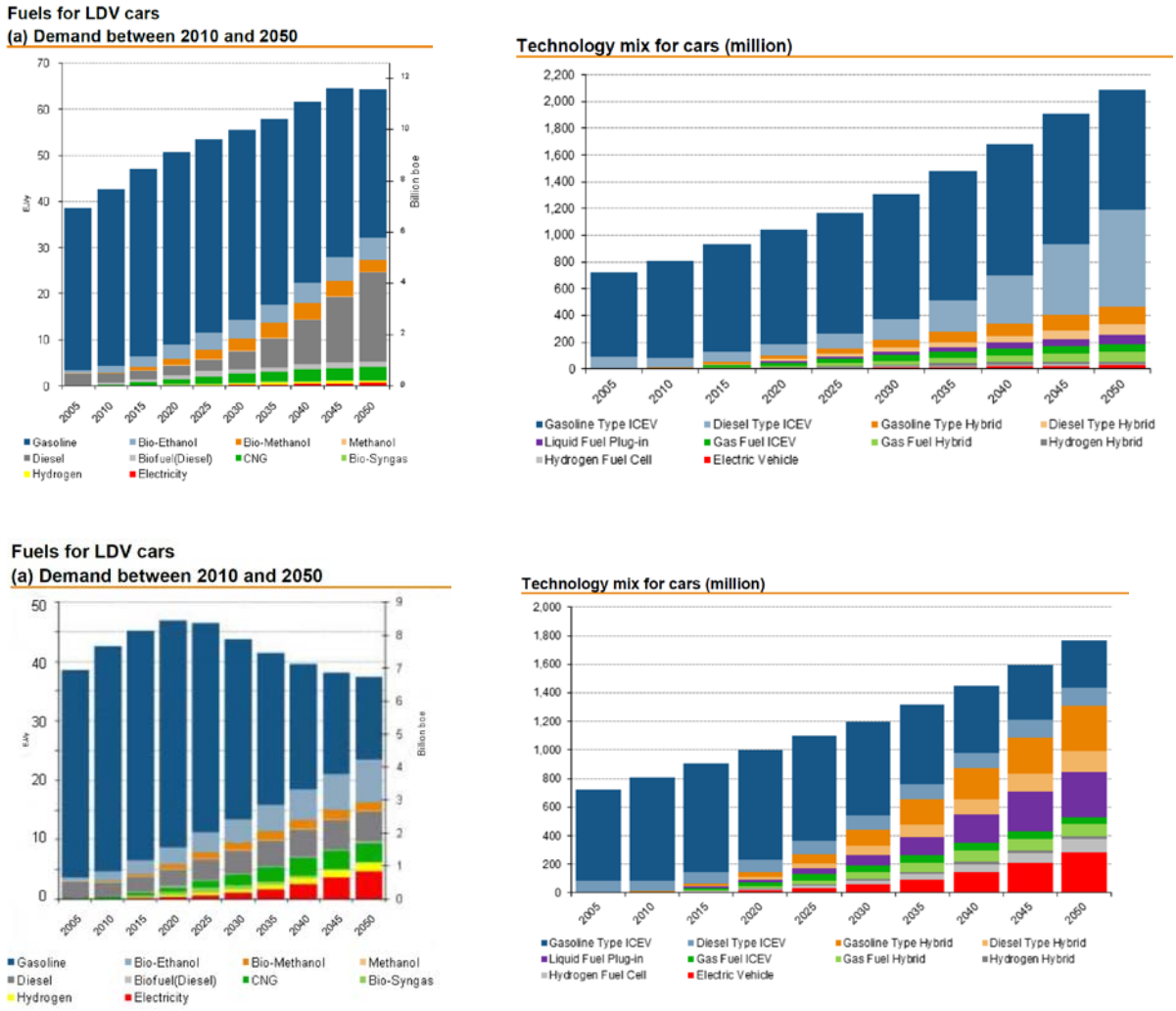
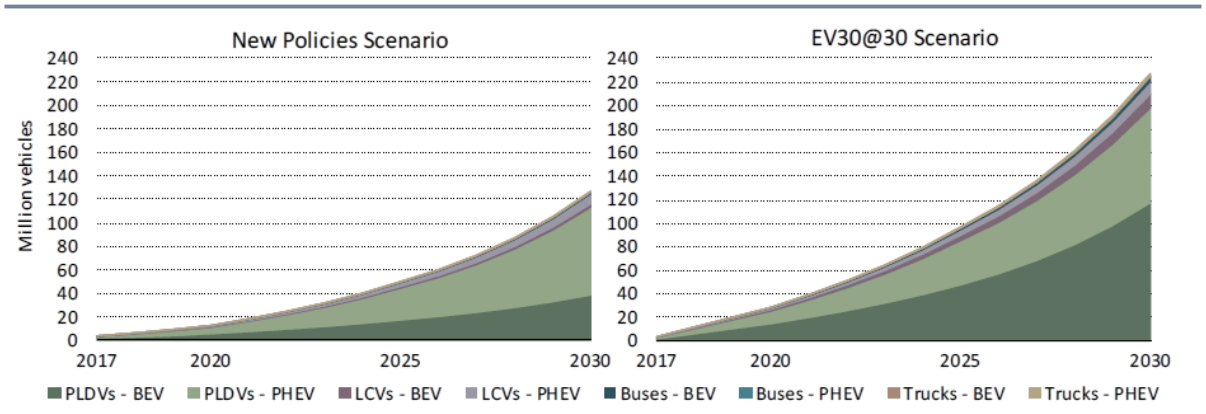


Figure 1: Predictions for global energy demand for LDV's and Technology mix until 2050 according to two scenarios: the FREEWAY scenario (above) and the TOLLWAY scenario (below) [3]



Notes: PLDVs = passenger light duty vehicles; LCVs = light commercial vehicles; BEVs = battery electric vehicles; PHEV = plug-in hybrid electric vehicles.

Figure 2: Predictions for global EVs on the market from 2017-2030 according to two scenarios: The New Policies and EV30@30 scenarios [4]

An impact analysis [5] conducted for the 2011 EC White Paper “Roadmap to a Single European Transport Area”, studies the effect of 4 different scenario’s (policy options) on the energy demand in transport in Europe till 2050:

- Policy Option 1: the baseline scenario (continuation of current trends)
- Policy Option 2 relying on managing mobility and on carbon pricing
- Policy Option 3 designed to show the effect of policies that emphasise the rapid deployment of new powertrains, by imposing very stringent CO2 standards on new vehicles
- Policy option 4: an intermediate scenario between option 2 and 3.

In Option 1 the total energy demand after 2015 is about the same, whereas Option 2 results in the largest decrease in total energy demand in European transport. In this scenario modelling also, the effect on accidents was studies, which will be shown in Chapter 4.4.

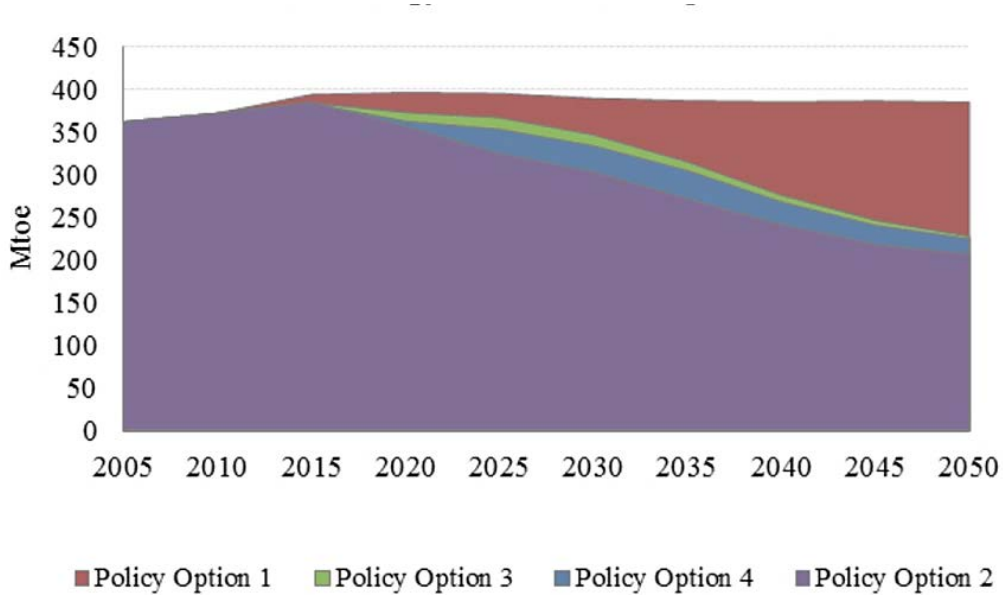


Figure 3: Final energy demand in European transport for four different policy options [5]

3 The global road safety problem

The World Health Organization [6b] estimated that in 2016 worldwide around 1.35 million people yearly died due to road accidents and this number is increasing (see Figure 4). The number of deaths per 100.00 population is slightly decreasing in this period. The number of road traffic injuries is increasing in low- and middle-income countries, while it is stabilizing or decreasing in many high-income countries [7]. This tragedy affects in particular persons that are economically active, creating important losses in their families.

Fatalities due to road accidents are just the tip of the iceberg. Non-fatal injuries are much more difficult to record and measure than fatal injuries, also in high-income countries. The reasons for this include difficulties in defining the severity of injuries and availability of good hospital data linked to police data [6a] [7] [8]. This is particularly true for pedestrians and cyclist injuries that in many cases are not reported.

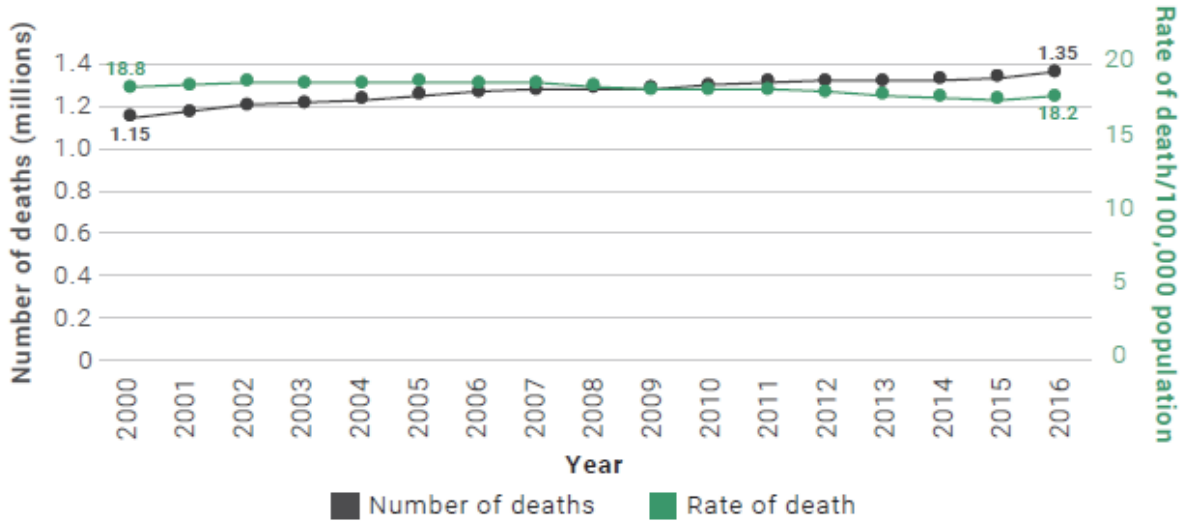


Figure 4: Number of global road traffic fatalities from 2000-2016 [6b]

Data presented in 2014 by the Global Road Safety Facility at the World [7] which are based on the Global Burden of Diseases, Injuries, and Risk Factors Study 2010 ("GBD 2010"), represent the first attempt to quantify data on non-fatal injury on a global level. For the year 2010, the number of injured persons worldwide due to road accidents was estimated to be 78.2 million persons needing medical care of which 9.2 million were requiring a hospital admission. These hospital admissions were defined as "injuries that would have required at least an overnight hospital stay if adequate access to medical care had been available to the victims". The number of injuries is higher and more precise than the 50 million injuries reported by the WHO in the 2015 global status report on road safety[6a].

Figure 5 shows the global distribution of road fatalities in 2013 over various parts of the world (based on data in [9]). More than halve of all global fatalities are in Asia and almost 20% in Africa.

Figure 6 shows the number of road fatalities per 100.000 inhabitants in different parts of the world [6b]. In Africa this number is 2-3 times higher than in Europe and for South-East Asia this is a factor 2 higher.

Figure 7 shows the distribution by region and type of road user of death in road crashes in 2010 [7]. The proportion of vulnerable road users (pedestrians, pedal cyclists and motor cyclists) shows large variations between regions. Where it is less than 50% in Western Europe it can be up to 70% in some regions in Sub-Saharan Africa and Asia.

Concerning accident data it should be noted that there is a large problem of underreporting. Both WHO [6a] and IHME/World Bank [9] estimates for the number of fatalities are exceeding the official country statistics indicating underreporting in many countries. In particular in sub-Saharan Africa and in Asia the difference between the two sources appears to be large, for instance a factor 4 in China and more than a factor 6 in Western Sub-Saharan Africa.

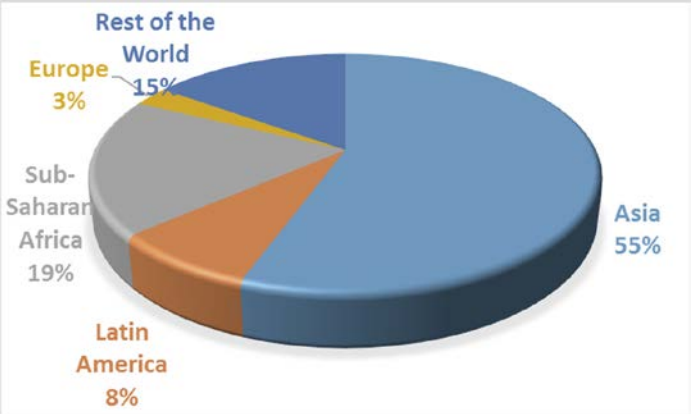


Figure 5: Global distribution of road fatalities in 2010 over various parts of the world [9]

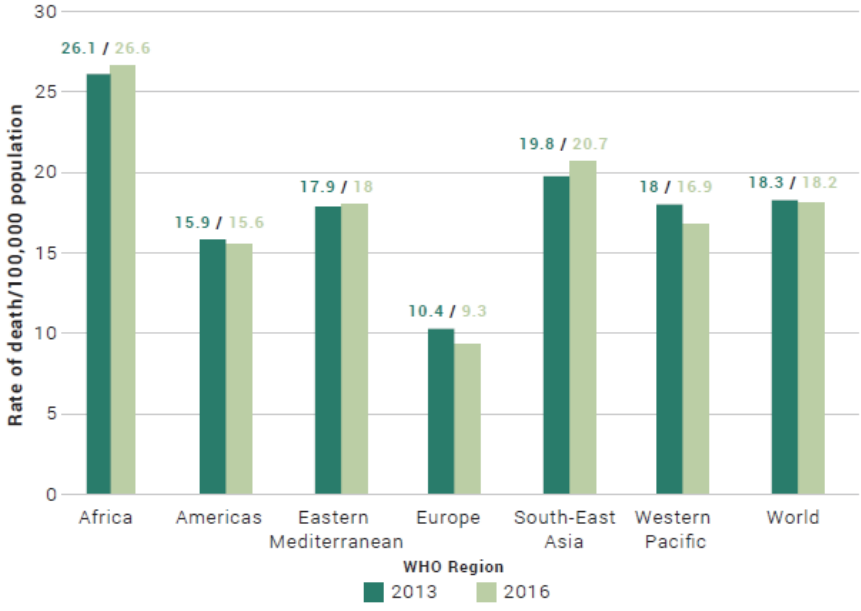


Figure 6: Number of road fatalities per 100.000 capita in different parts of the world [6b]

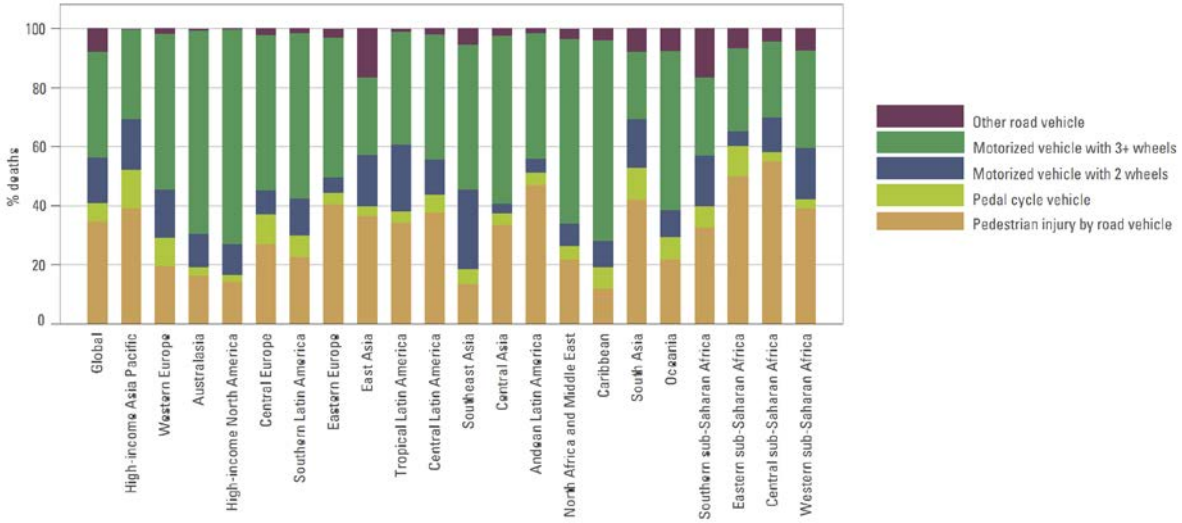


Figure 7: Distribution by region and type of road user of death in road crashes in 2010 [7]

4 Road Safety plans, scenarios and targets.

This chapter deals with road safety plans, scenarios and targets on a global and regional level. The literature review carried out as part of this pre-study showed that the number of scenarios used in road safety plans is rather limited. The best example on a global level are the 2 scenarios used in the 2011-2020 Decade of Action for Road Safety, which will be introduced in the next section. The Sustainable Development Goals (SDG), adopted in 2015, resulted in a more ambitious target compared to the Decade of Action target and will be discussed in section 4.2. How to achieve the SDG's on a global level will be discussed in section 4.3. The remaining sections deal with regional plans and scenarios for road safety and implementation of these plans. The regions to be discussed are Europe, the USA, Asia and the Pacific and Africa.

4.1 Plan for the Decade of Action

The most well-known future road safety scenario is the one used in the Plan for the 2011-2020 Decade of Action for Road Safety shown in figure 8. The Decade of Action was initiated by the United Nations General Assembly resolution 64/255 of March 2010. Main objective of the Plan was to stabilize global road accident fatalities until 2020 and then reducing the forecasted levels of global road fatalities by increasing road safety improvement activities at national, regional, and global levels [10]. Fig. 8 illustrates the two road safety scenarios used in the Plan. If no measures would be taken the number of road fatalities would globally increase to 1.9 million (red line) till 2020 and if the measures included in the Plan for the Decade of Action would be implemented, the number of road fatalities are predicted to decrease to 900.000 (blue line).

The basis of the measures proposed in the Plan was defined by the Commission for Global Road safety 2008 [11], resulting in a framework of 5 pillars summarized in table 1. Within the Plan special emphasis was put on 5 risk factors within pillar 4 (Safe Road Users): speed, drunk–driving, not wearing motorcycle helmets, not wearing seat-belts and not using child restraints in cars.

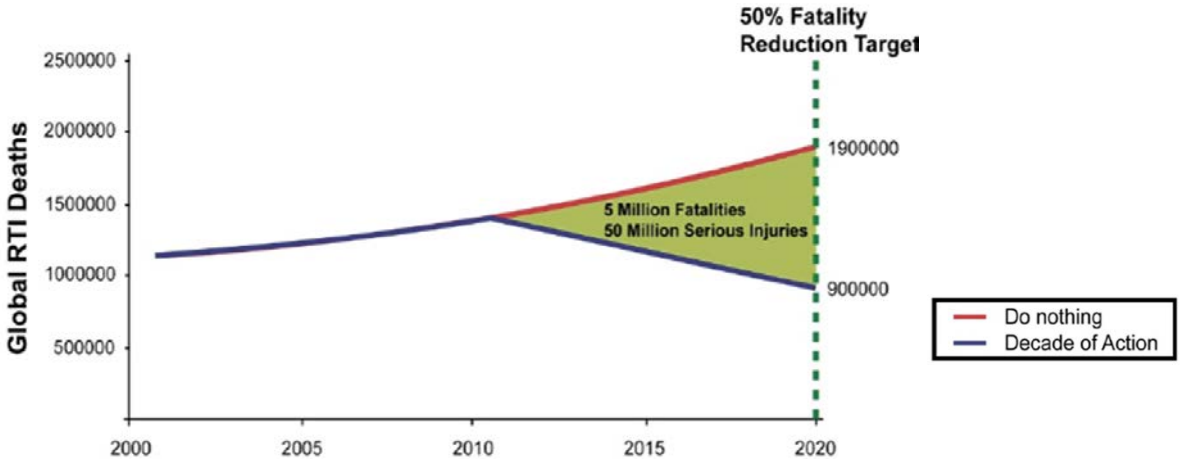


Figure 8: Example of two Road safety scenarios in the Plan for the 2011-2020 Decade of Action for Road safety [10].

Table 1: Summary of important actions within the 5 pillars of the Global Plan for the Decade of Action for Road Safety [10].

Pillars	Important activities
1: Road safety management	• establishment of a national lead agency • establishment of a national road safety plan with safety targets and budgets • setting-up monitoring systems for accident data and other indicators of safety improvement.
2: Safer roads and mobility	• elimination of high-risk roads by 2020 • safety impact assessments as part of all planning and development decisions • speed management and speed sensitive design of the road network • ensuring work zone safety • set minimum safety ratings for new road investments that ensure the safety needs of all road users • encouragement of education and R&D in the field of safe road infrastructure
3: Safe vehicles	• implementation of UN vehicle safety regulations and New Car Assessment Programmes (NCAPs), recommendations for inclusion of technologies such as ESC and ABS. • discouragement of import and export of new or used cars that have inferior safety levels • increased research into safety technologies designed to reduce risks to vulnerable road users • encouragement of managers of governments and private sector fleets to purchase vehicles that offer advanced safety technologies and high levels of occupant protection
4: Safe road users	• implementation (if not done yet) and enforcement of laws and/or standards concerning the five risk factors *speed, drunk-driving, and the usage of helmet, seatbelts and child restraints*, combined with public awareness/education concerning these risk factors. • introduction of policies and practices to reduce work-related road traffic injuries in the public, private and informal sectors • establishment of Graduated Driver Licensing systems for novice drivers.
5: Post-crash response	• the implementation of a single countrywide telephone number for emergencies • development of hospital trauma care systems • early rehabilitation and support to injured patients • encouragement of research and development into improving post-crash response.

4.2 Sustainable Development Goals

In 2015 the United Nations General Assembly adopted “Transforming our World: The 2030 Agenda for Sustainable Development” [12]. In this Agenda, Road safety is explicitly addressed in two of the Sustainable Development Goals (SDG’s), namely Goal 3 with target 3.6 and Goal 11 with target 11.2, see table 2.

Table 2: Road Safety Goals and Target in the SDG’s

Goals	Targets
3: ensure healthy lives and promote well-being for all at all ages	3.6: by 2020, halve the number of global deaths and injuries from road traffic accidents.
11: make cities and human settlements inclusive, safe, resilient, and sustainable	11.2: by 2030, provide access to safe, affordable, accessible, and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women and children, persons with disabilities and older persons.

These two goals are a strong mandate for action to promote road safety. In particular, the ambitious target for 50% reductions of both road crash fatalities and injuries is a significant challenge to all governments and other stakeholders worldwide. Figure 9 illustrates this new target together with the 2 scenarios in the Plan for the Decade of Action. This SDG target

indicates in 2020 an almost 300.000 additional fatality reduction target compared to the lower scenario in the Plan.

It should be noted that these targets have been criticised and judged not to be realistically. For example, Perkins from the International Transport Forum (ITF), OECD, suggested that a more realistic target would have been if the red line in Fig. 3 would be shifted 5 years to the right, so running from 2020-2025 [13]. Prince Michael of Kent in his keynote at the ITF Summit on "Transport Safety and Security" in May 2018, proposes to shift the target "to halve road deaths and serious injuries" even further, namely to 2030. He explained that "the serious risk is that, without a new casualty reduction target, the road safety performance of UN Member States will be weakly measured and consequently poorly managed" [14].

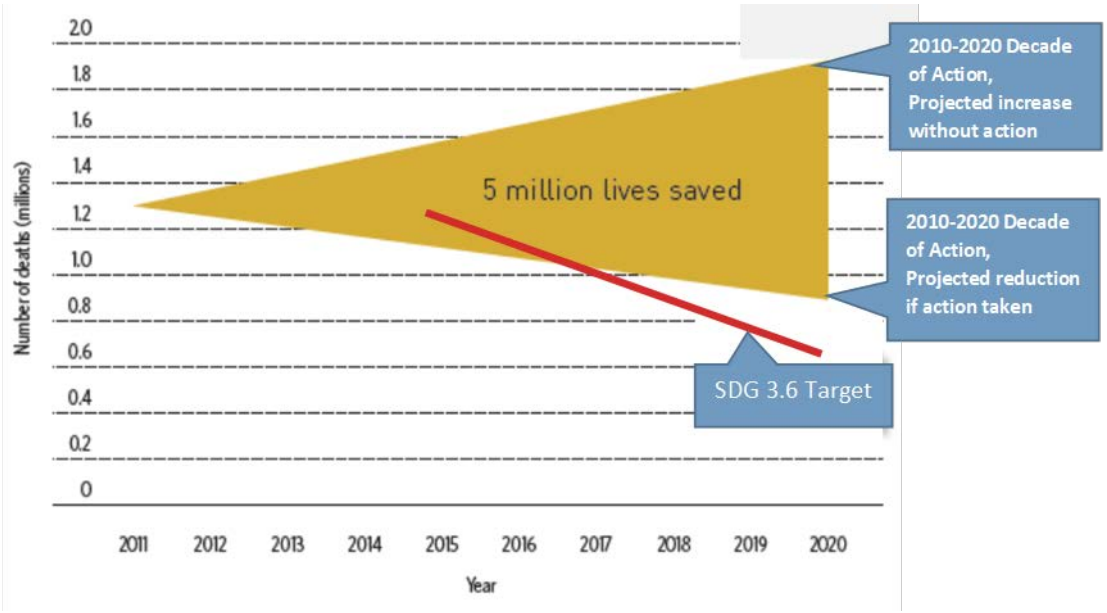


Figure 9: SDG 3.6 Target "by 2020, halve the number of global deaths from road traffic accidents", together with the 2010 predictions in the Plan for the Decade of Action for Road Safety in case of no action (upper boundary) and if actions are taken in line with the goal of the Plan (lower boundary)

Other SDGs also have links to road safety. A highly relevant example concerns the reduction of work-related road accidents. These accidents represent a significant part of all road accidents, dependent on the region up to one third of all road casualties and even 50% if commuting to work is included [15]. This includes professional transport, driving during work hours (for example, truck, bus and van drivers as well as sales people), and workers on the road (for instance road maintenance crews). That's why many companies nowadays are promoting policies and practices to improve the safety of their workers when driving for work. The importance of this is expressed in SDG 12 "Ensure sustainable consumption and production patterns" by the following targets:

- 12.5: Encourage companies, especially large and transnational companies, to adopt sustainable practices and to integrate sustainability information into their reporting cycle
- 12.7: Promote public procurement practices that are sustainable, in accordance with national policies and priorities

The International Standard Organization (ISO) standard 39001 [16] offers a framework for reviewing and developing a continuous improvement process for road safety in an organization. It is a tool for any organization that wants to work in a systematic way with road traffic safety setting out a process where the management has an overarching responsibility for safety and the elimination of fatalities and severe injuries in the organization's sphere of influence of the organization.

4.3 How to achieve the SDG's for road safety on a Global level?

Progress in several of the SDGs is strongly related and dependent on advances in sustainable transport. For a broad discussion on this see the report from the UN secretary-general's **High-Level Advisory Group on sustainable transport** [17]. Accomplishing the SDGs in this field will rely on advances in for example reductions in greenhouse gasses (climate change) and polluting emissions, food security and healthcare, safe and efficient transport to schools, safe and accessible transport for disabled and elderly people, resilient infrastructures, responsible production etc. Concerning safety of road transport, this group developed several high-level recommendations summarized in table 3. The numbering in this table refers to the numbering in the report.

Table 3: Policy Recommendations concerning road safety from the UN SG's High-Level Advisory Group on Sustainable Transport [17]

Number	Recommendation
1a	Give paramount attention to **safety for all transport users** and ensure that quality of life improvements and advances against negative environmental impacts are fundamental to policy and investment decisions.
4b	**Promote the collection, analysis and sharing of relevant data** especially in developing countries for well-informed transport policy and investment decision making, and for the development of indicators on transport safety and equity and quality of life and resilience.
5a	**Prioritize the prevention of deaths and injuries of road users**, using the **Sustainable Development Goal target** of reducing global road traffic deaths and injuries by 50% by 2020 as a guide, and follow **a systemic approach to improving road safety**.
5b	Promote road and transport system design that gives priority and emphasis to **protecting people from death and injury, taking into account human fallibility and vulnerability**.
5c	Disseminate to local stakeholders' **best practices on road safety legislation** and public policy.
5d	Ensure that **minimum safety standards for vehicles and vessels are set and enforced**, with particular attention to the secondary market in developing countries. National governments lead these efforts.
5e	**Reduce behavioral risk factors** that lead to road traffic deaths and injuries through **legislation, awareness raising, signage and rules and regulations**. Governments and civil society organizations work hand in hand in these efforts.
6a	**Establish comprehensive monitoring and evaluation methodologies** for sustainable transport by national and local governments, linking tracking frameworks, targets and indicators, where appropriate, to the Sustainable Development Goals.

The Brasilia Declaration, resulting from the Nov. 2015 2nd Global high-level conference on road safety in Brasilia, confirmed support for the target to halve the number of deaths and injuries caused by road accidents by 2020. The resulting **Brasilia Declaration on Road Safety** [18] consists of 30 actions organised in 7 groups of which 5 groups are equivalent to the 5 pillars of the Global Plan (see table 2) and two separate groups, one of them dealing specifically with vulnerable road users (which include children, youth, older and disabled persons, gender issues and motorcyclists) and one on strengthening cooperation and global road safety coordination.

Most actions in the Brasilia Declaration are largely a recommitment and/or strengthening of the actions included in the Global Plan for the 2011-2020 Decade of Action for Road Safety. New or partially new actions in the Declaration include:

- **New risk factors** which lead to distracted or impaired driving due to medicines, narcotic or psychotic drugs, distraction by cell phones and other causes (Action OP4)
- Introduction of **new technologies in traffic management and intelligent transport systems** to mitigate road traffic crash risk and maximize response efficiency (Action OP9)
- Actively **protect and promote pedestrian safety and cycling mobility**, such as pedestrian walkways and bicycle lanes and/or tracks, adequate lighting, speed cameras, road signs etc. (Action OP12)
- Introduction of **legislation and policies on motorcycles,** including training, driver licensing, vehicle registration, work conditions, and the use of helmets and personal protection equipment by motorcyclists (Action OP19)
- Creation of **new funding possibilities** to improve road safety (Action OP28)
- Development, under coordination of the WHO of detailed national, regional, and global **targets and indicators** to reduce road traffic crashes and fatalities in view of the SDG targets (Action OP29).

WHO has started this process of development of detailed national, regional, and global targets and indicators and as a first step in Nov. 2017 a set of 12 Global Road Safety Performance Targets were adopted by the UN Member States summarized in figure 10 [6b] [19]. The 12 Targets are subdivided in the 5 pillars from the Plan for the Decade of Action. Two targets deal with road safety management, two with infrastructure, one with safe vehicles, six with safe road user behaviour and finally one with post-crash response.

Concerning road safety in future urban environments the United Nations Conference on Sustainable Urban Development and Housing - Habitat III, held in Quito, Ecuador, in October 2016 stressed the importance of SDG 11 “make cities and human settlements inclusive, safe, resilient and sustainable”. The New Urban Agenda adopted at this conference [20] included several actions dealing with road safety, as an integrated component of a sustainable urban transport system, with the focus on Non-Motorized Transport (NMT) and vulnerable road users through measures like safe public spaces, sidewalks, cycling lanes, safe public transport etc. In particular, the items 113 and 114 in this Agenda deal with safe road transport (see table 4).

The most recent global effort that will be mentioned here, is the Ministerial Declaration on Transport Safety and Security which was adopted at the 2018 Summit of the ITF forum in Leipzig, Germany, on 24 May 2018 [21]. The ministers of the countries involved in the ITF agreed, among others, to:

- support efforts and initiatives that consider the need for safe transport for everyone across all means of transport, notably vulnerable travellers such as pedestrians, cyclists, children, older and disabled people
- support initiatives to improve the quality of road safety data and data science techniques to understand risk factors and monitor and evaluate road safety policies
- seek the rapid deployment of advanced safety technologies on all types of conventional motor vehicles and endorse the exchange of information and the sharing of best practice to enable and accelerate the safe and secure deployment of these innovative technologies within and across national borders, in cooperation with the recognised international transport organisations.

Table 4: New Urban Agenda items 113 and 114 from Habitat III concerning road safety [20]

Number	Action
113	We will take measures to improve road safety and integrate it into sustainable mobility and transport infrastructure planning and design. Together with awareness-raising initiatives, we will promote the safe-system approach called for in the Decade of Action for Road Safety, with special attention to the needs of all women and girls, as well as children and youth, older persons and persons with disabilities and those in vulnerable situations. We will work to adopt, implement and enforce policies and measures to actively protect and promote pedestrian safety and cycling mobility, with a view to broader health outcomes, particularly the prevention of injuries and noncommunicable diseases, and we will work to develop and implement comprehensive legislation and policies on motorcycle safety, given the disproportionally high and increasing numbers of motorcycle deaths and injuries globally, particularly in developing countries. We will promote the safe and healthy journey to school for every child as a priority.
114	We will promote access for all to safe, age- and gender-responsive, affordable, accessible and sustainable urban mobility and land and sea transport systems, enabling meaningful participation in social and economic activities in cities and human settlements, by integrating transport and mobility plans into overall urban and territorial plans and promoting a wide range of transport and mobility options, in particular by supporting: (a) A significant increase in accessible, safe, efficient, affordable and sustainable infrastructure for public transport, as well as non-motorized options such as walking and cycling, prioritizing them over private motorized transportation; (b) Equitable “transit-oriented development” that minimizes the displacement, in particular, of the poor, and features affordable, mixed-income housing and a mix of jobs and services; (c) Better and coordinated transport and land-use planning, which would lead to a reduction of travel and transport needs, enhancing connectivity between urban, peri-urban and rural areas, including waterways, and transport and mobility planning, particularly for small island developing States and coastal cities; (d) Urban freight planning and logistics concepts that enable efficient access to products and services, minimizing their impact on the environment and on the liveability of the

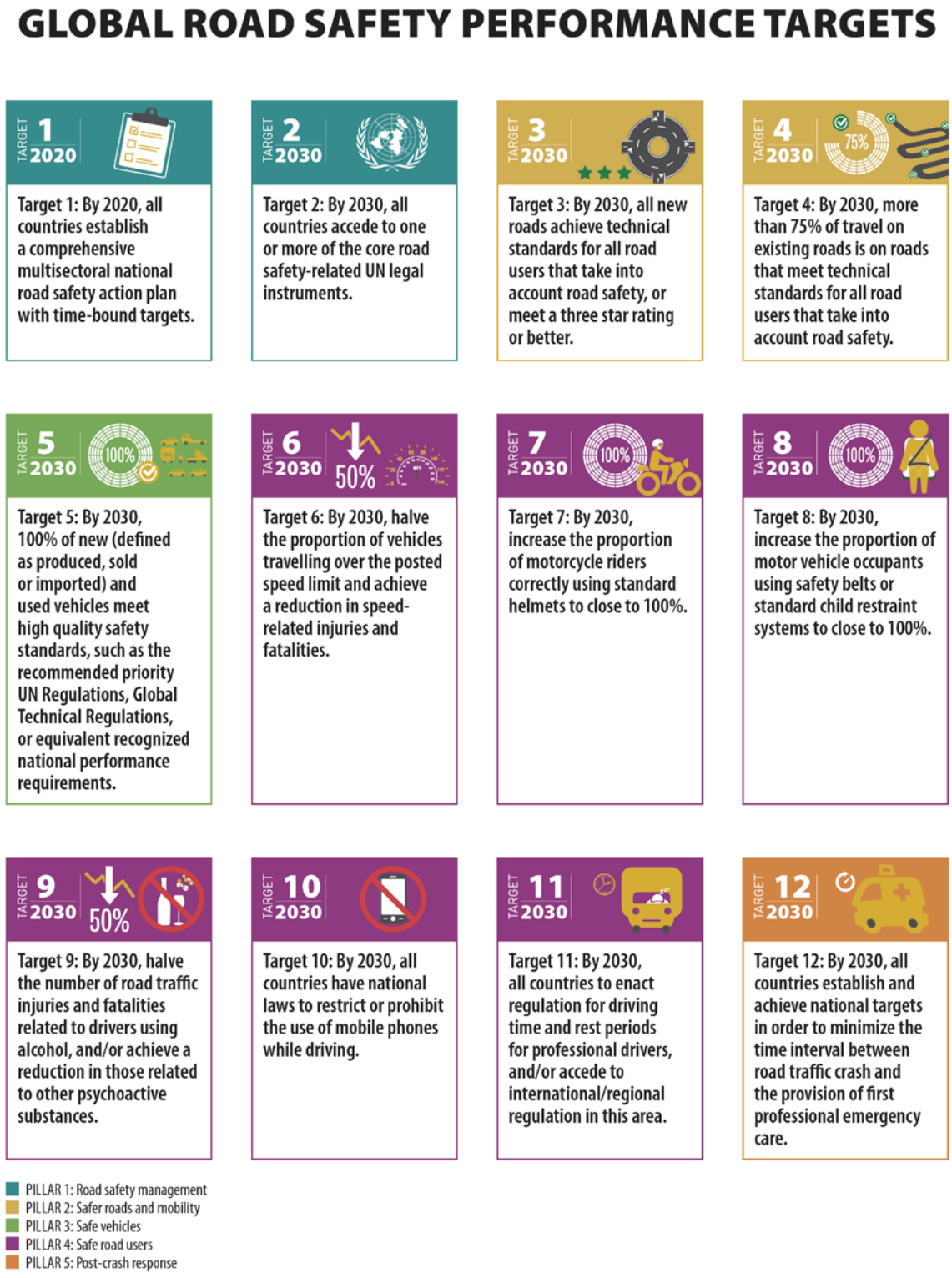


Figure 10: Global Road Safety Performance Targets developed under coordination of the WHO [6b] [19]

4.4 Road safety plans and developments in Europe

In 2001, road accidents killed 54,000 people in the European Union (EU) [22]. The 3rd EU road action plan published in 2003 [23] noted the following main causes of accidents and injuries:

- Excessive and inappropriate speed causing 1/3 of the fatal and serious accidents.
- Drunk-driving responsible for about 10 000 deaths each year.
- Failure to wear a seat belt or crash helmet. If seat-belt use would increase to the best performing countries more than 7 000 lives would be saved each year.
- Driving less-safe cars: if all cars on the road would have the same safety as the best performing cars in a class 50% of all fatal and disabling injuries could be prevented.
- High-risk accident sites (black spots) for all road users.
- Non-compliance with driving and rest times by commercial drivers.
- Poor visibility of other road users

The target of halving the number of road fatalities within the EU until 2010 has not been reached. In 2009 there were still more than 35,000 deaths due to road accidents and about 1,500,000 persons were injured [22]. In the 2011 White Paper – "Roadmap to a Single European Transport Area" [24] the EU aims at a further reduction of 50% of road fatalities from 2011 until 2020 and for 2050 to move close to zero fatalities. This "zero vision" goal should be achieved by new intelligent safety technologies, applying improved safety testing (also considering new vehicle concepts with alternative propulsion systems), education and promotion of use of safety equipment and in particular also attention to vulnerable road users (pedestrians, cyclists and motorcyclists) through safer infrastructure and new vehicle technologies [24].

The impact analysis that was introduced in Chapter 2, carried out in support of the 2011 EC White Paper, studied the effect of 4 different scenario's (policy options) on the energy demand in transport till 2050 presented in Chapter 2, but also the effect on the price of congestion, air pollution, noise and accidents. Figure 11 shows the effect of these 4 scenarios for the years 2020, 2030 and 2050. The largest positive effect (-27% in 2050) on accidents follows from policy option 2, which relies on managing mobility and carbon pricing.

Table 5: Effect of different policy options on, among others, fatal accidents in 2020, 2030 and 2050 [5]

Policy options	*Policy Option 2*			*Policy Option 3*			*Policy Option 4*		
compared to Policy Option 1 (in %)	2020	2030	2050	2020	2030	2050	2020	2030	2050
Congestion	-6%	-16%	-26%	0%	1%	-3%	-3%	-4%	-11%
Air pollution	-6%	-23%	-84%	-2%	-15%	-79%	-3%	-18%	-78%
Noise	-6%	-18%	-46%	-1%	-4%	-39%	-2%	-4%	-32%
Accidents	-4%	-14%	-27%	-1%	0%	-2%	-2%	-3%	-9%

There are several efforts underway in Europe in preparation on the 5th EU Road Safety Action Programme 2020-2030. In the Valetta declaration [25] resulting from a meeting of the Transport ministers of the Member States of the European Union on Malta, 29 March 2017, the transport ministers ask the Commission, among others, to enhance the protection of road users, and in particular vulnerable road users, by ensuring the deployment of new safety features for vehicles, for instance through accelerating the review of type-approval rules in the General Safety Regulation as outlined in [26]. This document refers among others to a

study of TRL completed in 2015 [27], which reviews several measures and the potential cost-benefit of such measures.

The European Transport Safety Council (ETSC) has formulated several recommendations for the 5th EU Road Safety Action Programme 2020-2030. Nine main priorities were defined among others dealing with vulnerable road user safety, automation and reducing the numbers of seriously injured persons on Europe's roads [28].

The latest ERTRAC Strategic Research Agenda 2010 - Towards a 50% more efficient road transport system by 2030, identified for safety a 60% fatality and serious injury reduction target from 2010-2020, and the way to achieve this goal is described in the roadmap for road safety in 2011 [29]. A new strategic ERTRAC research agenda and roadmaps for the next decade are under preparation.

The latest EuroNCAP (European New Car Assessment Program) roadmap, "Road Map 2025 - In Pursuit of Vision Zero" [30], introduces enhanced or new protocols for, among others, Driver monitoring, Automatic Emergency Steering, Autonomous Emergency Braking and Vehicle-Vehicle and Vehicle-Infrastructure Data Exchange to be introduced the next years. NCAP programs aim at enabling car buyers to make informed choices of vehicles by providing a comparative safety rating and encourage automobile manufacturers to promote development and sales of vehicles with high safety performance.

The latest communication from the European Commission (3rd mobility package May 2018) [31] [32] notes that the EU objective of halving road fatalities between 2010 and 2020 is now on an extreme challenge. It confirms the EU's long-term goal of moving close to zero fatalities and serious injuries by 2050 ("Vision Zero"), with an interim target of minus 50% between 2020 and 2030. Focus is on vehicle and infrastructure safety as illustrated in figure 11, which shows the main measures proposed and the expected impact in 2020-2030.

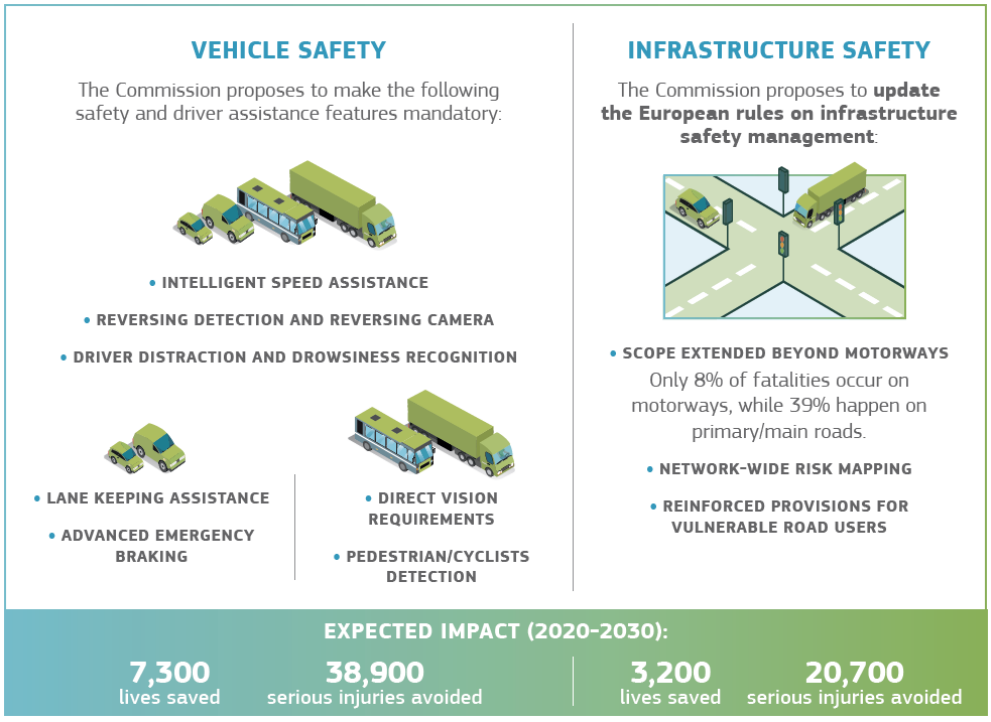


Figure 11: European plans (3rd mobility package May 2018) for vehicle and infrastructure safety with expected impact [31]

4.5 Road safety plans and developments in the USA

The yearly number of road fatalities in the USA is not decreasing like in Europe. In 2009, 33.808 people were killed in road accidents in the USA [33], while in 2015 it was slightly higher: 35,092 [34]. The USA is supporting the UN Decade of Action 2011-2020, but the road safety plans developed in the US do not include such stringent targets like halving the number of road fatalities in 10 years. The time horizon of national road safety plans in the USA is usually 5 years. There is also a national effort, initiated by over 20 safety organizations and other stakeholders, to develop a national highway safety strategy called "Toward Zero Deaths: A National Strategy on Highway Safety" (TZD)" [33] [35]. In the latest National Highway Traffic Safety Administration (NHTSA) road safety plan for 2016-2020 "The Road Ahead" [34] this is included as a long-term vision to eliminate traffic fatalities and major injuries on the Nation's roadways, the so-called "Three Lanes on the Road to Zero" (table 6). NHTSA is the coordinating federal organisation in the USA for road traffic safety.

Table 6: NHTSA's "Three Lanes on the Road to Zero"

Proactive Vehicle Safety	Advanced Safety Technology	Human Choices
Proactive Safety Principles	Highly Automated Vehicles	Innovative Solutions
ODI Enhancements	Vehicle-to-Vehicle Communications	Leverage Law Enforcement
Improve Recall Completion Rates	Democratize Safety Technology	Guidance and Oversight for State Highway Safety Programs
Inform and Empower Consumers	Automated Emergency Braking (AEB)	
New Car Assessment Program (NCAP) Upgrades	Driver Alcohol Detection System for Safety (DADSS)	
Global Road Safety	Cybersecurity	

NHTSA's road safety plan 2016-2020 includes 5 Strategic Goals and several strategic objectives as summarized in table 7. Note that under Strategic Objectives no quantitative targets on fatality and injury reduction are defined in the plan.

For each of the strategic objectives several so-called "Performance Goals and Indicators for Safety" have been defined. See in table 8 the example for Proactive Vehicle Safety. In this example the 5th "Strategic objective" is: "Coordinate Global Road Safety''. The corresponding performance goal included in the plan is: "Through global harmonisation, improve safety of motor vehicles and promote the deployment of proven safety technologies. The corresponding Safety Performance Indicator is: "GlobalNCAP to improve safety technologies on vehicles worldwide".

Table 7: Strategic Goals and Objectives in the NHTSA's road safety plan 2016-2020

Strategic Goal	Strategic Objectives
Safety	› Reduce Fatalities and Injuries › Increase Survivability From Crashes › Reduce Economic Costs
Proactive Vehicle Safety	› Promote the Proactive Safety Principles › Enhance ODI › Conduct Campaigns To Improve Recall Completion Rates › Inform and Empower Consumers › Coordinate Global Road Safety
Automated Vehicles	› Safely Deploy Highly Automated Vehicles › Safely Deploy V2V Communications › Enable a Robust, Layered Framework for Vehicle Cybersecurity
Human Choices	› Promote Innovative Solutions for Behavioral Safety › Leverage Law Enforcement Partnerships › Provide Oversight and Guidance to State Highway Safety Offices
Organizational Excellence	› Improve NHTSA's Ability To Deliver Quality Data and Analysis › Strengthen Mission Critical Information Technology › Properly Identify Human Capital Needs › Improve Financial Performance

Table 8: Example performance Goal and Indicators for proactive vehicle safety

Strategic Goal: Safety

Strategic Goal: Proactive Vehicle Safety	
Performance Goal	**Performance Indicators**
Improve EWR reporting and analysis fatalities.	Establish an Agency/industry EWR working group.
Improve cybersecurity threat information sharing across the automotive industry.	Support continuous updates, through the Auto-ISAC, of industry-wide cybersecurity best practices.
Strategic Objective: Retool Recalls	
Increase recall completion rates.	Identify industry-wide best practices and conduct nationwide campaigns.
ODI Enhancements.	Roll-out realignment.
Strategic Objective: Inform and Empower Consumers	
Improve NCAP.	Issue NCAP upgrade final rule. Conduct a consumer awareness campaign.
Increase public recognition of NHTSA's activities.	Increase the engagement of the public with our content through our social media channels.
Strategic Objective: Coordinate Global Road Safety	
Through global harmonization, improve safety of motor vehicles and promote the deployment of proven safety technologies.	Global NCAP to improve safety technologies on vehicles world-wide.

4.6 Road safety plans and developments in Asia and the Pacific

In Asia and the Pacific UNESCAP has played a central role in the coordination of the development of regional goals, targets and indicators for road safety. For an overview of their activities since 2006 see [36]. The latest update of the "Regional road safety goals, targets and indicators for Asia and the Pacific" was adopted in the Third Session of the Ministerial Conference on Transport in Moscow, 5-9 December 2016 [37]. In line with the SDG target 3.6, as an overall objective was defined: "50 per cent reduction in fatalities and serious injuries on the roads of Asia and the Pacific over the period 2011 to 2020". The 8 goals included in this update are identical to the original goals defined in 2006 and are shown in table 9.

Table 9: Regional road safety goals for Asia and the Pacific [37]

Goal 1: Making road safety a policy priority
Goal 2: Making roads safer for vulnerable road users, including children, elderly people, pedestrians, non-motorized vehicle users, motorcyclists and persons with disabilities
Goal 3: Making roads safer and reducing the severity of road crashes ("self-explaining" and "forgiving roads")
Goal 4: Making vehicles safer and encouraging responsible vehicle advertising
Goal 5: Improving national and regional road safety systems, management and enforcement
Goal 6: Improving cooperation and fostering partnerships
Goal 7: Developing the Asian Highway network as a model of road safety
Goal 8: Providing effective education on road safety awareness to the public, young people and drivers

In addition to these goals, 30 targets were defined as well as 40 indicators to monitor the progress on the goals and targets. Examples of indicators are reduction in fatalities and serious injuries in total and per 100.000 habitants, adoption of regulations, implementation and enforcement of laws concerning risk factors (like helmets, speed etc.), infrastructure improvements like separate pedestrian and cycle tracks and information on national road safety plans and their implementation. For a number of these indicators relevant data are available in the WHO Global Status reports on road safety. Indicators included in the 2015 Global Status report [6a] have been analysed and this analysis is summarized in [36]. Annex A, resulting from this analysis, provides an overview of the status of road safety measures in 2014 in most of the Asian countries, the so-called dashboard of Asian Road Safety Indicators.

4.7 Road safety plans and developments in Africa

Based on the Plan for the Decade of Action for Road Safety", the African Union (AU) and the United Nations Economic Commission for Africa (UNECA) defined the African Road Safety Action Plan 2011-2020 (ARSA) [38]. The objective of the ARSA Plan is to reduce road accidents (defined as "road traffic crashes" in the ARSA plan) in Africa by 50% by the year 2020. The ARSA Plan is organised around the 5 pillars: road safety management, safer roads and mobility, safer vehicles, safer road users and post-crash response [38]. For each of the pillars several expected accomplishments and activities are defined. Like the Asian countries in the preceding section, a Dashboard of Road Safety measures in Africa was developed, for several indicators closely linked to the expected accomplishments and activities in the ARSA Plan. These indicators are based on the WHO Global status report on

road safety 2015 [6a]. The resulting overview is presented in Annex B and contains 50 road safety performance indicators for 46 African countries. This dashboard was developed by SAFER in the EC Horizon 2020 SaferAfrica project. For an analysis of the observations in Annex B see [39].

5 Prediction models, tools and other information relevant for development of future road safety scenarios

5.1 Introduction

This chapter deals with prediction models and tools/methods that can help developing future road safety scenarios. An example for illustrative purposes of the type of scenario we would like to develop is shown in Fig. 12. It shows the effect of different categories of safety measures on the development of future road accident fatalities. A distinction is made here in measures concerning vehicles (accident avoidance and injury mitigation), measures dealing with human behaviour (like the risk factors in the Plan for the Decade of Action), infrastructure (like separate roads for VRU, star rating for roads, safe public transport etc…) and the rather new area of connected mobility (C-ITS, V2X communication, platooning ….).

Note that this is just a schematic example and that the prediction models and other tools should help us in developing realistic road safety scenarios. Note also that several measures cannot be assigned to a single category but are part of several categories. For example, the aim of a helmet is injury mitigation, but enforcement and education (part of human behaviour) are needed to realize a high rate of helmet usage.

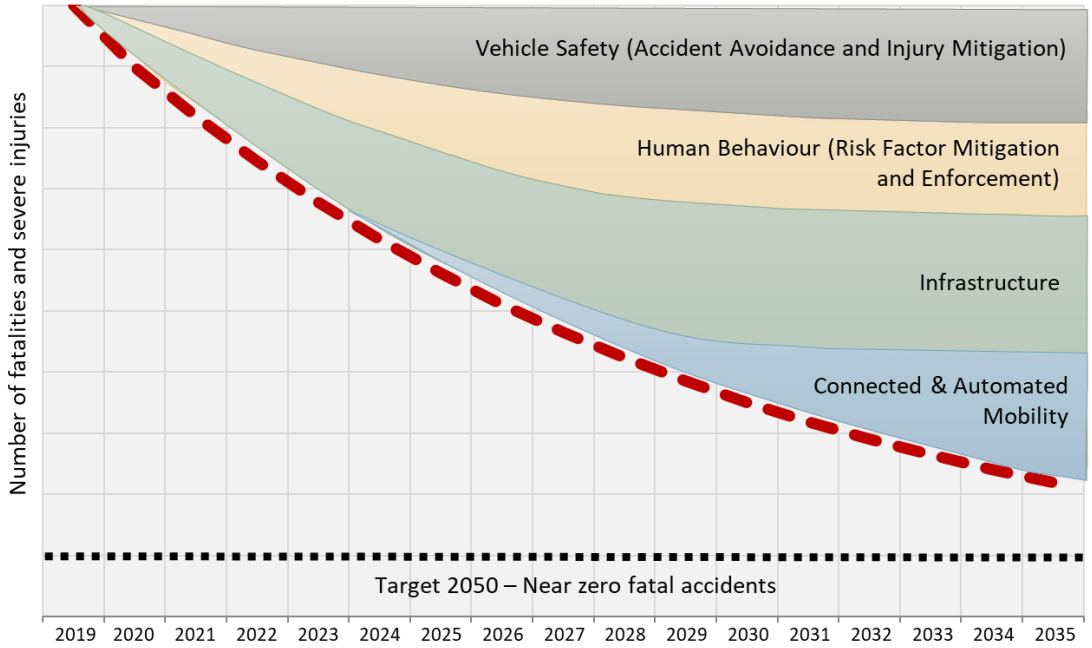


Figure 12: Example of a road safety scenario, illustrating the effect of active and passive vehicle safety measures as well as other measures

A literature review was carried out to achieve an overview of various methods and the state-of-the-art in this field. The focus of the review is on methods that predict the effect of future safety measures and the cost-benefit of measures.

The Transport Research Board (TRB) divides methods in statistical (black box) methods and structural methods (white box) [40]. The TØI Handbook developed by the Institute of Transport Economics (TØI) in Oslo, presented in the section 5.2, is largely based on statistical methods. The Swedish STA/Chalmers method for the evaluation of the future

impact of vehicle safety technology, which will be presented in 5.3, is primarily a structural method.

Section 5.4 deals with the methodology of Regulatory Impact Analysis (RIA) proposed by the OECD. In an RIA a Cost benefit Analysis (CBA) is an important element and therefore this section includes a brief introduction in CBA and the importance of human costs in a CBA. Section 5.5 discusses Decision Support Systems (DSS), like the SafetyCube European Road Safety developed in a European research project and other tools and sources of information that may be helpful to support development of future road scenarios.

5.2 The TØI Handbook

In the Handbook of Road Safety Measures [41] a systematic search of the literature on traffic safety is carried out and summarised by means of the formal technique of meta-analysis. The meta-analysis approach is a statistical methodology that combines the results of multiple scientific studies to minimise the contribution of subjective factors, which are often included in traditional literature surveys. However, it should be noted that many of the studies are carried out in Europe or US, which may bias the results.

The Handbook summarises a total of 142 road safety measures in the latest 2012 edition (currently available only in Norwegian) (table 10). For each measure problems and objectives are described as well as description of the measure, effect on accidents, mobility and environment and finally, where available, cost and a cost-benefit analysis. Measures are evaluated in ten different areas.

Table 10: Measures evaluated in Handbook of Road Safety Measures [41]

Measures	Number of measures
General purpose policy instruments	13
Road design and road equipment	22
Road maintenance	9
Traffic control	27
Vehicle design and protective devices	34
Vehicle inspections	4
Requirements for drivers, driver training and professional driving	12
Road user education and information	4
Enforcement and sanctions	15
First aid	3

Several of the measures in the Handbook have been presented on an EC Mobility and Transport, Road Safety website [42]. See table 11 for an overview of these measures, together with benefit-to-cost ratios mainly derived for Norwegian conditions. Examples in table 11 are coming from the field of road design, vehicle safety, enforcement, and user behaviour. All of the measures included in this table show a benefit-cost ratio above 1, and many are very high.

5.3 The Swedish STA/Chalmers method

The aim of this method is the prediction of the impact of future vehicle safety technology. The original method is a structural method and was developed by the Swedish Transport Administration (STA) in cooperation with Chalmers University. The method is based on the analysis of real accident data, using the data of accidents in a database, and the prediction of the outcome of the accident in case the vehicle(s) involved in the accident would have

been equipped with a certain safety technology. Details of the methodology can be found in [43]. Fig. 13 illustrates the methodology. The method can be used for fatalities and injuries and allows to take future fleet development and penetration of safety features into account. The method also allows for compensation of double counting of the effect of various safety interventions.

Table 11: Examples of Benefit-Cost ratios of road safety measures in Norway [42]

	Benefit-cost ratio		***Benefit-cost ratio***
Road-related safety measures		***Enforcement-related safety measures***	
Bypass roads	*1.38*	*Speed enforcement*	*1.49*
Pedestrian bridge or tunnel	*1.47*	*Speed cameras*	*2.11*
Converting T-junction to roundabout	*1.86*	*Section control (co-ordinated speed cameras)*	*1.58*
Converting X-junction to roundabout	*2.62*	*Feedback signs for speed*	*2.35*
Roadside safety treatment	*2.77*	*Drink-driving enforcement*	*1.80*
Reconstruction and rehabilitation of roads	*1.57*	*Alcohol interlock for drivers convicted of drink-driving*	*8.75*
Guardrails (along roadside)	*2.53*	*Seat belt enforcement*	*2.44*
Median guard rails on undivided roads	*1.40*	*Technical inspections of heavy vehicles*	*1.41*
Median rumble strips (1 metre wide)	*2.41*	*Service- and rest hour enforcement*	*1.45*
Horizontal curve treatments	*2.37*	*Bicycle helmet law*	*1.02*
Road lighting	*1.94*	*Law requiring pedestrian reflective devices*	*3.49*
Upgrading substandard road lighting	*2.75*		
Follow up road safety inspections	*2.48*		
Traffic signals in T-junctions	*5.17*		
Traffic signals in X-junctions	*3.95*		
Lowering speed limit on hazardous roads	*14.29*		
Upgrading pedestrian crossings	*2.36*		
Vehicle-related safety measures		***Road user-related safety measures***	
E-Call	*1.61*	*Accompanied driving*	*1.25*
Event recorders	*2.15*	*Elderly driver retraining*	*1.85*
Electronic stability control	*3.98*		
Front and side air bags	*1.01*		
Enhanced neck injury protection	*20.25*		
Seat belt reminders	*16.21*		
4 or 5 stars in Euro NCAP	*1.24*		
Intelligent speed adaptation (ISA-systems)	*1.95*		
Design of car front to protect pedestrians	*4.52*		
Front impact attenuators on heavy vehicles	*2.12*		

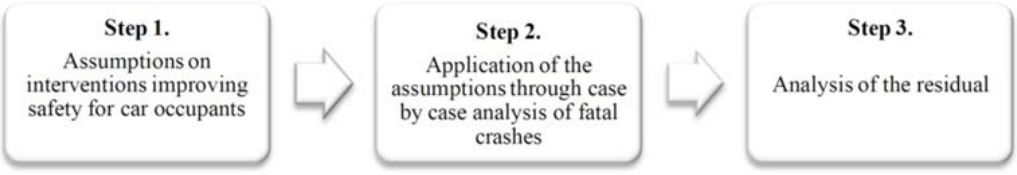


Figure 13: The Swedish STA/Chalmers methodology

The method has been applied using the in-depth Strada database, for example, to study AEB effect [44] and the effectiveness of EuroNCAP pedestrian regulation [45].

In a later study from this research group, rather than a structural method, a statistical approach was used to predict the effect of several interventions for the prediction of future fatalities and injuries in crashes in Sweden in 2020 and 2030 [46]. It was shown that the planned actions in Sweden mainly address car occupants, but they are insufficient to protect vulnerable road users.

5.4 Regulatory Impact Analysis (RIA)

Regulatory Impact Analysis (RIA) is a process of systematically identifying and assessing the expected effects of regulatory proposals and setting priorities for road safety interventions. The general methodology is described in an OECD Handbook [47]. The various steps in the RIA process are summarized in table 12.

Table 12: Steps in the RIA process [47]

Section Title	*Description*
1. Objective	Clearly state the policy objective(s) and goal of the regulatory proposal
2. Problem	Describe your assessment of the nature and extent of the problem to be addressed by the regulatory proposal
3. The regulatory proposal	Explain the regulatory proposal: • Describe the regulations • Outline the legal authority to make the regulation • List the groups likely to be affected by the regulation (citizens, business and within government) • Outline the enforcement regime and proposed strategy for ensuring compliance
4. Analysis of Benefit and Costs	Clearly outline the benefits and costs expected from the regulatory proposal for each group; • Administrative • Economic • Social • Environmental • Enforcement and Compliance
5. Compare the costs and benefits	Include a table comparing the cost and benefits for each of the above categories, listing the monetary values of each or providing a description.
6. Identify Alternatives	List the practical alternatives, including any non regulatory approaches that have been considered as options instead of the proposed regulatory approach.
7. Compare the costs and benefits of Alternatives	Describe the benefits and costs for each practical alternative that was considered.
8. Compare the alternatives with the regulatory proposal	Outline how and in what ways the identified regulatory proposal is superior to the alternatives that were considered.
9. Consultation	Describe the process of consultation that have been undertaken to collect stakeholder views. List all the groups that were invited to comment on the regulatory proposal and summarise their comments.

Many countries have introduced some kind of RIA process within their regulatory development process. For example, in the EU it was introduced in 2002.

An important step in the RIA process is Step 4: Cost-Benefit-Analysis (CBA) of the measures under consideration. OECD distinguishes 8 steps in a CBA, as is shown in table 13 [47].

Concerning the costs due to an accident usually 5 cost categories can be distinguished: medical costs, administrative costs, property damage costs, production lost and human costs

(like suffering and pain). Human costs represent often the largest cost category and are the most difficult one to determine. For an overview of the cost categories and the methods to determine human costs, i.e. the human capital, willingness-to-pay and the iRAP rule of thumb method, see Wismans et al. [36].

Table 13: Steps in a Cost-Benefit-Analysis [47]

1.	Decide on the base case – business as usual – and the alternative measures or programs to assess
2.	Identify all effects that are different between the base case and the alternative(s)
3.	Measure the effects in physical units
4.	Value the measured effects in monetary units
5.	Discount the monetized effects into a common year
6.	Assess if the present value of benefits is greater than the present value of costs
7.	Assess who bears the benefit and costs and, if necessary, conduct a distribution analyses
8.	Perform a sensitivity analyses

5.5 Decision Support Systems (DSS) and other tools and information sources

5.5.1 SafetyCube DSS

SafetyCube is a European Horizon 2020 project that finished in 2018. One outcome of the project is the Decision Support System DSS that aims to provide the European and Global road safety community with a user friendly, web-based, interactive decision support Tool. An important aim of this tool is to support evidence-based policy making. It provides detailed interactive information on a large list of road accident risk factors and related road safety countermeasures [48]. The main content of the SafetyCube DSS (see also figure 14) is:

- road accident risk factors and problems
- road safety measures
- best estimate of effectiveness
- cost-benefit evaluation
- all related analytic background.

The April 2018 version of the SafetyCube DSS contains more than 1.250 scientific studies with more than 7.500 estimates of risks/measure effects in 4 categories: road user, infrastructure, vehicle and post impact care. It also contains 36 cost-benefit analyses. Figure 15 shows an overview of examples of questions where the SafetyCube DSS may be useful to find the answers.

One tool within the SafetyCube DSS is the he SafetyCube DSS calculator. This tool allows to combine information about the effectiveness of a measure (i.e. the percentage of crashes or casualties prevented) with the costs of this measure. The calculator contains information of crash-costs of European countries and allows to conduct cost benefit analysis and explore different options.

5.5.2 UNECE SafeFITS

Where the SafetyCube DSS primarily seems to focus on European stakeholders using data from European countries, SafeFITS presents itself as a “A macroscopic road safety decision making tool to aid stakeholders in developed and developing countries”. SafeFITS is developed by the university of Athens within the framework of the “Safe Future Inland Transport Systems (SafeFITS)” project of the United Nations Economic Commission for

Europe (UNECE) and was financed by the International Road Union (IRU) [https://unecetrans.shinyapps.io/safefits].

The SafeFITS Tool consists of two background components (figure 16):

- a database with data on indicators from all layers of the road safety management system for 130 countries worldwide
- a set of statistical models of global causalities

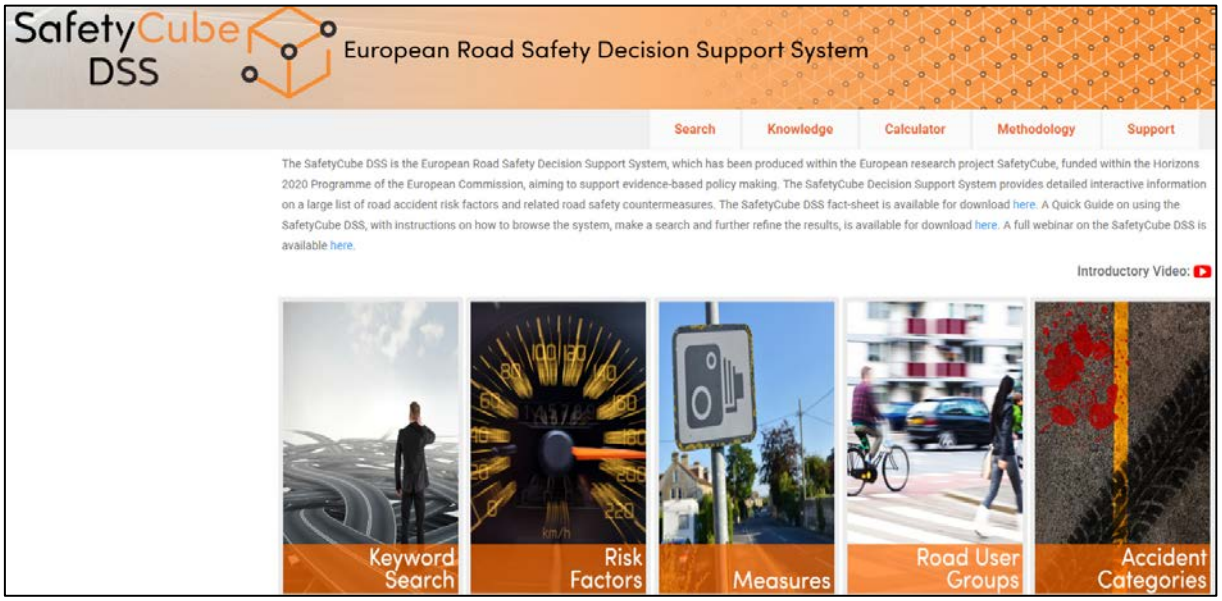


Figure 14: The SafetyCube DSS [48]

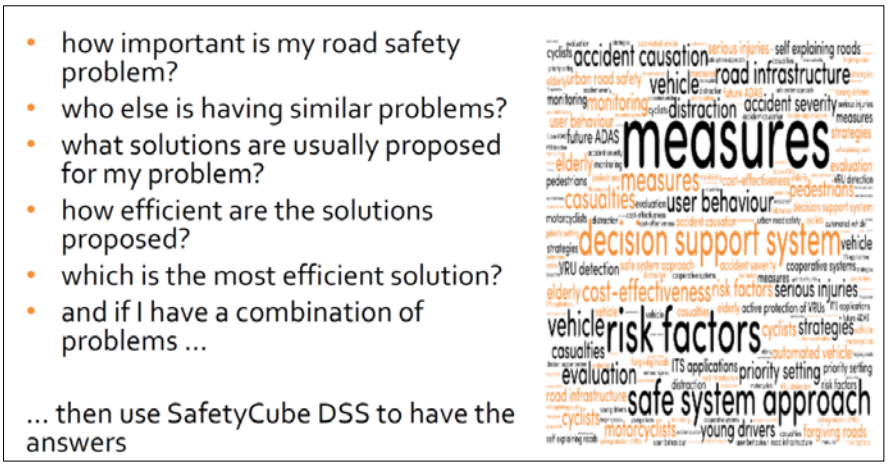


Figure 15: Examples of questions to be answered with help of the SafetyCube DSS

Furthermore, the SafeFITS Tool has modules for (figure 16):

- Intervention analysis which allow to examine the effects of single interventions at national or country cluster level
- Forecasting analysis which allow the user to define own scenarios of measures (or combinations of measures) in a country and obtain medium/long term forecasts of each scenario
- Benchmarking analysis which allow a user to benchmark a country against a group of countries (e.g. all countries, countries of similar economic or road safety performance)

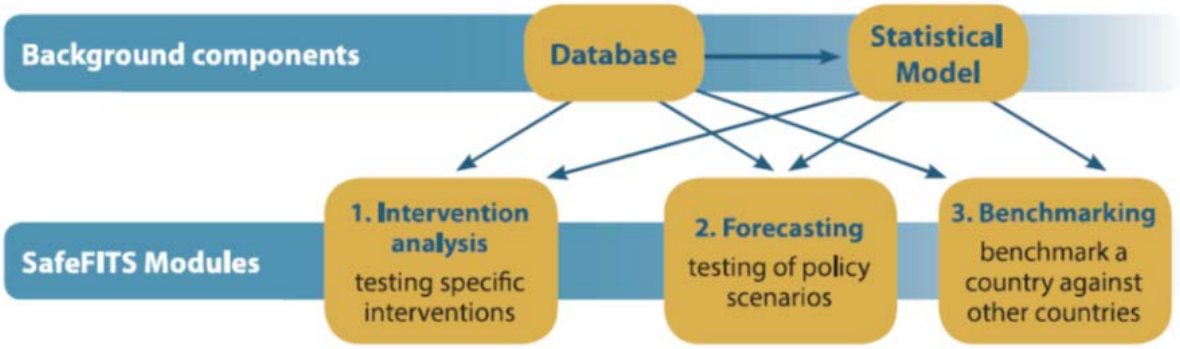


Figure 16: Components and Modules in SafeFITS

5.5.3 iRAP Tools

The International Road Assessment Programme (iRAP), which is a star rating tool for road networks, has several resources that may be helpful for the development of future road safety scenarios. One of them is the iRAP Road Safety Toolkit which is a web-based tool available online [49] for various crash and road user types and contains measures dealing with infrastructure, vehicle safety, road user behaviour as well as road safety management. It provides information on the causes and prevention of road crashes. The tool is the result of collaboration between iRAP, the Global Transport Knowledge Partnership (gTKP) and the World Bank Global Road Safety Facility. It is intended to help engineers, planners and policy makers to develop safety plans for car occupants, motorcyclists, pedestrians, bicyclists, heavy vehicle occupants and public transport users.

Other resources of iRAP are ViDA [50], which is the central database of iRAP that contains results from almost 1,000,000 km of road assessments from around the world and the Big Data Tool which contains, among others, for more than 85 countries information on the star rating of roads including the distance of these roads and the distance travelled by various road users on these roads [51]. This database also contains the business case (cost benefit in terms of reduced fatalities and serious injuries) for many countries, if road investments would be carried out, such that more than 75% of road users would travel by 2030 on roads with a star rating of 3 or higher (on a scale from 1 – 5, where 5 is highest).

Table 14: The business case for investments in safer roads [52]

What could be achieved	Low-income countries	Lower-middle income countries	Upper-middle income countries	High-income countries	All
Improve 10% of highest risk roads	108 000 km	610 000 km	992 000 km	1 546 000 km	3 255 000 km
Build viable countermeasures (USD)	8 billion	61 billion	149 billion	464 billion	681 billion
Reduction in fatalities over 20 years	384 000	1 483 000	1 528 000	283 000	3 678 000
Reduction in fatalities and serious injuries over 20 years	4 224 000	16 313 000	16 808 000	3 113 000	40 458 000
Economic benefit over 20 years (USD)	83 billion	663 billion	2 766 billion	2 202 billion	5 715 billion
Benefit cost ratio	11	11	19	5	8

An example of a business case for investments in road infrastructure was presented in [52]. The business case is to improve the 10% highest risk roads in the world to a 3 star or higher level. The proposed investments in road infrastructure of almost 681 billion US$ worldwide (which is less than 1% of global yearly GDP) would result in a saving of more than 3,6 million fatalities in 20 years. The return on investment (Benefit-Cost ratio) was estimated 8 on a global level and even higher (11) in LMIC's, see table 14. In other words, in LMIC's for every dollar invested in road safety infrastructure there would be a return of investment of 11 dollars in 20 years, due to a reduction in trauma and economic costs.

5.5.4 Highway Safety Manual (HSM)

The Highway Safety Manual (HSM) in the USA, published in 2010, presents a variety of methods for quantitatively estimating crash frequency or severity at a variety of road locations. The manual provides knowledge, techniques, and methodologies to quantify the safety-related effects of road and infrastructure design. By using the HSM, crash frequency and severity can be estimated. The HSM includes a catalogue of crash modification factors (CMFs) for a variety of geometric and operational treatment types. For more details see [53].

5.5.5 Effectiveness of measures in Low- and Middle-Income Countries (LMICs)

ICORSI (Independent Council for Road Safety International) organised a Workshop in Paris on March 2018 with the focus on road safety in LMICs. For the proceedings of this workshop see: [54]. Some findings presented at the workshop mainly based in studies in India:

- It may not be possible for LMICs to reduce fatality rates below 7[1] per 100,000 population along with high exposure of VRUs, unless there are innovative developments in road design and vehicle safety standards, including all vehicle types with special emphasis on VRU protection.
- If all cars in India were similar to those in OECD countries in 2014 and seat belt laws were being enforced, 5.000 - 6.000 lives annually would be saved in India.
- Very different crashworthiness standards (than current NCAP) need to be developed for low mass vehicles incapable of operating speeds greater than 50 km/h. Such vehicles may be optimal for urban use and could be prohibited for roads with speed limits greater than 50 km/h
- Legislative interventions had the strongest evidence for reduction in crashes and injuries while educational interventions had limited effect.
- Road improvements (paved vs unpaved road) lead to increase in crashes.
- Measures to change pedestrian behaviour to use pedestrian bridges and underpasses failed due to perceived risk and inconvenience and led pedestrians to increase their personal risk by creating their own path through the traffic.
- Highways in LMICs do not appear to have become safer. In India, up-gradation of undivided highways into divided highways from 2 lanes to 4 lanes have increased rate of traffic fatalities. Pedestrian fatalities form a very small proportion of fatalities in HIC highways, whereas many LMICs continue to have 20-40% pedestrian fatalities on highways.

[1] Some countries in Europe have fatality rates around 3 per 100.000

6 Conclusions and recommendations

The objective of this study was to perform a state-of-the-art review of 1) regional and global road safety plans and 2) prediction models and other tools and data for the development of future road safety scenarios, dealing with the whole safety system (infrastructure, vehicles, human behaviour, policy etc.) as well as different geographical and/or economical regions.

This study started in Chapter 2 with an overview of general global trends in our society and the use of scenarios to predict future trends as function of measures taken. It could be seen that the use of scenario modelling is quite common in transport energy forecasts, in contrast to the field of road safety were scientifically based road safety forecasts are rare.

Chapter 3 dealt with the current global road safety problem and it was shown using estimates from the World Health Organisation, that in 2016 worldwide around 1.35 million people yearly die due to road accidents and that this number is increasing. Vulnerable Road Users (VRU's: pedestrians, cyclists and motor cyclists combined) are particularly at risk. The number of road traffic injuries is increasing in low- and middle-income countries, while it is stabilizing or decreasing in many high-income countries. More than halve of all global fatalities are in Asia and almost 20% in Africa. There are large differences in the number of road fatalities per 100.000 inhabitants in different parts of the world. In some parts of Africa this number is 3-4 times higher than in Western Europe and for Asia and Latin America this is a factor 2-2.5 higher than in Europe. Fatalities are just the top of the iceberg. In 2010 almost 80 million persons needed medical care due to a road accident, of which more than 9 million were requiring hospital admission.

Chapter 4 dealt with road safety plans on a global and regional level. Important milestones in the field of road safety are the establishment in 2011 of the UN Decade of Action for Road Safety (2011-2020) with a goal to stabilize and reduce the predicted levels of road traffic fatalities around the world and in 2015 the adoption of the sustainable development goals (SDGs) with the important road safety related target SDG 3.6: "By 2020, halve the number of global deaths and injuries from road traffic accidents". Several studies in the meantime have indicated that this goal is too ambitious.

In Chapter 4 also an overview of regional plan was given in Europe, the USA, Asia and Africa. Most regions and countries have adopted similar targets as the SDG target 3.6, with as a remarkable exception the USA, where in the governmental plans no quantitative targets for reduction of road safety fatalities and injuries have been explicitly specified in the documents that were reviewed.

Furthermore Chapter 4 includes an overview of the status of implementation of road safety measures in Africa and Asia by means of a Dashboard of road safety measures. Most developed countries have introduced a vision how to reduce the road safety problem, like the vision zero or safe system approach, but in several developing countries this is not the case yet. There is a lack of good accident data in many developing countries and methods to monitor the progress and effect of measures taken.

The most important part of this report is Chapter 5, that summarizes prediction models and other tools, methods and information that can help to develop future scenarios of countermeasures to improve the road safety situation a country. Table 15 shows an overview of the available information in this Chapter, with among others the applicability of the

information for the five pillars of road safety and whether the prime focus of the information is global or regional (Europe, USA or LMICs).

Table 15: Overview of Information in Chapter 5 concerning coverage of pillars and regions

	Pillars					Region			
Prediction models, tools and other information	*Mana-gement*	*Infra-structure*	*Vehi-cles*	*Road users*	*Post Crash*	*Global*	*Europe*	*USA*	*LMICs*
The TOI Handbook	■	■	■	■	■		■		
The STA/Chalmers method			■				■		
Regulatory Impact Analysis (RIA)	■	■	■	■	■	■			
SafetyCube DSS		■	■	■	■	■	■		
UNECE SafeFITS	■	■	■	■	■	■			
iRAP Resources	■	■	■	■	■	■			
Highway Safety Manual (HSM)		■						■	
Measures in LMICs (ICORSI Workshop)		■	■	■					■

The reviewed sources contain a lot of useful information and elements that can be used for the development of future road safety scenario's, but none of them offer in their current status an integrated, unique and ready to use framework/methodology to develop such scenario's. It is recommended that some of the prediction models like the SafetyCube DSS and SafeFITS, are analysed in more detail in order to assess their appropriateness as a basis for a future framework/methodology for the development of road safety scenarios.

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Annex A Dashboard of road safety measures in Asia [36]

For UNESCAP Road Safety Indicators see [37]. The enforcement levels are rated on a scale from 1-10 (10 = highest). For Tables and Figures related to indicators 1, 7 and 9, please refer to [36]

UNESCAP Indicator see Annex	Related WHO 2015 indicator see Global Status report on road safety 2015	Afghanistan	Bangla-desh	Bhu-tan	Brunei WHO 2013	Cam-bodia	China	India	Indo-nesia	Japan	Lao	Ma-laysia	Maldives
1	Number of road death and /100,000 pop.	See Table 1											
7	Numbers of pedestrian deaths	**See Figure 2**											
9	Number of motorcyclist deaths												
3	National Road Safety strategy?												
	Fatility reduction target?		50% (2011-2020)	< 1.0 / 10000 vehicles (2011-2020)		50% (2011-2020)	< 2.2 / 100000 veh. (2011-2015)		50% 2020	<3000 / year in 2015	50% (2011-2020)	50% (2020)	
4	Name of designated lead agency on road safety												
16	Formal audits for new road construction projects												
	Regular inspections of existing road infrastructure												
	Policies to promote walking or cycling												
	Policies to separate road users and protect VRUs												
21	Frontal impact standard (UNECE)?												
	Electronic Stability Control standard (UNECE)?												
	Pedestrian protection standard (UNECE)?												
30	Emergency acces tel. Number												
	Risk Factors												
10, 25	National Motorcycle Helmet law?												
	Helmet standard?												
	Required for Drivers and Passengers?												
	Helmet to be fastened?												
	Wearing rate % drivers/passenger					64/6	20	60/-	80/52			97/89	
	Enforcement level		4	10	10	5	6	4	8	9	7	5	7
12	Law for child restraints in cars?												
13	Usage and enforcement of child seat restraints?												
26	National seat belt law												
	Applies to drivers and passengers												
	Enforcement level			3	6	5	8	4	8	8	2	4	4
	Seatbelt wearing rate, front/rear in %				72/-		37/-	26/-		98/68		77/13	
	National Law mobile phone use during driving?												
27, 28	National drink-driving law?												
	BAC limit g/dl general population			<0.08	<0.08	<0.05	<0.02	<0.03		<0.03	<0.05	<0.08	
	Random Breath testing?												
	Enforcement level drunk-driving	1	2	5	9	4	9	4	5	9	2	5	
	% death involving drunk driving				9	15	4	5		6		23	
	Urban speed limit km/hr		No	30	80	40		No	70	60	40	90	30
	Rural speed limit km/hr	90	112	50		90		No	100	60	90	90	30
	Motorway speed limit km/hr		No	50		100	120	No	No	100		110	No
	Speed Enforcement	1	3	5	6	4	8	3	5	7	4	6	6

	No		Alcohol consumption legally prohibited
	Yes		Sub-national but actual information not available

UNESCAP Indicator Annex 1	Related WHO 2015 indicator see Global Status report on road safety 2015	Mon-golia	Myan-mar	Nepal	Pakis-tan	Philip-pines	Rep. of Korea	Rus-sia	Singapo re	Sri Lanka	Thai-land	Timor-Leste	Viet-nam
1	Number of road death and /100,000 pop.	See Table 1											
7	Numbers of pedestrian deaths	**See Figure 2**											
9	Number of motorcyclist deaths												
3	National Road Safety strategy?												
	Fatility reduction target?	50% (2012-2020)	50% (2011-2015)	35% (2013-2020)		50% (2011-2020)	<4000 / year by 2017	8000 reducti on by 2020			<10 /100000 pop. (2010-2020)		5-10% annuall y (2012-2020)
4	Name of designated lead agency on road												
16	Formal audits for new road construction projects												
	Regular inspections of existing road infrastructure												
	Policies to promote walking or cycling												
	Policies to separate road users and protect VRUs												
21	Frontal impact standard (UNECE)?												
	Electronic Stability Control standard (UNECE)?												
	Pedestrian protection standard (UNECE)?												
30	Emergency acces tel. Number												
	Risk Factors												
10, 25	National Motorcycle Helmet law?												
	Helmet standard?												
	Required for Drivers and Passengers?												
	Helmet to be fastened?												
	Wearing rate % drivers/passenger	7/-	48-51		10	87/51All	74				52/20		96/83
	Enforcement level	1	5	9	3	6	6	6	9	7	6	6	9
12	Law for child restraints in cars?												
13	Usage and enforcement of child seat restraints?												
26	National seat belt law												
	Applies to drivers and passengers												
	Enforcement level	3		5	3	5	7	7	8	8	6	2	6
	Seatbelt wearing rate, front/rear in %	42/-				80/-	84/19	70/24			54/-		
	National Law mobile phone use during driving?												
27, 28	National drink-driving law?												
	BAC limit g/dl general population	<0.04	<0.08			<0.05	<0.05	<0.03	<0.08	<0.08	<0.05	<0.05	...-0.05
	Random Breath testing?												
	Enforcement level drunk-driving	3			3	1	8	6	8	6	6	4	5
	% death involving drunk driving	20				1	14	9	11		26		34
	Urban speed limit km/hr	60	40	80	90	40	80	60	70	50	80	50	50
	Rural speed limit km/hr	80	80	80	110	80	80	90		70	90	90	80
	Motorway speed limit km/hr	100	No	No	130	No	120	110	90	No	120	120	No
	Speed Enforcement	2	5	7	4	5	8	8	8	4	3	5	6

	No		Alcohol consumption legally prohibited
	Yes		Sub-national but actual information not available

Annex B Dashboard of Road safety measures in Africa [39]

For African Action Plan see [38]. The enforcement levels are rated on a scale from 1-10 (10 = highest).

Expected Accomplishment in UNECA African Action Plan	Related WHO indicator according to Global Status report on road safety 2015	Algeria	Angola	Benin	Botswana	Burkina Faso	Cameroon	Centr. Afric. Rep.	Chad	Congo	Côte d'Ivoire	D. R. of the Congo	Egypt	Eritrea	Ethiopia	Gabon	Gambia	Ghana	Guinea	Guinea-Bissau	Kenya	Lesotho	Liberia	Libya
PILLAR 1: ROAD SAFETY MANAGEMENT																								
Established or strengthening of Lead Agency	A lead agency is present																							
	The Lead Agency is funded																							
	National Road Safety (NRS) strategy present																							
	Funding available to implement NRS Strategy																							
	Fatility reduction target (see also separate Table)																							
Improved Management of Data	Registration of total number of vehicles																							
	Good death registration data																							
PILLAR 2: SAFER ROADS AND MOBILITY																								
Safer Roads Infrastructure for all road users	Formal audits required for new road construction																							
	Regular inspections of existing road infrastructure																							
	Policies to promote walking or cycling																							
	Policies to encourage investment in public transport																							
	Policies to separate road users and protect VRUs																							
PILLAR 3: SAFER VEHICLES																								
Road Worthiness of Vehicles (Vehicle Safety)	Vehicle standards for:																							
	Seat Belts																							
	Seat Belt anchorages																							
	Frontal impact																							
	Side Impact																							
	Electronic Stability Control																							
	Pedestrian protection																							
	Child seats																							
PILLAR 4: SAFER ROAD USERS																								
Use of Helmets	National Motorcycle Helmet law?																							
	Applies to Drivers and Passengers?																							
	Helmet to be fastened?																							
	Helmet standard?																							
	Enforcement level (0 .... 10)	5	4	3	6	1	1	3	4	3	2	3	5	8	1	6		4	2		4	5		1
	Wearing rate % drivers or All		60	15		9								95				34						
	Wearing rate % passengers		40	1										90				2						
Seat Belts	National seat belt law																							
	Applies to front and rear seat occupants																							
	Enforcement level (0 ... 10)	10	8		7	0	4	7	2	3	4	4	8	6	8	7	10	5	3		6	3		3
	Seatbelt wearing rate, front, drivers or all in %	90	90										14	60	1			18						
	Seatbelt wearing rate rear seat occupants in %		15											10										
Alcohol	National drink-driving law?																							
	BAC limit																							
	Random Breath testing?																							
	Enforcement level drunk-driving (0 .... 10)	7	5		6	1	2	5	1	3	3	3	6	6	1	2	1	3	2	1	5	3	0	4
	% death involving drunk driving				10										4		2			5				2
Speeding	National speed limit law																							
	Urban speed limit km/hr	50	60		60	50	60	60	60	60	60	60	60	60	60	60	no	50		60	50	50	40	50
	Rural speed limit km/hr	100	90		80	90	100	110	110	110	110	90	90	100	70	110	no	90		no	100	80	56	85
	Motorway speed limit km/hr	120	120		120	no	no	no	no	no	120	120	100	no	100	no	no	100		no	110	no	72	100
	Speed Enforcement (0 ....10)	8	5		7	3	2	5	3	3	6	3	5	5	3	3	5	4		2	6	4	1	2
Mobile Phone Use	National Law mobile phone use during driving?																							
Child restraints	Law for use of child restraints in cars																							
	Enforcement of child seat restraints?		4		2									1	1		1							
PILLAR 5: POST-CRASH RESPONSE																								
Emergency Care	Universal access telephone number(s)																							
	Estimated % seriously injured patients transported by ambulance	> 75	< 11	11.. 49	11.. 49	> 75	< 11	< 11	< 11	< 11	11.. 49	< 11	< 11	11.. 49	< 11	< 11	< 11	11.. 49	< 11	< 11	< 11	0*	< 11	< 11
	Training in emergency medicine available for doctors																							
	Emergency-room based injury surveillance system																							
	Vital registration system exists																							
	Estimated % road traffic crash victims with permanent disability								5,0											5,0				

	Yes
	No
	Partially
	Subnational
0*	No ambulance service available

Expected Accomplishment in UNECA African Action Plan	Related WHO indicator according to Global Status report on road safety 2015	Madagascar	Malawi	Mali	Mauritania	Mauritius	Morocco	Mozambique	Namibia	Niger	Nigeria	Rwanda	Senegal	Sierra Leone	Somalia	South Africa	Sudan	Swaziland	Tanzania	Togo	Tunisia	Uganda	Zambia	Zimbabwe
PILLAR 1: ROAD SAFETY MANAGEMENT																								
Established or strengthening of Lead Agency	A lead agency is present																							
	The Lead Agency is funded																							
	National Road Safety (NRS) strategy present																							
	Funding available to implement NRS Strategy																							
	Fatility reduction target (see also separate Table)																							
Improved Management of Data	Registration of total number of vehicles																							
	Good death registration data																							
PILLAR 2: SAFER ROADS AND MOBILITY																								
Safer Roads Infrastructure for all road users	Formal audits required for new road construction																							
	Regular inspections of existing road infrastructure																							
	Policies to promote walking or cycling																							
	Policies to encourage investment in public transport																							
	Policies to separate road users and protect VRUs																							
PILLAR 3: SAFER VEHICLES																								
Road Worthiness of Vehicles (Vehicle Safety)	Vehicle standards for:																							
	Seat Belts																							
	Seat Belt anchorages																							
	Frontal impact																							
	Side Impact																							
	Electronic Stability Control																							
	Pedestrian protection																							
	Child seats																							
PILLAR 4: SAFER ROAD USERS																								
Use of Helmets	National Motorcycle Helmet law?																							
	Applies to Drivers and Passengers?																							
	Helmet to be fastened?																							
	Helmet standard?																							
	Enforcement level (0 …. 10)	5	8	2	2	9	8	3	4	6	6	10	3	8		5	5	8	5	7	3	3	9	9
	Wearing rate % drivers or All			18			43		12				54									49		
	Wearing rate % passengers						8						14									1		
Seat Belts	National seat belt law																							
	Applies to front and rear seat occupants																							
	Enforcement level (0 … 10)	5	4		4	8	7	4	5		8	8	5	9		2	8	6	6	7	2	3	8	8
	Seatbelt wearing rate, front, drivers or all in %					97	50		55		87					33								
	Seatbelt wearing rate rear seat occupants in %					1			1		10													
Alcohol	National drink-driving law?																							
	BAC limit																							
	Random Breath testing?																							
	Enforcement level drunk-driving (0 …. 10)	5	3	2	8	5	2	5	2	4	2	8	2	4	1	4	6	5	4	4	4	4	7	4
	% death involving drunk driving					24	3				1			40		58					1			
Speeding	National speed limit law																							
	Urban speed limit km/hr	50	50	50	80	90	60	60	60	50	50	40	no	50	40	60	50	100	50		50	50	50	60
	Rural speed limit km/hr	no	80	90	100	90	100	120	120	no	80	80	90	80	60	100	90	100	no		90	100	100	120
	Motorway speed limit km/hr	no	100	120	100	110	120	no	120	no	100	no	110	no	no	120	no	100	no		110	no	no	120
	Speed Enforcement (0 ….10)	5	5	3	3	7	6	4	7	5	6	6	3	3	2	3	6	6	4		4	5	8	7
Mobile Phone Use	National Law mobile phone use during driving?																							
Child restraints	Law for use of child restraints in cars																							
	Enforcement of child seat restraints?			1				3	1		2			6									6	
PILLAR 5: POST-CRASH RESPONSE																								
Emergency Care	Universal access telephone number(s)																							
	Estimated % seriously injured patients transported by ambulance	< 11	0*	> 75	11..49	> 75	> 75	0*		> 75	11..49		> 75	11..49	< 11	50..74	11..49	11..49	< 11	> 75	< 11	< 11	< 11	< 11
	Training in emergency medicine available for doctors																							
	Emergency-room based injury surveillance system																							
	Vital registration system exists																							
	Estimated % road traffic crash victims with permanent disability																					2,8		
	Yes																							
	No																							
	Partially																							
	Subnational																							
0*	No ambulance service available																							

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