11

Traffic safety

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11.1 Introduction

The number of road crashes, fatalities and injuries is considered unacceptably high in many countries. This can be derived, for example, from the fact that the European Commission (EC, 2010) announced the ambition of halving the overall number of road deaths in the European Union by 2020, starting from 2010. At this stage a European target for reducing serious injuries is not possible, owing to a lack of a common definition of serious and minor injuries. In many highly developed and highly motorized countries the number of fatalities has decreased over the last few decades (OECD/ITF, 2011a). However, this favourable development cannot be observed in low- and middle-income countries so far (Peden et al., 2004).

Risks in road traffic are considerably higher than in other transport modes, and the amount of injuries in road traffic is far higher than the numbers in trains, planes or ferries. Although crashes in these other modes attract a lot of public and media attention, road crashes kill far more people, but in a 'diluted' way, resulting in only limited media coverage and relatively limited attention from the public and politicians. At the same time, serious road crashes are tragedies at a personal level. Road crashes can happen to everybody, anytime, anywhere, and they are unexpected. Often the lives of young people and their families are suddenly changed.

This chapter aims to give a concise introduction to road safety. Using this chapter the reader will be able to explain some basic concepts of road safety, get an insight into some recent traffic safety developments worldwide and be able to talk about a new policy vision and options for how to reduce further crashes and (serious) injuries. The relevance of various technologies was discussed in Chapter 8.

Risk factors in traffic are discussed in section 11.2. Section 11.3 treats the subject of identifying the causes of crashes. In section 11.4 there is an explanation of three important components of road traffic when it comes to risks: transport modes, age of road users and road types. In section 11.5 the difficulties of measuring road safety (danger) are discussed. Some developments in road safety are given in section 11.6. Section 11.7 explains the development in dominant thoughts about traffic safety. This section shows that the amount of knowledge on causes for road accidents and how to implement successful policies has increased dramatically over the years. Still, the next steps for further improvements can be made. Scientific information to support this statement and one such next step, Sustainable Safety, are presented in section 11.8. The chapter's main findings are presented in section 11.9.

11.2 Risk factors in traffic

Taking part in traffic is a dangerous affair in itself. This is due to some fundamental risk factors in traffic (sometimes also denoted as basic factors): the vulnerability of the body of road users in combination with speed levels in traffic as well as the presence of objects with large mass and/or stiffness with which one can collide. In addition, there are also road user factors that increase crash risk, such as alcohol use, fatigue or distraction.

Fundamental risk factors

Fundamental risks are inherent to road traffic and are the basis of the lack of safety in current road traffic. These are a combination of factors such as speed and mass (and the kinetic energy in a crash) and the vulnerability of the human body.

Speed is related to the risk of being involved in a crash (for an overview, see Aarts and van Schagen, 2006). Higher absolute speeds of individual vehicles are related to an exponential increase in risk. If the average speed on a road increases, then the increase in crash risk can be best described as a power function: a 1 per cent increase in average speed corresponds with a 2 per cent increase in injury crashes, a 3 per cent increase in serious injury crashes and a 4 per cent increase in fatal crashes (Nilsson, 2004). With the same increase in speed, for both individual speed and average road section speed, an increase in risk is higher on urban roads than on rural roads and motorways. Speed is also related to crash severity. This is based on the kinetic energy (of which speed is an important component), which is converted into other energy forms and/or bodily damage during a crash. Injury risk (the chance of being injured in a crash) is also determined by (impact) speed level, the relative directions of crash partners, their mass differences and the protection level.

Speed differences are also linked with increases in crash risk. Aarts and van Schagen (2006) show that it has not been proven that vehicles travelling at lower speeds than the traffic flow have a higher risk than vehicles that go with the flow. However, vehicles going faster than the traffic flow have an increased risk (Aarts and van Schagen, 2006). Speed variance at the level of a road section is also linked to increased crash risk.

Mass differences are also fundamental risk factors. In a crash between two incompatible parties, the lighter party is at a disadvantage because this party absorbs more kinetic energy and the vehicle generally offers less protection to its occupants than a heavier vehicle. Mass differences between colliding objects can amount to a factor of more than 300 (a pedestrian weighing 60 kg versus a heavy goods vehicle weighing 20 000 kg). Furthermore, in view of their stiffness and structure, heavier vehicle types generally offer better protection to their occupants in the event of a crash. For occupants of vehicles with a high mass, injury risk is much lower than that of the lighter crash party. If we assume the injury risk for a crash party of an 850 kg passenger car as 1, then the injury risk for an average crash partner is 1.4 if the car weighs 1000 kg, and 1.8 if the vehicle weighs more than 1500 kg (Elvik and Vaa, 2004).

Finally, vulnerability is to be considered a fundamental risk factor. Several methods can be used to protect the human body in a crash, foremost by improving the crashworthiness of a vehicle. Over the years great progress has been made to improve vehicle design to protect car occupants. The most famous example is the use of seat belts in combination with airbags. Glassbrenner and Starnes (2009) estimate that seat belts reduce fatality and injury risks by more than 40 per cent, and in combination with airbags by more than 50 per cent. However, vulnerable road users such as pedestrians and cyclists have almost no possibilities to protect themselves from injury risk in a crash. Only a crash helmet for (motorized) two-wheelers can be considered, and some developments of airbags for motorcyclists can be seen in practice. Furthermore, modern car designers try to incorporate safety features when designing a car front, which aim to be safer for pedestrians and cyclists in the case of an accident.

Risk-increasing factors

Besides these fundamental risk factors, road traffic also has to contend with risk-increasing factors caused by road users:

- **Lack of driving experience.** Lack of driving experience results in higher risks. The effect of (lack of) driving experience on crash risk is strongly linked to age effects. Since driving experience is strongly correlated with age and as both factors are associated with specific characteristics which increase risk, it is difficult to separate the effects of age and experience. About 60 per cent of the (relatively high) crash risk for novice drivers (broadly speaking, people who have driven less than 100 000 kilometres) can be explained by lack of driving experience, and the other 40 per cent is age related (see Wegman and Aarts, 2006). The increased crash risk for novice drivers decreases rapidly within the first year after passing a driving test (Vlakveld, 2005). Male novice drivers especially run an additional risk (a factor of 10) compared to more experienced drivers (male and female) and also compared to novice female drivers (a factor of 2.5).
- **Psycho-active substances: alcohol and drugs.** Alcohol consumption by road users is one of the most important factors that increase risk in traffic. Crash risk increases exponentially with increased blood alcohol content (BAC). Compared to sober drivers, the crash risk is a factor of 1.3 with a BAC between 0.5 and 0.8 per mille, a factor of 6 with a BAC between 0.8 and 1.5 per mille, and a factor of 18 above 1.5 per mille (Blomberg et al., 2005).The crash risk of road users under the influence of psycho-active substances (Walsh et al., 2004) can be about a factor 25 higher with the use of drugs. This risk can even increase up to a factor of 200 with the combined use of alcohol and drugs, relative to sober road users, also depending on the quantity of alcohol consumed; there is cumulative road crash fatality risk when combined with the use of alcohol and drugs. Drugs in traffic is not a very mature area of research and policy-making; however, it has received quite a lot of (political) attention recently.
- **Illnesses and ailments.** Visual limitations or ailments are generally associated with a very small increase in crash risk (on average a factor of 1.1), relative to healthy people (see Vaa, 2003). Further examination indicates that crash risk is higher under two conditions: reduced useful field of view (UFOV) and glare sensitivity. Decreased hearing only results in a slightly increased risk. People with Alzheimer's disease run a risk of crash involvement which is twice as high as that of healthy people. Other psychiatric disorders, such as cognitive disorders and depression, result in a slightly increased risk with a factor 1.6, on average.
- **Emotion and aggression.** During the past few years some have expressed the view that aggression in traffic is a major contributor to road crashes. Several questionnaire studies show the (positive) relationship between self-reported aggressive behaviour (offending behaviour)

and self-reported road crash involvement. However, this does not imply a causal relationship between the two elements. It is also the case that aggressive behaviour coincides with risk-seeking behaviour. This makes it difficult to draw conclusions about the relationship between aggression and road safety. The literature leaves the impression that there is a coherent behavioural pattern of a combination of various aggressive and/or risky behaviour types that result in a dangerous driving style. However, for the time being it is not possible to quantify the risk associated with this risk factor (Mesken, 2006).

- **Fatigue.** Fatigue is most probably a much more frequently occurring factor in increasing risk than data from police reports show. Participating in traffic whilst fatigued is dangerous because, in addition to the risk of actually falling asleep behind the steering wheel, fatigue reduces the general ability to drive (keeping course), reaction time and motivation to comply with traffic rules. Research shows that people suffering from a sleep disorder or an acute lack of sleep have a 3 to 8 times higher risk of injury crash involvement (Connor et al., 2002).
- **Distraction.** Like fatigue, distraction is probably a much more frequent crash cause than reported police data show (Regan et al., 2009). Currently, one of the more common sources of distraction is use of the mobile phone while driving. The hands-free option, permitted in many countries, does not reduce the effect of distraction either (McEvoy et al., 2005). This research indicates that using a mobile phone while driving results in an increase in risk by a factor of 4 relative to non-users. Other activities such as operating route-navigation systems, tuning CD-players and radios and so forth can also be a source of distraction, as can activity such as eating, drinking, smoking and talking with passengers (Young et al., 2003).

11.3 Cause: 'unintentional errors' or 'intentional violations'?

In identifying the cause of crashes in whatever system, 'man' is always quoted as the most important cause of crashes. People make errors, no matter how hard they try. At the same time, people do not always (consciously or otherwise) obey rules and regulations designed to reduce risks. The question arises: how serious are offences actually for road safety and with what frequency do they cause traffic crashes? However, this section will show that no clear picture emerges from the research of the relative contribution to crashes by intentional violations and unintentional errors.

A Canadian study looked into the relationship between violations and crashes as evidenced by driver behaviour (Redelmeier et al., 2003). The research team tracked car drivers who were convicted of causing a fatal crash and recorded the crash involvement of these offenders in the period following the conviction. The first month after the penalty, the chance of being involved in a fatal crash was 35 per cent lower than could be expected on the basis of coincidence. The authors attributed this effect to the fact that there were fewer traffic violations immediately after the period in which the drivers were fined. However, this benefit lessened substantially over time and disappeared after three to four months. Out of the above research, a strong relationship emerges, particularly between violations and crash involvement. It must be emphasized, however, that this type of research cannot prove anything conclusive about causality between the two phenomena.

Thus both errors and (intentional) violations (and related extreme behaviour) play a role in the cause of crashes and therefore deserve a place in road safety policies. How large the share of (unintentional) error and (intentional) violation is exactly cannot be stated, based on current knowledge. The role of (unintentional) error seems to be the more important one. Unfortunately, the information that can be extracted from police registration forms about crash causes cannot be used to identify the underlying causes of crashes. This is not surprising given that the data are gathered primarily with the objective of being able to identify the guilty party, rather than identifying precisely the underlying causes of a crash. It should also be remembered that crashes are always the result of a combination of factors.

On the one hand, it is logical that unintentional errors form the lion's share of crash causes, given that intentional offending in itself never leads directly to a crash. Violations certainly can increase the risk of error and the serious consequences of these errors. On the other hand, there is no evidence to support the widely held opinion that anti-social road hogs are the major perpetrators of crashes. Without doubt they cause part of the road safety problem, if only because other road users cannot always react appropriately to them. However, many crashes are the result of unintentional errors that everybody can make in an unguarded moment, as illustrated by Dingus et al. (2006).

Dingus et al. (2006) concluded that, in nearly 80 per cent of the recorded crashes and in 65 per cent of the near-crashes, driver inattention was involved just prior to the onset of the conflict. In this study drivers (100 cars) were followed for a year by observation systems installed in their cars: a black box and small cameras. The idea was to observe everyday behaviour. The role of driver inattention is rarely found on police registration forms, because who would tell the police that a cigarette fell to the floor just prior to the crash and that in a state of some panic he was trying to retrieve it? Therefore, it is time to rethink the idea many people, including road safety professionals and decision-makers, have of crashes only being caused by the traffic offences that are frequently found on police registration forms.

11.4 Transport modes, age groups and road types

A lot can be learned about the differences in risks by comparing transport modes and road types. These differences relate to the fundamental risk factors (section 11.2), speed, mass and vulnerability, in combination with protection. Users of motorized two-wheelers, for example, have the highest fatality and injury risk in road traffic (Table 11.1), which can largely be explained by a combination of high speed with the relatively low mass of the vehicle in conflict with other motorized traffic, as well as poor crash protection. In relation to crash protection, the relatively high amount of motorcycle deaths in the USA is striking (Table 11.1). The reason is the weakening of state helmet laws in the USA. Two-thirds of fatally injured motorcycle riders were not wearing a helmet in states without universal helmet laws (OECD/ITF, 2011b). On top of these factors, two-wheelers (especially mopeds) are popular with young people. This age group already has a relatively high risk in traffic because of age-specific characteristics and needs, and lack of experience (Table 11.2 and Figure 11.1).

Table 11.1 Road fatalities per 1 billion vehicle kilometres

	All[a]	Mopeds[a]	Motorcycles[a]	Cars[a]	Heavy goods vehicles[a]	Bicycles[a]
Austria	9	113.2	98.1	6.6	1.7	
Belgium	9.6		82.9	6.3	2.8	
Denmark	8.2	41[b]	38	5	2	
France	7.8	125	135	6	2	
Ireland	4.9		84.3	3.8	2	
Netherlands	5.6	63	64	3	1.3	11
Slovenia	9.6		170	5	3	
Sweden	4.4	39.8	75.7	3.9	1.3	
Switzerland	5.7	60.2	34.4	2.6	0.3	
USA	7.1		227.9	5.8	5.2	

Notes:

Only those countries are shown for which data regarding risk per mode were presented.

[a] The figures represent fatalities per users of the mode.

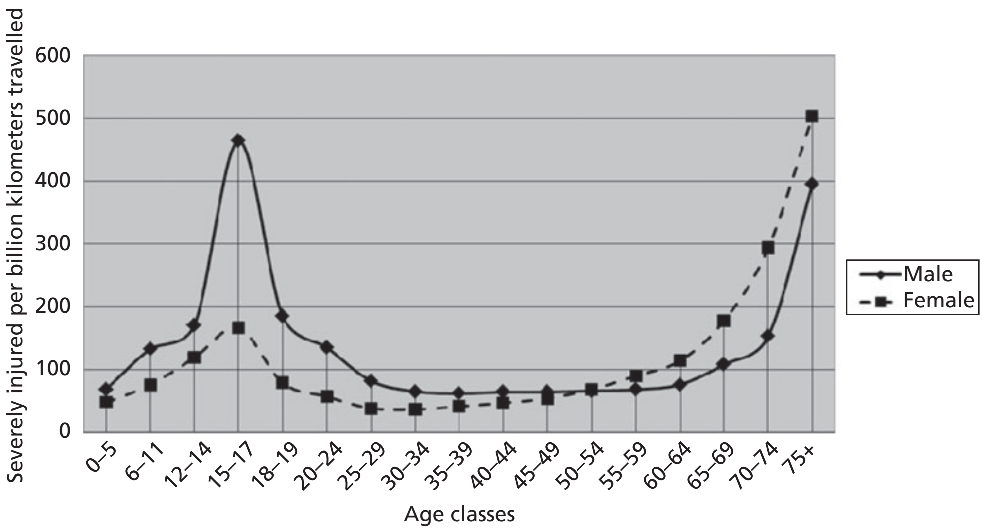
[b] Bicycles and mopeds.

Source: OECD/ITF (2011a).

Table 11.2 Road user fatalities per 100 000 population of the age group and per 1 billion vehicle kilometres per road type

	Per 100 000 population of the age group							Per 1 billion vehicle kilometres	
	All	0–14	15–17	18–20	21–24	25–64	65+	All roads	Motorways
Australia	6.7	1.7	7.6	15.3	11.1	7.1	7.6	6.7	
Austria	7.6	1.2	9.6	16.5	11.7	7.2	11.0		2.5
Belgium	8.8	1.2	–	–	–	9.5	9.5	9.7	3.9
Canada	6.6	1.0	–	–	–	6.4	8.3	6.5	–
Czech Republic	8.6	1.1	3.5	10.2	16.1	9.4	10.5	15.8	3.1
Denmark	5.5	1.0	8.1	15.1	9.2	5.5	7.0	6.6	1.8
Finland	5.2	0.7	11.5	15.2	8.1	4.5	7.7	5.0	–
France	6.8	1.1	8.3	16.7	15.7	6.9	7.6	7.8	2.4
Germany	5.1	0.8	5.2	14.4	9.6	4.5	6.6	5.9	–
Great Britain	3.7	0.6	5.4	9.2	6.4	3.8	4.2	4.4	1.3
Greece	12.9	2.7	10.9	24.9	29.2	13.1	13.1	–	–
Hungary	8.2	1.4	4.4	7.0	10.5	9.5	10.1	–	–
Iceland	5.3	0.0	7.1	6.7	0.0	7.1	8.1	5.5	–
Ireland	5.4	1.3	5.3	18.9	12.8	5.2	5.3	4.9	–
Israel	4.2	1.2	3.1	7.1	7.4	4.4	8.3	6.4	–
Italy	7.1	0.8	6.8	12.8	13.8	6.8	9.2	–	–
Japan	4.5	0.7	3.7	6.4	4.3	3.0	10.2	7.7	1.7
Korea	12.0	1.9	6.6	7.0	9.8	11.6	35.2	20.0	–
Luxembourg	9.7	6.8	0.0	29.4	21.7	8.2	13.0	–	–
Netherlands	3.9	0.8	4.3	8.8	9.2	3.1	7.6	5.6	–
New Zealand	8.9	2.5	13.1	19.4	15.4	8.8	10.1	9.6	–
Norway	4.4	0.9	8.9	14.2	8.2	4.1	5.3	5.4	–
Poland	12.0	2.2	8.2	22.1	19.6	12.1	15.7	–	–
Portugal	7.9	1.3	5.7	12.2	13.3	8.1	10.8	–	–
Slovenia	8.4	0.7	6.4	15.1	17.6	8.2	11.7	9.6	5.6
Spain	5.9	0.9	5.6	11.0	9.1	6.4	6.6	–	–
Sweden	3.9	0.6	6.5	8.9	5.7	3.6	5.6	4.4	–
Switzerland	4.5	1.8	4.1	11.6	8.6	3.8	6.9	5.7	–
United Kingdom	3.8	0.6	5.4	9.9	6.5	3.8	4.3	4.6	–
USA	11.1	–	–	–	–	12.8	13.4	7.1	–

Source: OECD/ITF (2011b).



Source: Reworking and presentation by the author of data from CBS, Ministry of Infrastructure and the Environment, and DHD, 2011.

Figure 11.1 Number of severely injured people in traffic per 1 billion kilometres travelled per age group and sex for the Netherlands, 1999–2009

Currently, in many highly motorized countries car occupants have the major share of the total number of road fatalities because of the relatively high amount of kilometres travelled in cars. On the one hand, the car is a fast and weighty collision partner in conflicts with two-wheelers and pedestrians, who also include especially vulnerable road users such as children and the elderly. On the other hand, the car is the vulnerable party in terms of weight in conflicts with heavy goods vehicles and not very 'forgiving' roadside obstacles. Young people are an especially high-risk group of those involved in serious crashes because of their lack of driving or riding experience and age-specific characteristics. Elderly road users (of 75 years old or more; see Figure 11.1) are the next most important risk group because of their physical frailty. In many low- and middle-income countries the majority of the casualties are vulnerable road users such as pedestrians and cyclists, most of the time young people.

Differences of safety for different road types can also, to a large extent, be explained by a combination of the fundamental risk factors introduced earlier. For example, serious crashes outside urban areas, and particularly on rural roads, are dominated by single-vehicle conflicts along sections of road, often running off the road. These are usually the result of inappropriate speeds, possibly in combination with other factors which increase risk such as alcohol consumption, distraction and/or fatigue. The fact that many roadsides are not 'forgiving' also results in severe outcomes. On urban roads, transverse conflicts, in particular, predominate. On these streets and roads, in particular, where most people are killed in urban areas, mass differentials and the vulnerability of road users are important factors, combined with comparatively high speeds and the vulnerability of vehicles in transverse conflicts (side impacts). Motorways are the safest roads when it comes to crash risk (see Table 11.2, where for some countries in the two right-hand columns road fatalities are given per billion vehicle kilometres for all roads and motorways). This is due to a combination of high-quality road design and slow-moving traffic not being allowed on these roads. This is appropriate for high driving speed conditions, both physically (separation of driving direction, grade-separated intersections) and psychologically (predictable design). Then high speeds can be managed safely.

11.5 Measuring safety and danger

All countries in the world seem to have the ambition to improve road safety, or at least no country is known to be making public statements that the road toll of today is acceptable. However, measuring road safety is not as simple as measuring a temperature. Researchers or policy-makers cannot read a simple measuring instrument. Additionally, they can even have a discussion about which elements to include in a definition, and which not. The most common measure used to define road safety is the number of road crashes and/or the number of casualties and the associated negative consequences resulting from such crashes. Sometimes subjective feelings related to fears of being involved in a crash are included in the measure as well. In those cases people's perceptions about (lack of) road safety are taken into account in the measure.

The definition of a road traffic crash is a collision or incident on a public road (or private road to which the public has right of access) that results in damage to objects and/or injury to people and that involves at least one vehicle in motion. The international definition of a road death, taken from the UNECE Glossary of Transport Statistics 2009, is someone who dies immediately or dies within 30 days as a result of a road crash, excluding suicides. For countries that do not apply the threshold of 30 days, conversion coefficients are estimated for international comparison purposes. The definition of injury and injury severity can be classified as follows: admitted to hospital, had to take sick leave, had to rehabilitate, suffered permanent injury, remained in a coma, or died from the consequences more than 30 days afterwards. Different countries use different definitions and different procedures to collect data; from this perspective, comparison of data of numbers of injured are difficult to compare, to some extent. However, international efforts are being made to improve sound and meaningful comparisons (OECD/ITF, 2011c).

Crashes can result in more serious or less serious outcomes: fatal injuries, other injuries or damage only to vehicles involved in a crash. Sometimes, damage-only crashes are not considered serious enough to be included in official crash statistics. Data collection is needed to learn how many crashes occurred in a certain time period and in a certain geographical area. The longer the time period or the larger the area, the more crashes. For that reason it is a good habit to normalize the number of crashes for time and space, expressing the road safety level. This normalizing can be done in different ways serving different purposes. If we relate the number of fatalities or injuries to the number of inhabitants (the first ratio) we have the mortality rate (fatalities per 100 000 inhabitants; see also Table 11.2, where mortality rates are presented for different countries) or morbidity rate (injuries per 100 000 inhabitants). These rates are public health indicators, allowing us to compare road injuries with other threats or diseases. Mortality rates are often used in international comparisons. An important reason is that fatal road crashes have a common definition (dead within 30 days) and are well recorded in many countries, as is the case with the number of inhabitants. This is not the case for injuries.

A second ratio is the so-called fatality rate or injury rate. In this case we relate the number of fatalities or injuries to the degree to which people are exposed to traffic or, more precisely, to risks in traffic. Often, the number of kilometres travelled is used to estimate this 'exposure' or, even more often, the number of motorized kilometres (see Table 11.1). We can also use time in traffic as a measure of exposure.

Unfortunately, the measuring of road crashes, and their consequences, and the measuring of exposure suffer from problems related to the use of different definitions, data quality, data completeness and data availability (OECD/ITF, 2011c). In almost all countries the crash registration is carried out by the police. However, crash statistics are always incomplete as a result of underreporting. Furthermore, data collections suffer from certain biases: crashes with motorized vehicles are better registered than crashes with non-motorized transport, such as pedestrians and cyclists (Derriks and Mak, 2007). Another bias in data collection is that the higher the severity of injuries, the lower the underreporting. At present, many initiatives are being developed in the world to improve the quality, comparability and availability of crash data.

An important measure for road crashes is their associated costs. There are two good reasons to estimate road crash costs. Firstly, it allows policy-makers to compare the economic consequences of road crashes with other impacts of traffic and transport, such as environmental impacts and congestion. A second reason is that it allows policy-makers to compare these costs with the costs of other public health issues. For that purpose, public health indicators denoted as 'DALY' (disability adjusted life years) or 'QALY' (quality adjusted life years) are also sometimes used. These are measures for loss of life years and/or quality of life.

In many countries, a growing interest in estimating the costs of road crashes can be observed. The cost estimation methods have improved considerably. However, an internationally accepted 'standard' method does not exist at the time of writing this chapter.

Some convergence on the cost categories to be included in cost estimates can be noted (Alfaro et al., 1994). However, the methods applied still differ in including or excluding certain cost categories (Elvik, 1995):

1. medical costs;
2. production loss;
3. value of statistical life;
4. property damage;
5. settlement costs.

Sometimes costs related to congestion as a consequence of a crash are added. For the cost categories 1, 4 and 5, a method is used called 'restitution cost method' and for 2 the 'human capital method'. In methods 1, 2, 4 and 5, direct financial costs related to crash injuries are estimated, for example the amount of money hospitals have to spend on injury treatment, vehicle repair costs, lost production hours (e.g. lost wages) and so forth.

Cost category 3 (value of statistical life, VOSL) is based on people's willingness to pay for lower risks (or willingness to accept a reward for higher risks). In this cost category the change in traffic casualties due to a measure is valued in monetary terms (e.g. de Blaeij, 2003). A VOSL does not reflect the monetized value of an individual life, which is, naturally, priceless. Instead, the VOSL is based on the relation between changes in risks and willingness to pay for these changes. For example, if someone drives on a road with a risk of 2.5/1 000 000 of death, but is willing to pay 6 minutes by taking a detour to drive on a road with a lower risk of 2/1 000 000, this driver is valuing his or her 'statistical life' at 2 million euros. The reason is that the VOSL is (assuming a value of time of 10 euros/hour, which equals 1 euro/6 minutes; see Chapter 14,):

$$\frac{d(travel\ time)}{d(risk)} = \frac{1\ euro}{\left(\frac{0.5}{1\,000\,000}\right)} = 2\,000\,000\ euros$$

Societal costs of road crashes can be compared with other road traffic societal costs. In the Netherlands, for example, the yearly societal costs of road crashes (around 10 to 14 billion euros) are higher compared to congestion costs (2 to 3 billion euros) and the environmental costs of road traffic (2 to 8 billion euros) (KiM, 2010).

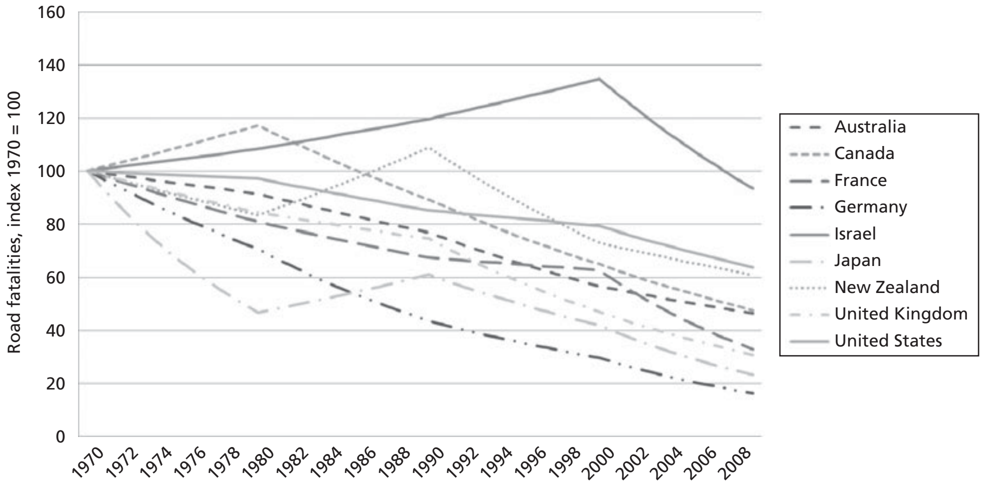
11.6 Developments in road crashes

Each year more than 1.2 million are killed in a road crash, and 20 to 50 million suffer non-fatal injuries worldwide (Peden et al., 2004). Peden et al. (2004) expect the number of road traffic fatalities to increase by 67 per cent over the period 2000 to 2020 to 1.9 million road fatalities a year, without appropriate action. With these numbers, road fatalities are the 11th leading cause of death, resulting in 2.1 per cent of all deaths. By far the majority of all crashes, deaths and injuries occur in low- and middle-income countries: 85 per cent of road traffic deaths (see Table 11.3 for road injury mortality rates per income class worldwide). The majority of these deaths and injuries are vulnerable road users. The economic costs of road crashes and injuries are estimated to be 1 per cent of GNP in low-income countries, 1.5 per cent in middle-income countries and 2 per cent in high-income countries. These developments resulted in a resolution adopted by the United Nations in 2010 (A/64/255) to declare the period 2011–20 a Decade of Action for Road Safety. This DoA started on 11 May 2011.

Table 11.3 Road traffic injury mortality rates (per 100 000 population) in WHO regions, 2002

WHO region	Low- and middle-income	High-income
African region	28.3	–
Region of the Americas	16.2	14.8
South-East Asia region	18.6	–
European region	17.4	11.0
Eastern Mediterranean region	26.4	19.0
Western Pacific region	18.5	12.0

Source: Peden et al. (2004).



Note: Index 1970 = 100.

Source: Based on OECD/ITF (2011a: 7, table 1), which gives this long-term trend in road fatalities for more countries worldwide.

Figure 11.2 Long-term trends in road fatalities for a selection of high-income countries, 1970–2009

Since 1970, many high-income countries have made remarkable progress (see Figure 11.2).

Three countries are the top-scoring countries worldwide, with mortality rates of less than 4.0: Sweden, the United Kingdom and the Netherlands (see Table 11.2). In the so-called SUNflower studies (Koornstra et al., 2002; Wegman et al., 2008) the road safety developments in these three countries were compared, and later six other European countries were added. The main conclusions (Koornstra et al., 2002) were that all three countries have achieved similar levels of safety through continuing planned improvements over recent decades and that policy areas targeted have been similar, but that implementation of policies has differed at a detailed level. It was assumed that differences in focus for safety programmes resulted from both different relative sizes of accident groups and differences in the structure of road safety capability, which influenced their ability to deliver different types of policy. Progress has been achieved through directing improved policies in all three areas – vehicle, road and road user.

An example: the Netherlands

To give more detail on the explanations for the relatively high rate of improvement in some countries, the Netherlands has been chosen as an example. Details for more countries can be found in *Safety Science*, Special

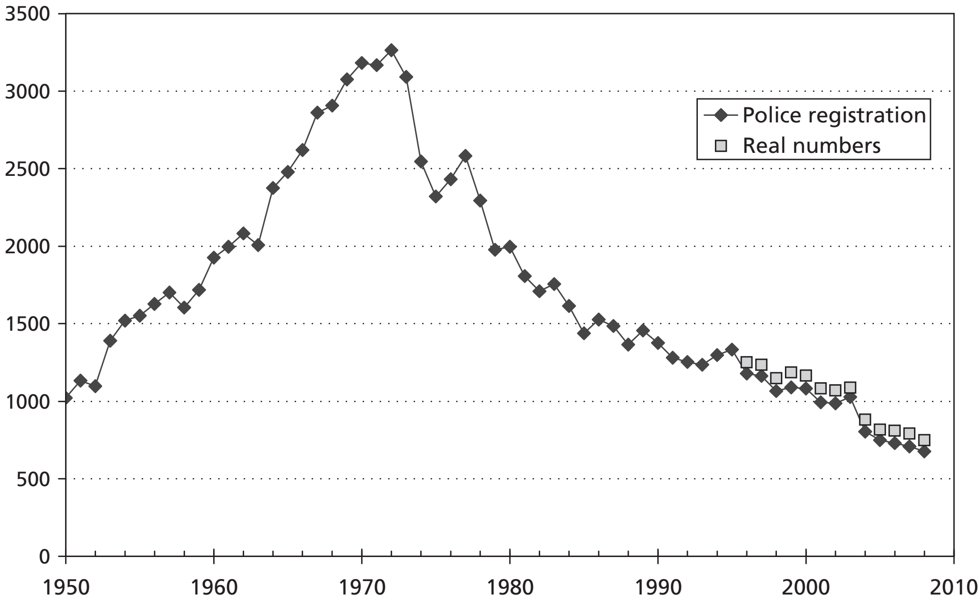


Figure 11.3 The development of the number of traffic deaths in the Netherlands

Issue on Road Safety Management (volume 48, issue 9, November 2010). A 50 per cent reduction in the mortality rate occurred in the period 1995–2007 in the Netherlands, whereas Great Britain and Sweden reached a little bit more than 20 per cent. This is partly due to a 'learning society' or an 'investing society', which has adapted itself to motorized, fast-moving traffic and making substantial safety investments at the same time. Infrastructural adaptation has taken place (such as the construction of relatively safe motorways), passive safety in vehicles has been improved, and there is more safety legislation and enforcement which takes account of factors which increase risk and reduce injury (such as alcohol consumption in traffic and mandatory crash helmet and seat belt use, respectively). These measures have all contributed to reductions in the number of traffic fatalities and injuries, despite increased mobility (Koornstra et al., 2002; Elvik and Vaa, 2004). But, as yet, researchers do not have a totally conclusive explanation for these improvements.

In the period 2008–2010, approximately 700 traffic deaths were lamented each year in the Netherlands. This is just a quarter of the 3264 traffic deaths in the disastrous year 1972. The number of traffic deaths in the Netherlands should not be based exclusively on police registration. Other sources reveal that approximately 8 per cent, in this period, of these deaths are missing from this registration. For this reason, in Figure 11.3, the concept of the 'real' number of traffic deaths during the last few years is used.

SWOV (2007) describes the major changes that occurred during the period 1950–2005 in a report with the striking title 'The summit conquered'. To begin with, there is a rise in the number of traffic fatalities, which is followed by a decline. This report illustrates that, for an understanding of why the annual number of fatalities has decreased, one should not look at the total number of traffic deaths; it is preferable to consider separate components (transport modes, age, road type, etc.), because these components develop differently compared with the totals. This approach shows that different developments take place concurrently. It becomes clear, for instance, that passenger car mobility in terms of vehicle ownership and vehicle use has been increasing steadily during this period. The sales and use of motorized two-wheelers, however, show a less steady picture: they fluctuate strongly and are sometimes popular, sometimes much less popular. This is clearly reflected in the road safety developments.

The quality of roads and vehicles with regard to safety has shown considerable improvement in the past few decades. The structure of the road network in the Netherlands has undergone considerable adaptations to meet the increased mobility. This can be illustrated by the fact that approximately half of all motorized vehicle kilometres travelled are travelled on relatively safe motorways. The separation of different traffic modes, mainly by the construction of safe bicycle facilities, has taken a considerable step forward. Secondary (passive) vehicle safety has been improved considerably.

Three important aspects of safety related human behaviour have also improved: drinking and driving has decreased, the safety belt is worn much more frequently, and the helmet for motorized two-wheelers is also worn much more frequently. These improvements are such that the behaviour problem related to drinking and driving, wearing safety belts and wearing helmets is reduced to 'only' a hard core of offenders. In the Netherlands, the speeds driven have gone down because the speed limits have been lowered on a substantial part of the road network. For driving speeds, it may be observed that, although road users have reduced their speed somewhat, a considerable proportion of road users exceed the limit.

11.7 Shifts in road safety paradigms

Section 11.6 explains that different countries in the world are at a completely different stage of development. Low- and middle-income countries, especially in Asia, face a serious risk of growing numbers of fatalities and injuries in the coming years. At the same time, we see a positive development in many highly motorized and highly developed countries (Figure 11.2). How

Table 11.4 Road safety 'paradigms' as seen over time

Period	Characteristic
1900–1920	Crashes as chance phenomena
1920–1950	Crashes caused by the crash-prone
1940–1960	Crashes as mono-causal
1950–1980	A combination of crash causes fitting within a 'system approach'
1980–2000	The person as the weak link: more behavioural influence
2000–	– Better implementation of existing policies – Safe system approach, e.g. Sustainable Safety (Netherlands) and Vision Zero (Sweden)

Source: Inspired by OECD (1997).

can these improvements be explained, and which road safety problems still remain? This section focuses on highly motorized countries.

Over the years, there have been very many different ways of tracing crash causes and how they can best be avoided. Table 11.4 presents, by means of a few words, what the dominant thoughts in the OECD countries were in the past century (see also OECD, 1997).

In short, one can notice an increase in sophistication in thinking about road safety. The 'crash-prone theory' (1920–50) dates primarily from the phase in which the legal guilt question was the main one: which road user has broken which law and is, thus, both guilty and liable? This question was answered by the police on the registration form of a crash, finally decided inside or outside the court room, and used by insurance companies to determine how to compensate damages. From 1940 to 1960 the idea shifted to the notion that crashes could be explained using a mono-causal model. In-depth studies showed, however, that there are few mono- or single-cause crashes; accidents are usually caused by, and the result of, a combination of circumstances, which led to the so-called 'multi-causal approach' (1950–80). This approach, sometimes also called the system approach, was strongly influenced by the so-called Haddon matrix.

Haddon (1972) designed a matrix using two axes: on the one hand he distinguishes three phases in the crash process: before a crash, during a crash and after a crash. The other axis is filled with the three components of our traffic system: the road user, the road and the vehicle. Consequently, this 3×3 matrix comprises nine cells. The Haddon matrix was used to classify crash factors and to indicate that more action could be taken than just 'pre-crash

– road user related interventions', as was a tradition at the time. As Haddon tried to structure road safety (in nine cells of a matrix), other attempts were made. One came from Sweden (Rumar, 1999) in which the size of the traffic safety problem is explained as the product of three dimensions:

1. exposure (E);
2. accident risk (A/E: number of accidents per exposure);
3. injury risk (I/A: number of people killed or injured per accident).

The additional 'dimension' given by Rumar (and Nilsson, 2004, as well) was the inclusion of exposure as a variable or dimension to be used to improve road safety and to reduce the number of fatalities and injuries.

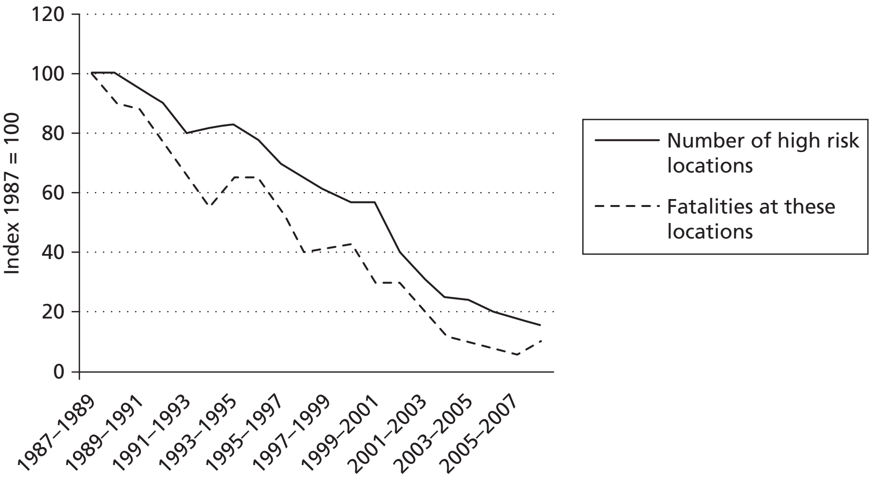
Since 2000 or thereabouts, two new main lines (paradigms) in road safety have appeared. The first one is especially aimed at evidence-based policies implemented in an efficient way. A lot of information has become available about several road safety interventions (see, for example, Elvik et al., 2009), and the idea here is not to develop new policy interventions but to improve the quality of implementing existing ones using evidence-based or research-based information on effects and costs of interventions. Greater effectiveness is considered to be a matter of scale and quality. Improving road safety in such a way that the number of casualties substantially decreases generally requires a considerable effort, given the relatively low frequency of crashes, their low densities in space and the modest effects of most safety interventions. In this first new line of reasoning, since 2000 there has been growing attention given to what is called 'safety culture' and 'cultural change' in the field of decision-making on road safety (Johnston, 2010). In this analysis, road safety progress results from an increased emphasis on strategic planning – comprising the data-driven selection of the major problems to address, the setting of objective but ambitious targets and a focus on effective implementation of programmes and measures through institutional cooperation and coordination: 'evidence-based policies' are the key words. However, despite overwhelming scientific evidence about certain themes, such as reducing speed limits to reduce speed and risks, both politicians and the public are not always convinced about introducing certain measures, even though the evidence supports this.

The second new line of thinking about traffic safety since 2000 is the Safe System Approach (OECD/ITF, 2008), such as the Sustainable Safety vision (Wegman and Aarts, 2006; see also section 11.8). The Safe System Approach recognizes that, prevention efforts notwithstanding, road users will remain fallible and crashes will occur. The approach also stresses that those involved in the design of the road transport system need to accept and share responsibility for the safety of the system and those that use the system need to accept responsibility for complying with the rules and constraints of the system. Furthermore, the Safe System Approach aligns safety management decisions with broader transport and planning decisions that meet wider economic, human and environmental goals, and the approach shapes interventions to meet a long-term goal, rather than relying on 'traditional' interventions to set the limits of any long-term targets.

The Safe System Approach paradigm shift is based on two assumptions: (1) the current traffic system is inherently dangerous, and (2) intensifying current efforts could lead to fewer casualties but not to substantially safer traffic, and the investments are less efficient than in the past and will be even more so in the future. To understand this position, it is useful to analyse the 'remaining' road safety problems in high-income countries.

In very broad terms, two types of problems can be identified in analysing road safety (Wegman, 2010): generic problems and specific problems. Specific problems are those safety problems that are concentrated on specific locations, specific road user groups, specific behaviour or specific vehicles (they relate, among other things, to the fundamental risk factors, as explained in section 11.2). Generic problems are caused by the fact that road traffic is inherently unsafe: ordinary people are killed in crashes under normal circumstances. This means that anybody can be involved in a crash at any particular time and that many people will be involved in a crash at some time in their lifetime because road traffic has not been designed with safety as an important requirement for design and operations.

In road safety policies in many highly motorized countries, for a long time the idea was to identify risk-increasing factors and reduce these specific risks. In public health too, this is a well-known and widely supported approach: cure those who are ill and identify and treat high-risk groups or circumstances. See, for example, vaccination strategies to protect 'high-risk groups' from viruses, such as the H1N1 virus (sometimes called swine flu). As a matter of fact, much of past road safety policy was based on high risks, high numbers and frequent causes, and on well-identified crash patterns. Crash and casualty rates, for example, were determined and divided into age groups, which showed that the young and the elderly had increased risks. The answer that policy-makers have come up with is the effort to reduce these high risks: smoothing the peaks in distributions. Analysis of road safety was aimed at the detection of peaks, explaining them, and finding measures to overcome them.



Source: SWOV (2010).

Figure 11.4 Number of high-risk locations and fatalities at these locations

The specific high-risk approach resulted in successful policy, certainly in the Netherlands, for example (Figure 11.4). Whereas, in the period 1987–89, 10 per cent of the seriously injured were from crashes at locations that could be labelled 'high-risk locations', this decreased to 1.8 per cent in the period 2004–06.

Therefore the least safe locations have successfully been dealt with. However, it is hardly possible for such an approach to have further positive effect in the future. One could say that the approach has become a victim of its own success and will barely make a further contribution to the reduction of the number of road crash casualties in high-income countries with a relatively long history of transport safety policies, such as the Netherlands.

The same case can be used when dealing with crash-prone drivers and for eliminating near wrecks, although the evidence is weaker. In many countries 'peaks in distributions' (hazardous locations, dangerous road users and defective vehicles) still exist and can still be eliminated. However, this approach will increasingly pose practical problems for high-income countries, such as *how* to identify and eliminate these 'relatively small peaks'.

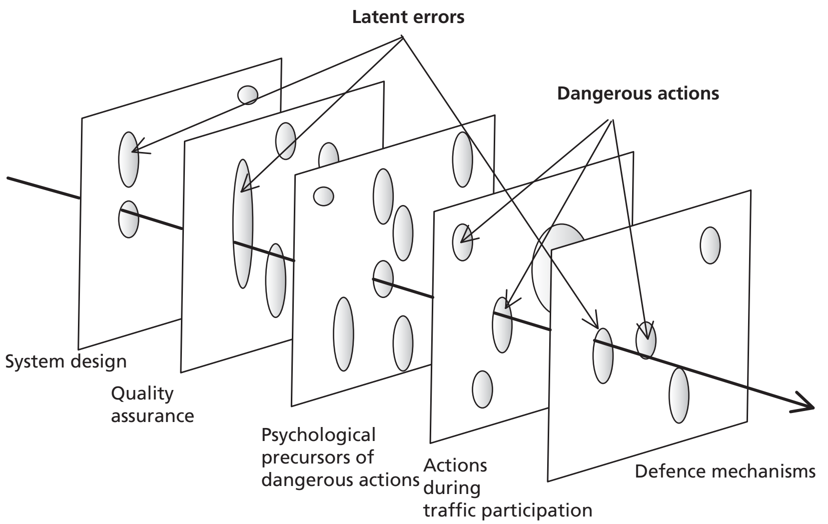
11.8 Sustainable Safety

Therefore the Sustainable Safety vision was developed in the Netherlands because the traditional policies were becoming less effective and less efficient and because the idea was that the Netherlands had not yet found out the core characteristics of its road safety problems. Although, at first glance, the vision seems to be a one-country approach, in this case, for the Netherlands, Sustainable Safety is in fact considered to be an appropriate and general vision for the future and not just for highly motorized and relatively safe countries like the Netherlands. This has been illustrated in the report about road safety by the World Health Organization (WHO) and the World Bank (Peden et al., 2004), in the report *Best Practices in Road Safety* commissioned by the European Commission (KfV, 2007) and in OECD and the International Transport Forum's publication *Towards Zero: Ambitious Road Safety Targets and the Safe System Approach* (OECD/ITF, 2008), for example. Sustainable Safety has also been discussed in the PACTS report about the future of road safety in Great Britain (Crawford, 2007).

The main lines of this vision will be explained here further. For more detail about Sustainable Safety, we refer to Koornstra et al. (1992) and Wegman and Aarts (2006). The vision aims for 'inherently safe' traffic (a concept used in rail and air traffic and also in energy production, for example). The Sustainable Safety approach starts with the idea that the present traffic system is inherently hazardous (that serious crashes can happen anywhere and at any time) and that all possible solutions are considered in an integral and rational manner. There is no a priori preference for improving roads or vehicles or changing behaviour. Furthermore, the rationale should not be restricted to road safety only, but wider deliberations are preferable (congestion, environment, scenery, economic development, health care and so on).

The following key aspects of the Sustainable Safety vision were identified:

1. Ethics:
    a. It is unfair to hand over a traffic system to the next generation with the current casualty levels.
    b. A proactive approach instead of a reactive approach.
2. An integral approach which:
    a. integrates road user, vehicle and road into one safe system;
    b. covers the whole network, all vehicles and all road users;
    c. integrates with other policy areas.
3. Man is the measure of all things:
    a. Human capacities and limitations are the guiding factors.
4. Reduction of latent errors (system gaps) in the system:
    a. In preventing a crash it is better not to be fully dependent on whether or not a road user makes a mistake or error.
5. Use criterion of preventable injuries:
    a. Which interventions are most effective and cost-effective?



Source: Based on Reason (1990).

Figure 11.5 The development of a crash (bold arrow) as a result of latent errors and unsafe actions in the different elements composing road traffic. If the arrow encounters 'resistance' at any moment, no crash will develop

As indicated in section 11.3, intentional or unintentional human errors play a role in nearly every crash. No matter how well educated and motivated people are, they commit errors and do not always abide by the rules. Studies of road traffic crashes invariably indicate that the factors 'road' and 'vehicle' play only a minor role. Present-day road traffic has not been designed with safety in mind. For avoiding crashes, road users now are almost completely dependent on the extent to which they are capable of correcting (and sometimes willing to correct) their own errors. And errors are also made in doing this. Both intentional errors and unintentional errors are made. Intentional errors are committed by the 'unwilling' road user; unintentional errors are committed by the 'incapable' road user.

Additionally, a crash is rarely caused by one single unsafe action; it is usually preceded by a whole chain of poorly attuned occurrences. This means that it is not only one or a series of unsafe road user actions that cause a crash; hiatuses in the traffic system also contribute to the fact that unsafe road user actions can in certain situations result in a crash. These hiatuses are also called latent errors (Reason, 1990) (Figure 11.5). Road crashes occur when latent errors in the traffic system and unsafe actions during traffic participation coincide in a sequence of time and place.

As unsafe actions can never entirely be prevented, the Sustainable Safety vision aims at banishing the latent errors from traffic. The road traffic system must be forgiving with respect to unsafe actions by road users, so that these unsafe actions cannot result in crashes. The sustainable character of measures mainly lies in the fact that actions during traffic participation are made less dependent on momentary and individual choices. Such choices may be less than optimal and can therefore be risk-increasing.

Adjusting the environment to the abilities and limitations of the human being is derived from cognitive ergonomics, which made its entry in the early 1980s, coming from aviation and the processing industry. In all types of transport other than road traffic, this approach has already resulted in a widespread safety culture. Further incorporation of the Sustainable Safety vision should eventually lead to road traffic that can be considered 'inherently safe' as the result of such an approach.

One option to make traffic more inherently safe is simply to ban certain road users from traffic. However, this policy can have very serious consequences for an individual. Therefore a reason for doing this must be well considered. In the current traffic system policy-makers barely make a selection at the start: everybody can participate in traffic; even more strongly, older people are encouraged to participate (independently) in traffic for as long as possible. (Temporary) prohibition of access, keeping someone away from traffic, may be justifiable from a repressive point of view, but under the present conditions it does not make a substantial contribution to a reduction in the number of road crash casualties. As it is, elimination is a rare occurrence and, in addition, the question remains whether those who have been disqualified from driving will not just continue to drive anyway. It remains to be seen how this option can be made more effective, and it seems advisable to work on innovating solutions in this area. Now, and probably also in the near future, only a relatively small proportion of the population is denied access (withdrawal of the licence), and this approach will therefore have limited effect on the further reduction in road casualties.

Another option to make traffic inherently safer is to adjust the environment to the human measure in such a way that people commit fewer errors. Here, environment not only means the physical environment (road and vehicle) but also includes the required 'software' like legislation and the traffic education that is made available. Adjustments can be made along three lines. In the first place, road designers can make potentially dangerous situations less

Table 11.5 The five Sustainable Safety principles

Sustainable Safety principle	Description
Functionality of roads	Mono-functionality of roads as either through roads, distributor roads or access roads in a hierarchical road network
Homogeneity of mass and/or speed and direction	Equality in speed, direction and mass at moderate and high speeds
Forgivingness of the environment and of road users	Injury limitation through a forgiving road environment and anticipation of road user behaviour
Predictability of road course and road user behaviour by a recognizable road design	Road environment and road user behaviour that support road user expectations through consistency and continuity in road design
State awareness by the road user	Ability to assess one's task capability to handle the driving task

frequent so that road users need to make fewer decisions and therefore can commit fewer errors. An example of this is physical direction separation on secondary roads, which prevents head-on collisions. The second possibility is to design the road user environment in such a way that fewer errors are committed and it is easier to make correct and safe decisions; this can, for instance, be done by the construction of a roundabout which makes high speeds at an intersection impossible. Thirdly, a traffic environment may be designed in such a way that *if* errors are still being committed they will not have very serious consequences for the road user. To achieve this, the road user must be presented with an environment which is forgiving of errors that are committed.

Five principles are identified as crucial for a sustainably safe traffic system (see Table 11.5). These are: functionality, homogeneity, forgivingness, predictability and state awareness.

Reduction percentages in traffic deaths in the Netherlands of more than 30 per cent and 40 per cent compared to business-as-usual levels have been estimated for policy interventions coming from or inspired by the Sustainable Safety vision (Weijermars and van Schagen, 2009; Weijermars and Wegman, 2011). Setting the societal cost of the investments alongside the societal benefits of the fatalities, injured and crashes saved shows that these interventions are socially cost-effective. The benefit–cost ratio is highly positive, around 4:1.

11.9 Conclusions

The most important conclusions from this chapter are:

1. Speed, speed and mass differences, and vulnerability are fundamental risk factors for road crashes and injuries. Pedestrians and cyclists are vulnerable road users in collisions with (high-speed) motorized vehicles.
2. Risk-increasing factors from the road users' side are impaired driving (alcohol and drugs), illnesses and ailments, emotions and aggression, fatigue and distraction.
3. Both human errors and (intentional) violations (and related extreme behaviour) are important contributory factors for road crashes.
4. Measuring road safety is not without its problems because of non-harmonized definitions, lack of data quality, data incompleteness and lack of data availability.
5. Low- and middle-income countries, especially in Asia, face a serious risk of a growing number of fatalities and injuries in the coming years. At the same time, a positive development in many highly motorized and highly developed countries can be noted. These highly motorized countries haves made considerable progress by taking all kinds of behavioural, vehicle and infrastructural related measures.
6. However, in the highly motorized countries the effectiveness of these 'traditional' policies will run out. The next step is to move from policies targeted at decreasing specific risks to policies aimed at lowering generic or inherent risks: in other words, to a systems approach.
7. One such generic approach is the so-called Sustainable Safety approach. It starts by using the idea that the present traffic system is inherently hazardous (that serious crashes can happen anywhere and at any time) and that all possible solutions should be considered in an integral and rational manner. Cost–benefit analyses show that such an approach can have high positive benefit-to-cost ratios.

REFERENCES

Aarts, L. and I. van Schagen (2006), 'Driving speeds and the risk of road crashes: a review', *Accident Analysis and Prevention*, 38, 215–224.

Alfaro, J.-L., M. Chapuis and F. Fabre (1994), *Socioeconomic Cost of Road Accidents*, Transport Research COST 313, Brussels and Luxembourg: Commission of the European Communities.

Blomberg, R.D., R.C. Peck, H. Moskowitz, M. Burns and D. Fiorentino (2005), *Crash Risk of Alcohol Involved Driving: A Case-Control Study*, Stamford, CT: Dunlap and Associates.

Connor, J., R. Norton, S. Ameratunga, E. Robinson, I. Civil, R. Dunn, J. Bailey and R. Jackson (2002), 'Driver sleepiness and risk of serious injury to car occupants: population based case control study', *British Medical Journal*, 324 (7346), 1125–1129.

Crawford, E. (2007), *Beyond 2010: A Holistic Approach to Road Safety in Great Britain*, London: Parliamentary Advisory Council for Transport Safety (PACTS).

Derriks, H. and P. Mak (2007), *Underreporting of Road Traffic Casualties*, Paris: Organisation for Economic Co-operation and Development (OECD)/IRTAD.

De Blaeij, A.T. (2003), *The Value of a Statistical Life in Road Safety: Stated Preference Methodologies and Empirical Estimates for the Netherlands*, Research Series, Amsterdam: Vrije Universiteit.

Dingus, T.A., S.G. Klauer, V.L. Neale, A. Petersen, S.E. Lee, J. Sudweeks, M.A. Perez, J. Hankey, D. Ramsey, S. Gupta, C. Bucher, Z.R. Doerzaph, J. Jermeland and R.R. Knipling (2006), *The 100-Car Naturalistic Driving Study, Phase II: Results of the 100-Car Field Experiment*, Washington, DC: National Highway Traffic Safety Administration, USDOT.

EC (European Commission) (2010), *Towards a European Road Safety Area: Policy Orientation on Road Safety 2011–2020*, COM (2010) 389 final, Brussels: European Commission.

Elvik, R. (1995), 'An analysis of official economic evaluations of traffic accident fatalities in 20 countries', *Accident Analysis and Prevention*, 27 (2), 237–247.Elvik, R. and T. Vaa (2004), *The Handbook of Road Safety Measures*, Amsterdam: Pergamon Press.

Elvik, R., T. Vaa, A. Hoye, A. Erke and M. Sorenson (2009), *The Handbook of Road Safety Measures*, 2nd revised edition, Bingley: Emerald Group Publishing.

Glassbrenner, D. and M. Starnes (2009), *Lives Saved Calculations for Seat Belts and Frontal Airbags*, Washington, DC: National Highway Traffic Safety Administration.

Haddon, W. (1972), 'A logical framework for categorizing highway safety phenomena and activity', *Journal of Trauma*, 12 (3), 193–207.

Johnston, I. (2010), 'Beyond "best practice" road safety thinking and systems management: a case for culture change research', *Safety Science*, 48 (9), 1175–1181.

KfV (2007), *Best Practices in Road Safety: Handbook for Measures at the Country Level*, final report of the Supreme project, Part C, Brussels: Directorate-General Energy and Transport, European Commission.

KiM (2010), *Mobiliteitsbalans 2010* [Mobility balance 2010], The Hague: Netherlands Institute of Transport Policy Analysis.

Koornstra, M.J., D. Lynam, G. Nilsson, P.C. Noordzij, H.-E. Petterson, F.C.M. Wegman and P.I.J. Wouters (2002), *SUNflower: A Comparative Study of the Development of Road Safety in Sweden, the United Kingdom, and the Netherlands*, Leidschendam, Crowthorne and Linköping: Stichting Wetenschappelijk Onderzoek Verkeersveiligheid (SWOV)/TRL/VTI.

Koornstra, M.J., M.P.M. Mathijssen, J.A.G. Mulder, R. Roszbach and F.C.M. Wegman (eds) (1992), *Naar een duurzaam veilig wegverkeer*: *nationale verkeersveiligheidsverkenning voor de jaren 1990/2010* [Towards sustainably safe road traffic: national road safety survey for 1990/2010], Leidschendam: SWOV.

McEvoy, S.O., M.R. Stevenson, A.T. McCartt, M. Woodward, C. Haworth, P. Palamara and R. Cercarelli (2005), 'Role of mobile phones in motor vehicle crashes resulting in hospital attendance: a case-crossover study', *British Medical Journal*, 331, 428–430.

Mesken, J. (2006), *Determinants and Consequences of Drivers' Emotions*, Leidschendam: SWOV.

Nilsson, G. (2004), *Traffic Safety Dimensions and the Power Model to Describe the Effect of Speed on Safety*, Lund Bulletin 221, Lund: Traffic Engineering, Lund Institute for Technology and Society.

OECD (Organisation for Economic Co-operation and Development) (1997), *Road Safety Principles and Models: Review of Descriptive, Predictive, Risk and Accident Consequence Models*, Paris: OECD.

OECD/ITF (International Transport Forum) (2008), *Towards Zero: Ambitious Road Safety Targets and the Safe System Approach*, Paris: OECD/ITF.

OECD/ITF (2011a), *IRTAD Annual Report 2010*, Paris: OECD/ITF.

OECD/ITF (2011b), accessed August 2011 at http://internationaltransportforum.org/irtad/pdf/risk.pdf.

OECD/ITF (2011c), *Reporting on Serious Road Traffic Casualties*, Paris: OECD/ITF.

Peden, M., R. Scurfield, D. Sleet, D. Mohan, A.A. Hyder, E. Jarawan and C. Mathers (2004), *World Report on Road Traffic Injury Prevention*, Geneva: World Health Organization.

Reason, J. (1990), *Human Error*, Cambridge: Cambridge University Press.

Redelmeier, D.A., R.J. Tibshirani and L. Evans (2003), 'Traffic-law enforcement and risk of death from motor-vehicle crashes: case-crossover study', *The Lancet*, 361 (9376), 2177–2182.

Regan, M.A., J.D. Lee and K.L. Young (eds) (2009), *Driver Distraction: Theory, Effects and Mitigation*, Boca Raton, FL: Taylor & Francis.

Rumar, K. (1999), *Transport Safety Visions, Targets and Strategies: Beyond 2000*, Brussels: European Transport Safety Council.

SWOV (2007), *De top bedwongen: balans van de verkeersonveiligheid in Nederland 1950–2005* [The summit conquered: assessment of road safety in the Netherlands 1950–2005], Leidschendam: SWOV.

SWOV (2010), 'The high risk location approach', fact sheet, SWOV, Leidschendam.

UNECE (2009), *Illustrated Glossary for Transport Statistics*, 4th edition, accessed at http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-RA-10-028/EN/KS-RA-10-028-EN.PDF.

Vaa, T. (2003), 'Impairments, diseases, age and their relative risk of accident involvement: results from a meta-analysis', Deliverable R1.1 of the IMMORTAL project, University of Leeds.

Vlakveld, W. (2005), *Jonge beginnende automobilisten, hun ongevalsrisico en maatregelen om dit terug te dringen* [Young novice drivers, their risk of accident and measures to reduce this], R-2005-3, Leidschendam: SWOV.

Walsh, J.M., J.J. de Gier, A.S. Christophersen and A.G. Verstrate (2004), 'Drugs and driving', *Traffic Injury Prevention*, 5, 241–253.

Wegman, F.C.M. (2010), 'De prijs van water bij de wijn' [The price of making a compromise], inaugural lecture, January, Delft University of Technology, TU Delft.

Wegman, F.C.M. and L.T. Aarts (eds) (2006), *Advancing Sustainable Safety: National Road Safety Outlook for 2005–2020*, Leidschendam: SWOV.

Wegman, F., J. Commandeur, E. Doveh, V. Eksler, V. Gitelman, S. Hakkert, D. Lynam and S. Oppe (2008), *SUNflowerNext: Towards a Composite Road Safety Performance Index*, Leidschendam: SWOV.

Weijermars, W.A.M. and I.N.L.G. van Schagen (eds) (2009), *Tien jaar duurzaam veilig: verkeersveiligheidsbalans 1998–2007* [Ten years of sustainable safety: road safety assessment 1998–2007], R-2009-14, Leidschendam: SWOV.

Weijermars, W.A.M. and F.C.M. Wegman (2011), 'Ten years of sustainable safety in the Netherlands: an assessment'. *Transportation Research Record* (2213), 1–8.

Young, K., M. Reagan and M. Hammer (2003), *Driver Distraction: A Review of the Literature*, Melbourne: Accident Research Centre, Monash University.