Sustainable Safety: A Short History of a Safe System Approach in the Netherlands

Fred Wegman, Letty Aarts, and Peter van der Knaap

Contents

Abstract

Although it has never been a real top priority, road safety is an important issue in the Netherlands and much progress has been made. In the last 50 years, the country experienced an enormous growth in population (+30%) and in kilometers travelled (+300%), but the mortality rate dropped by 80%. Many effective interventions were taken. Over time, new insights in traffic risks and causes of crashes led to the adoption of a new road safety vision in the early 1990s: Sustainable Safety, the first attempt worldwide of a Safe System approach (1992). This vision was inspired by the UN-Brundtland report Our Common

F. Wegman (✉)
Department of Transport and Planning, Delft University of Technology, Civil Engineering and Geosciences, Delft, The Netherlands
e-mail: f.c.m.wegman@tudelft.nl

L. Aarts
SWOV Institute for Road Safety Research, The Hague, The Netherlands
e-mail: letty.aarts@swov.nl

P. van der Knaap
The Hague, The Netherlands

K. E. Björnberg et al. (eds.), *The Vision Zero Handbook*,
https://doi.org/10.1007/978-3-030-23176-7_12-1

Future (1987) and applied to road safety. Its basis originated in the knowledge and experiences in the decades before.

In a sustainably safe road transport system, risks of crashes and serious injuries are drastically reduced or even eliminated by an infrastructure that is adapted to the limitations of human capacity by proper road design, by vehicles fitted with ways to simplify the tasks of man and constructed to protect the vulnerable human being as effectively as possible, and by road users who are adequately educated, informed, and, where necessary, controlled. If crashes still do occur, serious injuries must be excluded. The vision Sustainable Safety has been translated into a set of characteristics and into Sustainable Safety principles.

Sustainable Safety was welcomed by Dutch road safety professionals and received great political support. A massive implementation program was initiated and carried out as from 1995. Many stakeholders were engaged. An evaluation study covering the period 1998–2007 revealed a 30% reduction in the number of fatalities. Benefits of the investments were four times higher than costs. Sustainable Safety empowered and strengthened the Dutch road safety research community and heavily influenced the discourse on road safety in the country.

As from 2000, several developments (a different planning structure of road transport, less political priority for road safety – perhaps as a result of successes in the past – and decentralization of policies) caused that Sustainable Safety became less prominent and safety effects less visible. However, the vison and the principles remain a solid basis for making progress towards a casualty-free road transport system and to respond to new developments, such as a changing demography, changing transport modes and traffic patterns, and new technologies. Two more editions have been published (2005 and 2018). Results and impacts are being discussed.

Keywords

Safe system approach · Crash causation · Safe system principles · The Netherlands · Implementation

Introduction

The rapid reconstruction of the Netherlands after World War II was accompanied by an annual economy growth of about 4% (1950–1975). A similar growth was also to be observed in other Western European countries. This prosperity growth was accompanied by a growth in car mobility. On a population of ten million, the number of passenger cars increased from about 150,000 in 1950 to 500,000 in 1960, and to nearly 2.5 million vehicles on a 13 million population in 1970 (Harris 1989). The number of cars has now grown to 8.5 million, which means that 1 in 2 people in the Netherlands owns and drives a car.

In the twentieth century, the main transport modes in the Netherlands were cycling, walking, or public transport, but gradually the car took over public space.

The Netherlands has traditionally been a bicycle country and now has more bicycles than inhabitants: there are 23 million bicycles on a 17 million population. Almost 40% of the bicycle kilometers are for recreation and sport; the remaining more than 60% are for commuting, cycling to and from school (the vast majority of high school students – 12–18 years old – cycle to school), and for shopping (Harms and Kansen 2018). In 1950, one in two Dutch people owned a bicycle and that share remained constant until well into the 1960s. The passenger car became increasingly popular during this period and displaced the bicycle. Somewhat exaggerated we could say that in the 1960s, the bicycle was only used by those who could not or were not allowed to drive a car: school children, housewives, elderly, and those who did not (yet) have a driving license.

The growing popularity of the car led to a demand for more space for cars. This was found in expanding the street and road network, particularly the extension of the motorway network. The length of the motorway network enjoyed explosive growth and, in the densely populated Netherlands, is longer per square kilometer more than anywhere in the world. After the British motorways, the motorways in the Netherlands are the most heavily used worldwide.

But remarkably, public space being increasingly dominated by passenger cars led to a social reaction as early as the early 1970s. The car required more space (for driving and parking), but in the historic cities of the Netherlands (which experienced spectacular growth in the seventeenth century, when the Netherlands was an economic and political "world power"), the extra physical space could hardly be found and citizens were increasingly opposed to making the necessary changes. The tension between traffic and livability in towns and villages became an issue. It was the period in which civil society organizations did not want to subject to the passenger car becoming increasingly dominant, at the expense of the space for cyclist and pedestrian. Organizations dedicated to making school routes and the school environment safer could count on strong support. It was the period when cities prioritized the use of public transport and a start was made with the construction of tram and bus lanes. It was the period when "woonerf's" were created in the Netherlands, later followed by traffic calming (30 km/h) zones. The social developments outlined here were certainly not dominated by road safety considerations, but they certainly played a role.

Recent decades have been characterized by further growth in mobility, although the growth rate has fallen significantly and we observe hardly any growth in the last decade (KiM 2019). Congestion, particularly on the motorways, is perceived as worrying, but by citizens do not consider congestion as a major problem in Dutch society (KiM 2020). The Netherlands is a country of cyclists with more bicycles (23 million) than inhabitants (17 million). More than 25% of all trips are cycle trips (Harms and Kansen 2018). Separate cycling facilities are very popular and the expansion of these facilities, both within and outside cities, is impressive (Harms and Kansen 2018). Use of public transport was growing with 10% between 2010 and 2018 (KiM 2019). Freight transport by road increased dramatically over the years, with, for example, by almost 50% in kilometers travelled between 1999 and 2008 (Tavasszy and Ruijgrok 2013) and 12% between 2010 and 2018 (KiM 2019).

This is the context in which the history of road safety in the Netherlands is studied: a country with high population density, a high-quality and greatly expanded road infrastructure, where the available space is shared by motorized traffic, vulnerable road users (pedestrians and cyclists), and public transport. Road congestion, environmental problems (emissions and noise), and road safety require political attention and funding. This chapter discusses road safety development in this drastically changing road transport environment in recent decades.

This chapter starts with a brief outline of road safety in the Netherlands. We will then go deeper into the causes of road crashes as an introduction (and explanation) of the Netherlands opting for a Safe System approach in the late 1980s/early 1990s. In the Netherlands, the name Sustainable Safety was given to this approach. The Sustainable Safety vision will then be discussed according to the three editions of the vision that have so far been developed and published (1992, 2005/2006, and 2018). The development, as well as the implementation and evaluation results of the vision will be discussed. The chapter concludes with a reflection on almost 30 years of Sustainable Safety in the Netherlands.

Road Safety in the Netherlands: A Success Story

The number of road fatalities increased from about 1000 road deaths in 1950 to 3264 fatalities in 1972, a record height. This negative development was certainly cause for concern in Dutch society. It is striking that it was not the government that called for action, but civil society organizations, particularly the Dutch Touring Club ANWB (Bax 2011). The government did not join until later. This striking phenomenon is not so easy to explain. The following reasoning may, however, be plausible: the growth of motorization was considered a positive development because it went hand in hand with an intended growth of prosperity and well-being among the Dutch population. Negative consequences such as the growth in the number of road crashes and the number of road casualties were considered an unavoidable price that had to be paid.

In addition, there may have been another argument for the government not to intervene. It was generally accepted that road crashes were dramatic, but exceptional incidents, the cause of which was to be found mainly in humans who were inattentive and careless. More careful behavior was believed to result in fewer crashes (Asmussen 1983). Campaigns were used to call on the Dutch road user to act as "A gentleman in traffic" and thus to contribute to reducing the number of road casualties. Until the 1970s, a classic difference of understanding can be observed between "left-wing" and "right-wing" politicians: the political "right" primarily considered road crashes as a responsibility of the individual. Policy should call on road users to take that responsibility using laws and regulations and their enforcement. There was limited need for intervention from the government. The political "left" saw road crashes as a problem for vulnerable citizens (pedestrians and cyclists) who suffered from the behavior of "strong road users," mainly drivers of passenger vehicles.

In the 1960s and 1970s, the scale of the problem of road safety certainly became clear in the Netherlands and a multitude of activities were developed to improve the

situation. It is remarkable, however, that in a comparison between Sweden, the United Kingdom, and the Netherlands (the SUN countries, the best-performing countries in the world in the field of road safety) which was carried out in the SUNflower project (Koornstra et al. 2002), the Netherlands had a mortality rate of around 25 road deaths per 100,000 inhabitants and Sweden and the United Kingdom of around 15. This difference was eliminated in the following 20 years. There are a couple of possible explanations: the Netherlands was rather late to improve road safety or, secondly, road safety policy in the period 1970–1990 was more successful in the Netherlands than in both other countries. We tend to the first explanation, but whatever the explanation: in the period 1970–1990, the number of road deaths, mortality (deaths per 100,000 inhabitants), and traffic risk (deaths per motor vehicle-kms travelled) decreased significantly (60% fewer annual road deaths in 20 years). A third explanation, however, might be that the introduction of mandatory helmet use for riders of motorized two-wheelers (1972/1975) reduced not only the risk to be injured but also the exposure. In a relatively short period of time, the number of mopeds decreased with two-thirds, as did the number of moped fatalities (SWOV 2007).

During the same period (1970–1990), the policy interest in road safety increased considerably which was mainly reflected in a substantial amount of legislation (alcohol, speed limits, seat belts, helmets for motorcyclists and moped riders). A separate Road Safety Agency was set up at the national level, after an initiative from Dutch Parliament, a Road Crash Registration Department was established within that Agency and an independent Road Safety Council, led by Prof. Pieter van Vollenhoven, was established. Through an annual government subsidy, SWOV also acquired considerable leverage and acted as a driving force to support road safety policies.

In the late 1980s, however, the decrease in the number of road deaths did not continue and new initiatives were considered necessary. The national government drew up strategic plans with great frequency. It is worth noting that one of those plans announced that it was necessary to work with a quantitative target (−25% for the period 1985–2000). Not much later, it was decided to aim for −50% in the period 1986–2010. Road safety was on the rise in the Netherlands. In 1989, a book (Wegman et al. 1989) was published which drew up the balance of a large number of road safety issues. It also indicated where further profits could be made. However, one of the comments was that these were all isolated road safety issues and proposed measures that lacked a fundamental understanding of road crashes. Road safety plans at the time were basically a long list of individual measures and interventions. There was no cohesion between the various road safety issues and interventions and they also lacked a general vision of how proposed measures could be effectively implemented.

In this period (the late 1980s), road safety was given less policy priority by the Dutch government. This might be related to the impressive reduction in the number of road casualties in the 1970s/1980s after which policy attention could shift and actually did shift to other issues, such as combating congestion. In an interview in the staff magazine of the Ministry of Transport and Water Management in May 1992, the

then director of road safety in the Netherlands, Paul Hamelynck, says: "In the notes and speeches that end up on my desk, my field gets too little attention. In a whole series of notes on traffic and transport, I didn't even once come across the word road safety."

SWOV Institute for Road Safety Research was then invited by the Ministry's Road Safety Agency to develop a new vision for a road safety approach. Three issues were to be central to this vision: an in-depth analysis of why traffic leads to so many annual traffic casualties (numbers that are considered unacceptable in other transport modes such as rail transport and aviation), a vision of what significantly safer road traffic might look like, and, finally, along which lines that significantly safer road traffic could be established. Informal contacts with Swedish colleagues working on Vision Zero was a source of inspiration for both countries.

SWOV decided not to carry out this work by itself but enlisted the help of other researchers. Practitioners and representatives of government and interest organizations were invited to support this process. And together, they created a first version of a "System Approach" for road safety. The published book was named "Naar een Duurzaam Veilig Wegverkeer; Nationale verkeersveiligheidsverkenning 1990/2010" (Towards a Sustainably Safe Road Traffic; National Road Safety Outlook 1990/2010). The book was also referred to as the "Purple book," due to the color of the cover. During the years 1990/1992, a large number of people worked on this book, and it was published on the occasion of SWOV's 30th anniversary. It is noteworthy that the Road Safety Policy Plan which was released in 1991 (note, one year earlier!) introduced Sustainable Safety as one of the policy pillars, alongside six traditional spearheads for policy (driving under the influence of alcohol, safety devices such as seatbelts, airbags, child seats, and crash helmets, speed, hazardous situations (high-risk locations), cyclists, and heavy traffic). The authors of the Policy Plan could take a sneak preview!!

Before introducing Sustainable Safety, it is useful to take a closer look at how crash causation was looked at over the years, also in the perspective of crash prevention. This is of interest because Sustainable Safety set out to introduce a new way of thinking about crash causation and crash and injury prevention, based on literature on risk management (for example, by Jens Rasmussen) and human factors (Reason 1990). In the course of the previous century, the thoughts on road crash causation did certainly not remain unchanged. Thinking about this was crucial in developing the new vision.

Causes of Crashes

A rather comprehensive description of various road safety paradigms in the twentieth century can be found in an OECD report (OECD 1997). The concept of paradigms and paradigm shifts has been introduced by Thomas Kuhn in his 1962 publication "The Structure of Scientific Revolutions" (Kuhn 1962). He defines a paradigm shift as a fundamental change in the basic concepts and experimental practices of a scientific discipline. The concept of paradigm shift is certainly

applicable when it comes to road safety. The OECD paradigms for road safety were later used in, for example, a history of road safety research (Hagenzieker et al. 2014; Hakkert and Gitelman 2014). The OECD classification has also been supplemented in order to characterize crash causation as used in road safety policies over a certain period of time. The four paradigms in the OECD report are: (1) crashes as chance phenomenon, (2) crashes caused by the crash-prone, (3) crashes are monocausal, and (4) crashes are multicausal. Two paradigms were added to these original four (Wegman et al. 2007): (5) "the road user is the weakest link and road user behaviour can be changed by education/enforcement." The sixth paradigm is the Safe System's management perspective.

According to the OECD report (1997), early last century road crashes were considered an unfortunate incident in which the person concerned had the misfortune to be involved in a crash. Attempts were hardly made to prevent crashes. In the following period (1920–1950), crashes were attributed to persons who were unfit for traffic participation. The notion of crash-prone drivers was introduced and road safety improvement was considered a matter of making this (small) group of road users perform better. From 1950 onwards, the perspective was widened with the notion that crashes were the consequence of one single cause: either the road user, or the vehicle or the road. From 1960, it was increasingly being recognized that multiple causes can play a role in one crash and that crashes and injuries can be prevented by taking all possibilities into consideration. From the 1970s, a revival of "the road user is the weakest link" could be observed and more training, education, and enforcement of rules were believed to be the solution. This also contributed to a more integral approach being followed from 1990 onward: multiple crash causes and multiple possibilities to intervene. Adapting the "road traffic system" to humans and not, vice versa, trying to adapt humans to the system was more central in this approach. Johnston et al. (2014) suggests that these different paradigms reflect how a society feels about road crashes and road safety.

Not only the culture of a society is embedded in these paradigms, they also reflect the knowledge present or, perhaps better, the lack of knowledge. Knowledge is acquired from research and crash analyses. They provide a number of ways to detect crash causes (e.g., Shinar 2019). Data collected by the police after a crash is frequently used to assess crash causes. It must, however, be noted that the police task is not really to determine the causes of a crash, but to determine whether and to what extent a traffic offence has been committed (illegal behavior) and who was the guilty or the innocent party in the crash or the (vulnerable) party that is extra protected by law. This information is also used to determine whether behavior was inappropriate and if a person involved could be held liable for the crash consequences. Therefore, it is not surprising that "human error" emerged as a cause in the databases based on police registration of crashes: more than 90% of crashes involved a human error. This approach is sometimes called "a blame the victim-approach," and this view on crashes is a rather dominant and stubborn view (source).

This view on crash causation was reinforced by two in-depth studies from the 1970s, one from the United States and the other from the United Kingdom. Both are much quoted to this day when it comes to causes of crashes. Rumar (1985) presented

the results of both studies side by side and they are surprisingly similar (in 94–95% of crashes the human factor is involved, in 28–34% the road is involved, and in 8–12% the vehicle is involved). These findings are surprising, because the two research teams did not use the same definitions and studied crashes in rather different situations. These results seriously contributed to the often heard statement: "almost all crashes are caused by road users, and roads and vehicles play only a minor role."

Present in-depth studies, however, look not only at the events just before and at the time of a crash, they also try to consider the context of a crash and to understand the underlying circumstances. This perspective is rather common when analyzing industrial safety or, for example, causes of shipping and aviation crashes (Davidse 2003). This perspective tries to understand human behavior and, if opportune, human error. Road crashes are not the result of a series of unsafe road user actions but also of gaps in the traffic system. These gaps are also called latent errors (Reason 1990). This also led to the understanding that if a human factor is found as a cause, a solution is not necessarily found in humans, but in the surroundings of humans (Hauer 2020). For example, a head-on collision on a motorway due to fatigue can be prevented by an adequate median.

In addition to knowledge about the causes of road crashes, another dimension is relevant to conclude whether an idea develops into a road safety paradigm: expectations about the possibility of using policy to eliminate or mitigate causes of crashes. Dutch researchers made important contributions to the international discussions on the causes and the prevention of road crashes.

Erik Asmussen, SWOV's first managing director, was one of the first road safety professionals in the Netherlands who considered unsafe traffic conditions not to be only a problem of the individual road user, but as a problem of the road traffic system. Asmussen (1983) and a scientific working group of the OECD (1984) he chaired built on the previous work of William Haddon. Haddon, the first director of the American National Highway Traffic Safety Administration, introduced a public health model within road safety. This model is known as the Haddon matrix (see, for example, Haddon Jr. 1972).

This matrix contains two axes: one axis for the crash process (pre-crash, crash, and post-crash), and the other axis for the components of road traffic: humans, vehicles, and roads. The matrix consists of three times three cells, and in each cell, road safety problems and/or solutions to those problems can be identified. The great value of the Haddon matrix is that it describes the entire playing field of road safety and not just the field (humans) in which until then problems and solutions were described: the cell "pre-crash – humans."

Asmussen spoke of a dynamic system approach (he used "the phase model" describing how transport and traffic processes, which can result in crashes, and the crash process are regarded as a chronological – the dynamic aspect – complex of successive, increasingly critical combinations of circumstances and events) which he considered to be a tool to structure the road safety phenomenon. In his approach, Asmussen also discarded the idea that crashes have just one cause or solution: road crashes are the result of a combination of factors. If these factors reach a decisive point, a crash will occur. SWOV had already acquired this insight in the 1970s.

Another SWOV researcher, Matthijs Koornstra, the second SWOV managing director, also discarded the idea that road crashes were mainly caused by crash-prone road users. In an analysis, Koornstra (1978) showed that there are no crash-prone road users, but that one may refer to unlucky persons.

This evolution of road safety paradigms discussed in this paragraph is important to understanding the considerations regarding the Safe System approach; after all, the Safe System approach can be seen as the last in a series of paradigms until now. In addition to Matthijs Koornstra, Fred Wegman, SWOV's third managing director, also played a role in the development of the Safe System approach together with Letty Aarts, and more specifically in this new paradigm being further elaborated and accepted as a basis for road safety policy in the Netherlands.

Peter van der Knaap, the managing director since 2013-2021, set out to revitalize the by then 25-years-old approach. Building upon the evident successes and good benefit-cost ratios, together with Letty Aarts, he put special emphasis on the notion of "system responsibility" and the need for continuous policy-oriented learning, including the use of new data (see also Van der Knaap 2017).

This evolution in paradigms, or paradigm shifts, is important to understand the paradigm shift towards the most recent one: Safe System approach.

Start of the Dutch Safe System Approach: Sustainable Safety. National Road Safety Outlook for 1990–2010

As explained before, several good reasons emerged in the late 1980s to develop a new road safety strategy for the Netherlands based on a new paradigm. First of all, there was a strong ambition to further reduce the number of road fatalities, as expressed in road safety targets: minus 25% fatalities in 2000 (compared with 1985) and minus 50% fatalities resp. minus 40% hospitalizations in 2010 (compared with 1986). Secondly, the downward trend was not that impressive anymore and it was concluded that the 2000-target could not be reached by simply extrapolating trends. Thirdly, it was not expected that the then current set of additional measures and interventions would be sufficient to reach road safety targets. And last but not least, Dutch road safety professionals, more specifically the research community, supported the view that we could not rely anymore on the dominant view at the time: "to blame the road user for a crash and to carry out further training and education to reduce road risks."

The road safety research community developed a new road safety vision for the Netherlands under the leadership of SWOV-researchers (Koornstra et al. 1992). This report is also called "the Purple book." Two elements in this attempt were critical. The research community agreed on a new vision. Secondly, close contacts were established with road safety policy makers and practitioners in order to have them on-board while developing the new vision. As a consequence, we could observe positive responses to this new initiative: a willingness among policymakers to work with the results of this work and the work was welcomed by politicians, by the

professional community, by representatives of all tiers of government, and by interest groups.

The choice was made to name the new vision *Sustainable Safety*. This was not the first name to be considered. Initially two working names featured: "inherently safe" and "intrinsically safe." These "safety by design" approaches (avoiding hazards instead of controlling them) were seen as appropriate for road traffic as well. However, these terms were considered as too technocratic to be sufficiently appealing for this paradigm shift. Several Dutch politicians whispered Sustainable Safety in our ears as a strong brand name for this new approach. This was at the time that "sustainability" was a notion for the forefront of the environmental movement only!

The objective of Sustainable Safety is to prevent road crashes from happening, and where this is not feasible (yet), to reduce the incidence of (serious) injury whenever possible. This can be achieved by a proactive approach in which human characteristics are used as the starting point: a user-centric system approach. This approach refers on the one hand to human physical vulnerability to forces in crashes and on the other hand to human (cognitive) capacities and limitations.

The most important features of sustainably safe traffic are that gaps in the road transport system that result in human errors or traffic violations are prevented (as far as possible) and that road safety depends as little as possible on individual road user decisions. The responsibility for safe road use should not be placed solely on the shoulders of road users, but also on those of who are responsible for the design and operation of the various components of road traffic (infrastructure, vehicles, legislation/regulation). This means that a Sustainable Safe road traffic has an infrastructure that is adapted to the human limitations, vehicles that are designed to support road user tasks and to protect the human body in a crash, and road users that are adequately trained, informed, and when needed, controlled.

Three guiding principles were developed in "the Purple book" of 1991:

- Functionality of roads: monofunctionality of roads as through roads, distributor roads or access roads in a hierarchically structured road network and prevention of unintended road use.
- Homogeneity: equity in speed, direction, and mass at medium and high speeds in order to reduce levels of kinetic energy under tolerable levels for the human body.
- Predictability: predictability of the road course and road user behavior by recognizable road design using consistency and continuity as a design approach.

In order to prevent serious crashes on the road, the three guiding principles were operationalized into a set of practical principles which were used to design measures to be implemented. Large-scale implementation of these measures were realized through the Start-up Programme of Sustainable Safety (Ministerie van Verkeer en Waterstaat 1997).

It was evident that this new approach required a top-down approach to influence decisions of autonomous stakeholders, and a massive investment was envisaged, mainly in the road infrastructure. To illustrate this, we can use the predictability principle: if different road authorities treat similar design issues differently, road

Table 1 Distribution of road length of 30 km/h and 60 km/h in 1998, 2003, and 2008 (SWOV 2009)

	1998	2003	2008
Urban area			
30 km/h	8.900 (15%)	29.000 (45%)	50.300 (70%)
50 km/h	50.600 (85%	36.500 (55%)	21.600 (30%)
Total urban	59.600 (100%)	66.400 (100%)	71.900 (100%)
Rural area			
60 km/h	2100 (3%)	+/− 10.000 (15–20%)	35.400 (57%)
80 km/h	63.300 (97%)	54.000 (80–85%)	25.500 (43%)
Total rural (excl. motorways)	65.400 (100%)	64.000 (100%)	62.100 (100%)

users cannot predict from the road layout what to expect on the road's course. The idea behind the predictability principle is that road users are not aware of any difference between road authorities. Because hundreds of autonomous road authorities in the Netherlands design and maintain the road infrastructure, guidance must be given to road authorities as a binding legal instrument is not appropriate. Another approach was therefore chosen. It was decided to revisit all Dutch design manuals (with the exception of the manual for Dutch motorways) and, based on Sustainable Safety a couple of new design manuals for regional flow roads, for distributor roads and for access roads were developed (and published in Dutch by Knowledge Platform CROW in 2013). And Dutch road designers were found to use their design manuals!

The Dutch national government expressed a clear ambition to bring the Sustainable Safety ideas to implementation. Because the vision relied heavily on a better planned and designed road infrastructure, mainly for municipalities and provinces, the national government built a strong coalition with all road authorities. Furthermore, the national government was willing to co-fund investments to make existing roads and streets meet Sustainable Safety principles. Initial estimates indicated that a full treatment of the whole road network would cost dozens of billions of euro's, and this frightening perspective resulted in attempts to develop "low cost solutions." But it was not fully clear whether these low-cost solutions would be effective enough. Because of this, a three-step approach was designed: demonstration projects (for learning by doing), a Start-up Programme (the first couple of years of implementation, co-sponsored by the National Government), and a final phase of an integral and complete implementation (Ministerie van Verkeer en Waterstaat 1997).

After a couple of successful demonstration projects had been implemented, in 1997 an agreement for a so-called Start-up Programme Sustainable Safety was signed by the Association of Netherlands Municipalities, the Association of Waterboards, the Association of the Provinces of the Netherlands and the Ministry of Transport, representing all tiers of government and all road authorities. The agreement contained 24 measures and actions. The national government made a financial subsidy available and other governments were expected to supplement the subsidy with at least an equal amount. The Start-up Programme also contained an

outline of intentions concerning the decision-making process required for the second phase, a full-scale implementation of Sustainable Safety. However, this second phase did never get off the ground, due to reasons that are not related to road safety as such. It was decided to fundamentally change the relationship between the national government and provinces and municipalities resulting in decentralization of policymaking and implementation.

Many actions in the Start-up Programme were aimed at improving road infrastructure, more specifically at a functional categorization of the whole road network (functionality principle), guidelines on road type dependent road markings and the construction of 30 and 60 km/h zones. Furthermore, actions were taken related to enforcement, public campaigns, education, and vehicle safety (for an overview, see Weijermars and van Schagen 2009). Quite some attention in the Start-up Programme was spent on sharing information with road safety professionals. For example, an information point was established. This information point turned out to be a key-feature in supporting practitioners and was highly appreciated by them.

An example to illustrate the implementation process: during the period 1998–2002, which was extended in the years thereafter, nearly all road authorities drew up a categorization plan in which all roads and streets were functionally classified (first principle). Taking this as a starting point, it is estimated that more than 41,000 km of 30 km/h-roads and more than 33,000 of 60 km/h-roads were constructed (Weijermars and van Schagen 2009). See Table 1 for more details. Initially these streets and roads had a speed limit of 50 km/h or 80 km/h. This included not only a change in speed limit but also a redesign according to Sustainable Safety design principles. In other words, in 10 years time, a dramatic change in urban roads in Dutch cities and (secondary) rural roads took place. Traffic calming, not only urban but also rural, began to be the rule and not the exception in the Netherlands. A questionnaire study among road authorities (Doumen and Weijermars 2009) showed more about the quality aspects of implementing Sustainable Safety. The main conclusion was that a substantial amount of the redesigned roads met Sustainable Safety guidelines to a large extent, although further improvements were recommended to benefit fully from this approach to reduce the number of (serious) crashes.

Weijermars and Van Schagen (2009) assessed safety effects of individual measures and they also estimated combined effects (see also Weijermars and Wegman 2011). They compared actual developments on road fatalities (using police statistics) making use of an extrapolation scenario based on developments 1988–1997. The fatality rate (fatalities per kilometers travelled) dropped 5.3% per year between 1998 and 2007 compared to 1.8% in the 10 preceding years. Based on these earlier developments, fatality numbers in 2007 were about one-third lower than expected. A cost-benefit analysis revealed that the benefits were almost four times higher and all individual measures showed a benefit-cost ratio higher than one. Based on a comprehensive overview of the implemented interventions, the researchers made it plausible, that the fatality reduction was due to interventions that were derived from or inspired by Sustainable Safety.

It is worthwhile to notice that the set-up of the funding scheme for infrastructure, €200 million from the central government for a 4-years period, and raising the same amount from the other road authorities, worked excellently. A case study for the year 2007 (Wijnen and Stroeker 2009) revealed that on Sustainable Safe infrastructure €350 million (mean value per year) has been invested. Substantial amounts of money were also spent on safer vehicles and on police enforcement, and more limited amounts of money on public information, on education, and on research, advice, and policy. The estimate of infrastructure investments for a 10 years period (1998–2007) is 10 times €350 million, 3.5 billion euros. It is important to observe that these budgets were not "road safety earmarked" budgets, but regular budgets for road investments.

The main conclusion of the evaluation of its implementation was that Sustainable Safety was a great success: it resulted in a substantial reduction in the number of fatalities, considerable improvement of a major part of the Dutch road network, and in positive effects of increased and improved enforcement. For example, automated speed enforcement and enforcement on red light violations increased with more than a factor of three between 2001 and 2007 and violations went down most probably. Vehicle improvements also contributed to the success (SWOV 2009).

It is important to observe that interventions and measures were never targeted at the public as components of a road safety vision, but regular consultations took place with communities on interventions and measures. We limited the discussion on the vision Sustainable Safety to decision makers and road safety professionals. The interventions and measures, derived from and/or inspired by Sustainable Safety, were presented and discussed without generally disclosing the wider perspective of Sustainable Safety.

We learned a lot from the implementation of interventions and measures, and it is fair to say that several question marks arose. One example is the so-called "grey roads." The functionality principle proposes to give a road or street only one function to: access, distributor, or through function. However, sometimes it turned out to be inevitable to combine the access function and the distributor function. How to design for this combination, the "grey roads"? Another issue that arose: Sustainable Safety relied heavily on improving road infrastructure, but how about using modern (vehicle)technology instead of costly infrastructure investments? Could it be preferable to wait for new technologies?

Year after year the Start-up Programme was extended beyond the intended period 1997–2000 and as a consequence, the more fundamental decision what to do in the future was postponed. At that time, a couple of important developments occurred in Dutch public administration which led to issues far bigger than road safety. The national government decided to decentralize the implementation of policies to other tiers of government, such as provinces and municipalities. Furthermore, the Dutch government decided to move some tasks to civil society organizations and to the private sector. This was a major reform in Dutch society. In this process, the Dutch national government also delegated road safety tasks to other parties, but it became obvious that those who were supposed to take over these tasks were not yet prepared and equipped to do so. Hence, a period of uncertainty and ambiguity about the

implementation of road safety policies began. This period (the late 1990s) is characterized by a high level of ambition (ambitious road safety targets) and no clear ideas of how to realize the ambitions. In the first decade of the new millennium, it was therefore time to draft a second edition of Sustainable Safety trying to respond to these challenges and to new opportunities.

Advancing Sustainable Safety: National Road Safety Outlook for 2005–2020

Because unfortunately the Start-up Programme Sustainable Safety was not followed by a second phase, several new initiatives were developed. A collection of essays by experts was published in *Denkend over Duurzaam Veilig* (Thinking about Sustainable Safety) (Wegman and Aarts 2005). The Foreword title of this collection of essays, "Inspiration, commitment and synergy," reflected the spirit of that time. Sustainable Safety was considered to be a sound basis for future policy development on road safety and all authors of the book were in support of this. It was inspiring to learn about the many excellent recommendations, either based on the implementation so far, or anticipating on new opportunities, or just presenting creative new initiatives.

In the same year, a new "Purple book" titled *Door met Duurzaam Veilig* (Wegman and Aarts 2005) was published as the follow-up to *Naar een duurzaam veilig wegverkeer* (Towards Sustainable Road Traffic Safety) (Koornstra et al. 1992); the English translation *Advancing Sustainable Safety* was published in 2006. In this advanced edition, adaptations were made where necessary, based on what we had learned from our first steps towards a sustainably safe road traffic. The Sustainable Safety vision was also updated in accordance with new insights and developments. We chose a broader perspective for this book than we did in 1992. This broader perspective is justified, because we had been able to evaluate the results of our efforts to date. Moreover, there was high demand from practitioners to develop Sustainable Safety for specific problem areas or problem groups. Furthermore, the institutional settings for implementing governmental policies in the Netherlands, also for road safety, changed drastically (Wegman et al. 2008). Finally, this perspective offered the opportunity to "position" the vision again, to eliminate any misunderstandings and to create a new momentum for effective implementation.

The Dutch version of the second "Purple book" was presented to the Dutch Minister of Transport at the time, Mrs. Karla Peijs, and was welcomed by her. It is of crucial importance to notice that this book did not just address the Minister of Transport but also addressed representatives of institutions such as municipalities, provinces, water boards (road authorities in the western part of the Netherlands with an important road authority task), judicial authorities, police, car industry, etc.

We identified the following key approaches for this second edition (see also Wegman 2010):

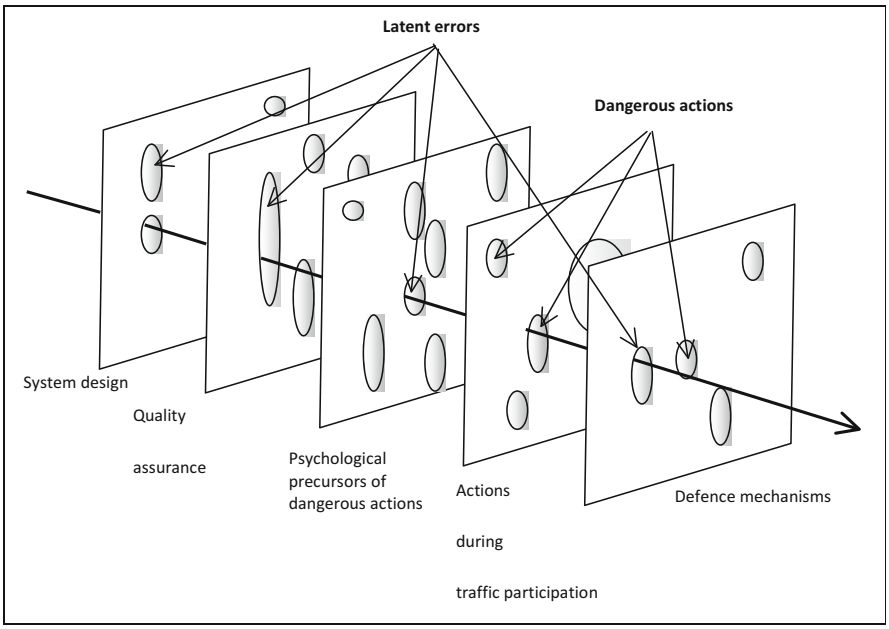

Fig. 1 Diagram showing the development of a crash (bold arrow) as a result of latent errors and unsafe actions in the different elements composing road traffic (based on Reason 1990). If the arrow encounters "resistance" at any moment, no crash will develop

- An ethical approach: we do not want to hand over a road traffic system to the next generation with the current casualty levels, but considerably lower ones.
- A proactive approach: we do not need to wait for crashes to occur before taking action, because we have a stock of knowledge that can be used.
- An integral approach: integrate man, vehicle, and road into one safe system; cover the whole network, all vehicles and all road users, and integrate with other policy areas.
- Man is the measure of all things: human capacities and limitations are the guiding factors together with the vulnerability of the human body in road crashes.
- Reduction of latent errors (system gaps) in the system: in preventing a crash we will not fully be dependent on whether or not a road user makes a mistake, commits an error or violation.
- Use criterion of preventable injuries: if we know the cause of a crash, if we know the cure, and if the cure is cost-beneficial for society.

As we illustrated earlier, 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; also gaps in the traffic system contribute to the fact that unsafe road user actions can result in a crash. These gaps are also called latent errors (Reason 1990). It is also known as the

Swiss cheese model of accident causation. The holes in the slices (of Swiss cheese) represent weaknesses. In summary: crashes occur when latent errors in the traffic system and unsafe actions during traffic participation coincide in a sequence of time and place (Fig. 1).

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 in the early 1980s made its entry 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 as "inherently safe" as the result of such an approach.

The fundamentals remained the same in the second edition of Sustainable Safety. The objective of Sustainable Safety was and remained to prevent road crashes from happening, and, where this is not feasible, to reduce the incidence of (serious) injuries whenever possible. This can be achieved by a proactive approach in which human characteristics are used as the starting point: a user-centric system approach. On the one hand, these characteristics refer to human physical vulnerability, and to human (cognitive) capacities and limitations on the other.

The principles of the first edition (functionality, homogeneity, and predictability) were reformulated where appropriate, and two new principle were added. This resulted in five principles:

- Functionality of roads.
- Homogeneity.
- Forgivingness (of the environment and other road users).
- Predictability (of the road course and road user behavior by recognizable road design).
- State awareness by the road user.

The forgivingness principle makes it possible to pay explicit attention to road side design and to the interaction between different types of road users. This "new principle" was in fact already embedded in the first edition of Sustainable Safety, but it is appropriate to position it explicitly.

The predictability principle, also already in the first edition, deals with a road environment and road user behavior which support road user expectations through consistency and continuity in road design. A road is self-explaining (Theeuwes and Godthelp 1993) if the design itself is made enough standardized and predictable. One of the main issues is to reduce speed variance between drivers, and also to minimize speed adaptation to prevailing conditions.

Table 2 Two visions on the implementation of Sustainable Safety

Implementation as rational programming	Implementation as co-ordination process in a multi-stakeholder setting
Sustainable safety is an effective concept that has to be implemented as completely and uniformly as possible.	Sustainable safety is not static. It is about realizing uniformity and an adequate adaptation in dialogue with executive organizations.
Central control is the best guarantee for a complete and uniform implementation.	Central control leads to adaptation problems and alienates potential partners, whereas central administration failed as an ally in the past.
Area-orientated policy and faceted policy are detrimental to uniform and complete implementation.	Area-orientated policy and faceted policy offer opportunities for adaptation of sustainable safety at decentralized level and proactive involvement of related policy areas.
Success is the extent to which the realized measures comply with the ideals of sustainable safety.	Success is comprised of road safety benefits relative to existing situations.
Research institutes contribute to the content of sustainable safety based on their scientific knowledge.	Knowledge about sustainable safety facilitates decentralized administrations and other actors in the preparation of measures with road safety impacts.

The state awareness principle is derived from the task-capability model as developed by Ray Fuller (Fuller 2005). In his model, Fuller compares road user task demands or task difficulty with the task capability to perform a task safely. Task capabilities is a combination of the competences of a road user minus the situation dependent state (for example, influenced by fatigue, distraction, impairment). Driving speed is the most distinctive factor in relation to decreasing or increasing task difficulty. The state awareness principle makes eliminating distraction, drinking and driving, fatigue, etc. explicit components of the Sustainable Safety approach.

The Dutch vision Advancing Sustainable Safety as presented by Wegman and Aarts (2005, 2006) has been translated in numerous ideas for practical proposals concerning road infrastructure, vehicles, intelligent transport systems, education, regulations and their enforcement, speed management, drink and drug driving, young and novice drivers, cyclists and pedestrians, motorized two-wheelers, and heavy goods vehicles.

The final part of the publication (Wegman and Aarts 2005, 2006) pays attention to various components of implementation. We learned a lot during the introduction of Sustainable Safety, and the new thoughts on organization of policy implementation, on quality assurance, on funding, and on accompanying policy are discussed in this part of the handbook.

The authors of the second edition acknowledged that, unlike the first edition, Sustainable Safety could no longer be regarded as the basis for a national road safety plan to be implemented. The environment changed with more decentralized responsibilities, with many different and more or less autonomous stakeholders and without a strong top-down push from the national government. Sustainable Safety was

expected to flourish more when used as a guiding concept for a multi-stakeholder setting. This different view on implementation did not really come about because the designers of Sustainable Safety expected better results. This was due to the fact that policy making and implementation, also in the field of road safety, changed because the Dutch public administration changed.

Decentralization became en vogue in the Netherlands some 20 years ago. Basically, this reform refers to the transfer of powers and responsibilities from the central government to elected authorities at a subnational level. The consequences for Sustainable Safety were huge. It resulted in an increase in mutual dependence between parties in the implementation context and it was necessary to base the implementation of the next phase of Sustainable Safety on the perspective of implementation as a coordination process in a multi-stakeholder environment, as presented in Table 2.

This new perspective became a very serious hurdle for road safety improvement and further implementation of Sustainable Safety. Decentralization is a major reform in many countries, such as the Netherlands, and certainly not a panacea for all problems in society. An OECD-report (OECD 2019) developed 10 guidelines for a successful implementation of decentralization, some of which were not met when decentralizing the implementation of road safety in the Netherlands. To name a few: no adequate subnational capacity building, insufficient funding for various road safety responsibilities, and no adequate coordination mechanisms across levels of government.

The next phase of Sustainable Safety did not come into being. A strong and leading Road Safety Agency was missing and moreover, at a regional and local level road safety professionals, who were familiar with Sustainable Safety, left because of budget reductions or because of (early) retirement. The assumption behind decentralization (more effective and efficient policies and implementation) failed to be true for road safety. Unfortunately, from a perspective of road safety, it is unavoidable and sad to conclude that Sustainable safety was not strong enough to survive in a climate of reduced political interest in road safety starting at the end of the first decade of the twenty-first century; there was no longer a decent “road safety plan.” Some people concluded that Sustainable Safety became a weary vision and something new was needed.

Sustainable Safety the Third Edition: The Advanced Vision for 2018–2030

In 2013 and 2014, the annual amount of road deaths in the Netherlands reached its lowest number since decades, and for the seriously injured, this point was reached in 2016. The years thereafter, however, the number of casualties increased. Furthermore, discussions were emerging about “who is responsible” for societal results such as safety. The question was raised whether people could be made more responsible for their contribution to societal needs, and this was illustrated in several examples such as citizens contributing to better neighborhoods. It was, however, maybe too

easy to put this idea further towards other domains such as road safety where the most recent insights were not to put the responsibility for crashes on the road user, but far more on the designers and operators of the road transport system This was also a general approach that got international support from road safety experts (ITF/OECD 2016). This development, together with the observation that still a number of effective measures were not yet implemented, provided the breeding ground for Sustainable Safety third edition.

The third edition of Sustainable Safety (SWOV 2018) builds upon the success of the earlier Sustainable Safety philosophy (Koornstra et al. 1992; Wegman and Aarts 2006) but aligns itself to several developments, such as the change in demography, increasing urbanization, and technological developments. In addition, ways were explored to "revitalize" the vision also inspired by discussions on the role of government, the role of citizens, civil society, and the private sector when it comes to relevant themes for society, like road safety.

International elaborations of what is considered as a "Safe System approach" (OECD/ITF 2008, 2016) also provided inspiration for the third edition of Sustainable Safety, for example, the concept of "responsibility." The third edition of Sustainable Safety makes use of new opportunities and recommends completion of several effective, yet unfinished measures with the ultimate aim to move towards a casualty-free traffic system. At a national level, the third edition of Sustainable Safety provided a substantiated framework for further development of the national road safety policy of the Netherlands as written down in the new Strategic Road Safety Plan (Ministry of Infrastructure and Water Management et al. 2018).

In brief, the following elements of the third edition can be highlighted:

- More focus on new and still frequently occurring serious crashes in the Netherlands, such as bicycle crashes without involvement of motorized traffic.
- A more explicit vision on what to accept in road traffic, what needs to be mitigated, and what needs to be eliminated.
- The road safety principles are more often linked to more than one type of measure (e.g., infrastructural measures and vehicle measures). They provide the opportunity to achieve similar results through a combination of complementary measures.
- The road safety principles are expanded and divided into three design principles and two organization principles.
- A more explicit emphasis on the specific responsibilities of different road safety stakeholders in realizing a sustainably safe road traffic system. Traffic professionals are crucial in this respect, even if the problem is the behavior of road users. Responsibilities are made more explicit in one of the organization principles, "effectively allocating responsibility," and in this respect links more clearly with the international vision of an inherently safe traffic approach.
- In order to better assist traffic professionals in making the traffic system structurally safer, not only are data on common crash types and casualties used as the basis of policy but also the use of surrogate safety measures in traffic (risk factors or road safety performance indicators, SPIs in short). The most important risk factors can serve as significant intermediate goals and offer deeper understanding

of the underlying problems. These risk factors are necessary for assigning roles and responsibilities to the various road safety stakeholders.

In the revised Sustainable Safety vision, the ideal for the future is to make road use as inherently safe as possible by taking into account the demands and possibilities of road users now and in the future. The vision acknowledges the mobility demands of various groups in our society, the importance of satisfactory accessibility by road, and the need for a personal freedom of choice. It is a fact that certain modes of transport are inherently less safe (i.e., two-wheeled vehicles) and certain road users are more prone to traffic injury than others (e.g., children, teenagers, elderly). With these facts as a starting point, Sustainable Safety's third edition aims at maximum safety for all, that is: as safe as possible.

To reach maximum safety, a Safe System approach builds on the following implementation stages, in accordance with the societal context:

- Elimination: ideally, dangerous situations are made physically impossible so that people do not find themselves in such situations.
- Minimization: the number of dangerous situations is limited, and certain modes of road transport are made unattractive to limit people's exposure to risks.
- Mitigation: where people are exposed to risks, their consequences should as far as possible be mitigated by taking appropriate mitigating measures.

The third edition of Sustainable Safety emphasizes that "the human dimension" is not only relevant in relation with human beings as road users but also in relation with the professionals who design, implement, and/or manage elements of the traffic system (roads, vehicles, information, control systems, etc.). The same human characteristics that apply when they are road users are also more or less valid when they act in a professional capacity. This implies that in the further development and maintenance of a Sustainable Safe system, it is necessary for the professionals to organize all the processes involved to take maximum account of the human dimension.

The elements of Sustainable Safety complement and reinforce one another, making it as fail-safe as possible. If one element in the system fails, it is to be substituted or compensated for by other elements. This applies for unsafe situations – such as temporary malfunctions – as well as for human behavior. It applies to the process of traffic participation as well as to the work processes of traffic professionals.

Road Safety Principles of the Third Edition

In the third edition of Sustainable Safety, five principles are essential: three design principles (1, 2, and 3) and two organization principles (4 and 5).

- Functionality of roads.
- (Bio)mechanics: Limiting differences in speed, direction, mass, and size, and giving road users appropriate protection

- Psychologics: Aligning the design of the road traffic environment with road user competencies.
- Effectively allocating responsibility.
- Learning and innovating in the traffic system.

The functionality of roads remains a solid basis for the vision, although the third edition pays attention to the earlier mentioned criticisms on, for instance, roads that do not fit well in a monofunctional approach (the so-called "grey roads"). Solutions are found in the concept of "safe speed" in case monofunctionality cannot be met.

The second design principle – (bio)mechanics – is a combination of the old principles of homogeneity (edition 1 and 2), physical forgivingness (edition 2), and new elements added that specifically apply to the safety of two-wheeled vehicles, especially bicycles. This last issue turned out to be a large and growing problem in road safety in the Netherlands. We discovered this by linking police data and hospital data to get a complete picture of "serious injuries" (SWOV 2019). According to the (bio)mechanics principle, ideally, traffic flows and transport modes ideally are compatible with respect to speed, direction, mass, size, and degree of protection. This is supported by the road design, the road environment, the vehicle, and, where necessary, additional protective devices. For two-wheeled vehicles, it is important that the road and the road environment contribute to the stability of the rider. Besides paying attention to the huge problem of single bicycle crashes in the Netherlands, this second design principle applies to infrastructure, speed, vehicle design, and protective devices.

The third and last design principle incorporates the old principle of predictability (edition 1 and 2) and state awareness (edition 2), and adds to it a number of other psychological issues which have turned out to be relevant for safe road user behavior. The principle of psychologics states that the design of the traffic system should be well-aligned with the general competencies and expectations of road users, particularly the elderly. This means that for them as well as others, the information provided by the traffic system is perceivable, understandable ("self-explaining"), credible, relevant, and feasible.

Nevertheless, road users should be capable to carry out their traffic task and should be able to adjust their behavior according to the task demands for safely participating in traffic under the prevailing circumstances. This applies for drivers (skilled and fit for the driving task) as well as for nonmotorized road users (skilled in dealing with traffic and fit to participate in traffic).

New in the third edition are principles for the organization of a Safe System. It starts with the principle of responsibility and states that this is allocated and institutionally embedded in such a way that it guarantees a maximum road safety result for each road user and optimally integrates with the inherent roles and motives of the parties involved. In principle, road users follow the rules and set a good example for children and teenagers. Thanks to a forgiving traffic system, road users will not be punished for their errors and weaknesses with crashes and serious injuries.

As the world changes continuously, this requires that a safe traffic system and the professionals who design, implement, and maintain the system to adequately adapt to these changes. Therefore, the last organizational principle of the third sustainable safety vision is about learning and innovating the traffic system. The Deming cycle is relevant here: it starts with the development of effective and preventive system innovations based on knowledge of causes of crashes and hazards (Plan). By implementing these innovations (Do), by monitoring their effectiveness (Check), and by making the necessary adjustments (Act), system innovation ultimately results in fewer crashes and casualties.

In order to design countermeasures that are feasible and practical, it is important to further operationalize principles into "Requirements for a Sustainably Safe Road Traffic System." In addition, it is also important to draw up a Sustainable Safety Knowledge and Research Agenda that will strengthen further development of Sustainable Safety.

A number of measures that fit in a Sustainable Safety are illustrated below.

Illustration 1: Exposure of vulnerable road users to motorized traffic where vulnerable road users share road space with motorized traffic, the road clearly has an exchange function (functionality principle). From the principle of (bio)mechanics, major differences in speed should be avoided. In order to prevent crashes with serious injuries, it is important that motorized traffic is limited to a maximum speed of 30 km/h. This can be realized by adapting road design, vehicle, information provision, and enforcement to these traffic conditions and to the needs of the prevailing road users' groups

Aim: Maximum speed of 30 km/h at locations where there is interaction between vulnerable road users and motorized traffic. Types of solution ranging from full freedom of choice, just informing to safety by design in relation to speeding behavior (and thus an increased level of Sustainable Safety):

- Mandatory open ISA (Intelligent Speed Adaptation) and fines: continuously inform motorized road users about the legal speed limit and fine them when they drive too fast.
- Credible road design: physically nudge motorized road users to maintain a maximum speed of 30 km/h by providing a road layout that is appropriate for no more than this speed. This can be achieved by limiting the length of tangents (straight road sections), by providing physical speed reduction measures (e.g., speed humps or raised junctions), a narrow cross-sectional profile, an uneven road surface, or by placing buildings or vegetation close to the road.
- Mandatory closed intelligent speed adaption: eliminate high speeds by limiting the speed of all motorized traffic to 30 km/h.

Illustration 2: Single-bicycle crashes. Cyclists form a significant proportion of the seriously injured traffic casualties, many of them being seriously injured in a single-vehicle (bicycle) crash. The bicycle infrastructure plays an important role in these single-bicycle crashes. In particular, obstacles (lack of forgivingness) and balance-disrupting road elements (combined in the principle of (bio)mechanics) are sources

of concern. To substantially reduce hazardous situations on the cycling infrastructure, special attention should be given to these crashes in the future

Aim: Cyclists do not fall, do not hit obstacles, and are physically protected in case something goes wrong. Types of solution within the traffic system and for the road user, again with an increasing amount of safety by design (less opportunity for unsafe choices) and thus an increasing level of Sustainable Safety:

- Physical protection of the cyclist: as long as the road infrastructure and the road environment do not offer sufficient protection against injuries in the event of a crash, protective cycling gear provides some level of protection to the cyclist.
- Obstacle-free, spacious, and skid-resistant bicycle infrastructure: create a bicycle infrastructure that is forgiving and therefore free from slippery substances (loose sand/gravel/leaves), obstacles, and vertical edges and ridges that can cause cyclists to lose their balance, fall, and injure themselves. Additionally, create a bicycle infrastructure that is wide enough to provide cyclists with the space for natural lateral movement and is sufficiently skid-resistant to prevent cyclists from skidding in bends.

Illustration 3: Distracted motor vehicle drivers, distraction among drivers, for instance, because of the use of the smartphone, contributes to a 3–4.5 times' higher crash risk compared to normal, undistracted driving. Causes and solutions are mainly found in the Sustainable Safety third edition principle of psychologics

Aim: Distraction of motorized vehicle drivers does not result in serious casualties. Types of solution with a decreasing amount of chances to make unsafe choices and consequently an increasing level of Sustainable Safety:

- Warning system: the car warns the driver against unsafe situations and gives priority to the most important information to prevent the driver from being overloaded with information.
- Restricting use of electronic devices: electronic non-traffic devices are automatically switched to a safe mode which prevents the driver from using them while behind the wheel. Other vehicle occupants can still use their devices.
- Autonomous (self-driving) vehicles: the vehicle undertakes the driving task without interference from occupants. The vehicle and related technology is programmed to safely deal with all types of traffic interactions. Vehicle occupants can engage in non-driving tasks, for example, reading a newspaper, operating a laptop, phoning, or participating in a meeting. The large-scale introduction of autonomous vehicles is not expected until 2030, but preparations for a safe operating system and the transition towards it are ongoing.

As we showed in this chapter, the third edition of Sustainable Safety builds on previously developed and shared principles, requirements, and measures. A primary recommendation is therefore also to complete what has proven to be effective. Past Sustainable Safety measures have had great success despite not being fully implemented. Examples of measures that should be finalized to have even more

effect are the full implementation of credible road layouts, sufficient separation of high-speed traffic (especially with vulnerable road users), and evidence-based education.

The third edition of the vision also provides a framework for elaboration, operational requirements, and measures that may be developed in the future or that already exist but cannot as yet be applied to accomplishing a sustainably safe road traffic. For example, policy makers may consider vehicle safety and protective measures, road and vehicle technology, responsibility of professionals and the role of education, regulation and enforcement for road safety professionals, as well as for road users. In other words: the Sustainable Safety vision incorporates and provides a framework for effectively dealing with new challenges and making effective use of new technologies.

The updated vision also looks back at the results that have already been achieved – fully or only partially. For instance, effective interventions focussed on the prevention of serious road injuries were insufficiently incorporated in the previous editions of Sustainable Safety. Also, further road safety improvements for vulnerable road users deserves more attention from the perspective of current insights. The problems encountered in the past stemming from the implementation of minimally designed 30 and 60 km/h zones should no longer impede the realization of maximum road safety. Road safety would also benefit from correcting flaws that stem from failing to sufficiently account for the human dimension as a basis for design and guidelines.

For the further implementation of a sustainably safe traffic system, it is beneficial to collaborate with other organizations and stakeholders. The elaboration of operational requirements clearly calls for collaboration with organizations that are active in the field of regulation, guidelines development, publication, and professional education, but also with interest groups representing groups such as motorists, cyclists, and traffic safety advocates. With respect to implementing measures, road authorities and other traffic professionals have the most important role. They are invited to reflect on how the updated vision may be relevant for their policy and how it may help them in taking new steps.

Current initiatives also offer opportunities in the Netherlands to implement a Sustainable Safe road traffic system. A number of civil society organizations invited the Dutch government to put road safety higher on the political agenda and proposed to make higher budgets available for road safety investments. The insight that investments in road safety measures are likely to be cost-beneficial and can contribute to stimulate economical developments is helpful here. The increasing numbers of people killed and seriously injured in Dutch traffic in recent years is considered as an undeniable signal. The Strategic Road Safety Plan 2030 (Ministerie van Infrastrutuur en Waterstaat et al. 2018) responded to this initiative and includes new directions such as a risk-based, proactive approach (based on the use of Safety Performance Indicators), the chain approach to implementation, and the reflection on the "governance" of road safety policy and ambitions to get to zero (serious and fatal) road

casualties. Sustainable Safety's third edition provides a framework to realize the formulated ambitions with maximum safety by adopting the following, most important policy aspects:

- Make clear choices when it concerns the functionality of roads.
- Take vulnerable road users as a basis from the perspective of (bio)mechanics.
- Adjust the traffic system to the competencies of the elderly.
- Further reflect on an effective allocation of responsibilities.
- Perform in-depth research into all fatal crashes and implement a risk-based approach with Safety Performance Indicators as the basis for learning and innovating.

Epilogue

We conclude this chapter with a couple of thoughts on looking back and looking forward.

Reflections on 30 Years Sustainable Safety

The Netherlands, along with Sweden, was one of the first countries to implement a Safe System approach. In 1992, the vision on a Sustainable Safety was conceptualized (Koornstra et al. 1992); in 1995, a small number of demonstration projects were launched; and in 1997, this culminated in the adoption of the Start-up Programme Sustainable Safety. The Start-up Programme was a milestone involving the adoption of a formal covenant, signed by all the public road authorities. Even before the formal adoption of the Sustainable Safety vision, and parallel to the Start-up Programme covenant, measures had been taken in the spirit of this vision, such as: building high-quality motorways, providing footpaths for pedestrians and separate bicycle tracks for cyclists. The Start-up Programme not only created a financial incentive for the further roll-out of Sustainable Safety measures, it also facilitated a coordinated approach to redress the growing road safety problems. Since implementation, these measures have proved to be cost-effective and reduced the number of road deaths. This systematic approach set an international example and certainly made a firm contribution to making the Netherlands a top-ranking player in the field of road safety.

In 2005, the second edition of the Sustainable Safety approach was presented with Advancing Sustainable Safety (Wegman and Aarts 2005, 2006). This generated renewed interest in the philosophy, partially attributable to two new principles: forgivingness and state awareness. Road authorities and policymakers continued with the implementation of measures in accordance with the outlines of the Start-up Programme. However, a lack of political priority for road safety, less effective coordination between different stakeholders and reduced resources prevented Sustainable Safety from being completed.

We have unfortunately seen that due to various developments (Weijermars et al. 2013), the number of road deaths has held constant and the number of serious road

injuries has been increasing. Evaluation results learned that implementing Sustainable Safety has been very successful in reducing the number of fatalities, but not successful in reducing the number of serious injuries, and more specifically in reducing the number of serious road injuries in crashes not involving motorized vehicles. Almost all of these seriously injured are cyclists (Weijermars et al. 2013). Because speed reduction is a key element of Sustainable Safety, it is not surprising that implementation is more effective in reducing fatalities than in reducing injuries. However, it is alarming that an increasing trend in single-cycling crashes has been observed. This leads to the important conclusion that the idea of forgiving infrastructure to prevent single-cycling crashes must be added to Sustainable Safety.

The need for a third edition of a Sustainable Safe road traffic (SWOV 2018) coincided with the increase of the number of road casualties. It tries to respond to developments regarding demography, urbanization, and technology, and national as well as international discussions on the organization of and responsibility for societal benefits such as road safety. The third edition gave room to these developments, making the vision "future proof" again, also by adding organizational principles like "effective allocation of responsibilities" and a renewal principle of "learning and innovating." The vision incorporated new insights based on an analysis of road crashes (e.g., single bicycle crashes causing a large number of serious injured) and taking especially the competencies of elderly road users as a reference point. The five principles of the third edition provide the framework for a casualty-free road traffic system the Dutch government is aiming for. At least, they are presented as such. The focus on a risk-based approach and making use of safety performance indicators (SPI's) may help in closing the gap between the vision and the pragmatic approach of a road safety plan. This process is expected to go on the coming years.

The Future of Sustainable Safety in the Netherlands

The third edition of Sustainable Safety is on its way. It is a matter of a stubborn continuation of effective measures and interventions and trying to reach "100%." Furthermore, it is a matter of trying to use new opportunities, especially those provided by technology: to prevent risky road use (fatigue, distraction, impairment), to support drivers to prevent dangerous behavior (application in enforcement), and to support in prevention of crashes by speed management. Three challenges lie ahead of us:

Challenge 1 – Decentralization: maintaining national standards and road layout uniformity. Since the early 2000s, decentralization has led to more tasks and responsibilities for local governments. One particular risk of decentralization is the loss of a uniform road layout and design.

Challenge 2 – Policy integration: discovering win-win opportunities for integrated policy initiatives while staying focussed on safety. Policy programs that work according to an integrated approach which not just includes road safety objectives but also objectives in, for instance, health, urban, and climate policies may yield substantial benefits. Whether or not these benefits are actually achieved depends on the quality of "connective" agenda setting and cooperation.

Challenge 3 – Wise spending: calculating the optimal cost-benefit ratio of the Safe System approach. Calculating the expected benefits of road safety investments ex ante can empower road authorities and other actors to make better investments in road safety. An even stronger "business case" for Sustainable Safety requires better evidence on the optimal results that (only) a well-designed use of infrastructural, technical, and behavioral measures can yield.

Sustainable Safety in International Perspective

Sustainable Safety is used in the Netherlands as a name for its Safe System approach. Vision Zero is the name chosen in Sweden and in many other countries. The OECD used Towards Zero (2008) and later "Zero road deaths and serious injuries." These different names do not really reflect major differences in approaches as the core idea how to reach these aims starts from the idea that the system needs to be tuned to the competences of traffic participants. It requires real understanding of the human component and how the system can deal with it safely. Whereas the Netherlands and Sweden were starters in developing a Safe System approach, other countries, regions, and cities have been showing a growing interest in developing their own version of a Safe System approach (OECD 2008, 2016). Four starting points have to be adapted everywhere: (1) people make errors, (2) the human body has a limited physical ability to tolerate crash forces before harm occurs, (3) improving road safety is a shared responsibility, and (4) all parts of the road transport system must be strengthened, and if one part fails users are still protected (OECD 2016). Many policy documents in the world use Safe System or Vision Zero in their name these days; however, the presented measures and interventions are not always really reflecting the genes of Safe System thinking. That is confusing.

Differences in conceptualization of the Safe System approach in practices and tools and in Safe System management between countries can be observed. Speed management is a key principle for Safe System and takes literally a very central role in the Australian approach (safe roads, safe vehicles, safe people, and safe speeds). These differences basically reflect differences in "structure and culture" between countries (see also Koornstra et al. 2002) and perhaps differences in "taste" of policy designers. Further (evaluation) research have to show us how these differences affect road safety.

Sustainable Safety: Fourth Edition or a Next Paradigm?

The current paradigm in road safety – Sustainable Safety as an example of a Safe System approach – has a solid basis in scientific knowledge and recognizes that the responsibilities to make road traffic truly safe (without serious injuries) is shared between individuals and a wide range of stakeholders. The individual road users remain a critical part. But a key feature of the Safe System approach is not to blame the road user when failing to behave safe. The Haddon matrix (1972) clearly depicts the many areas and fields to improve road safety. And it is a given that many different (autonomous!) stakeholders have responsibilities, not just different tiers of government, but also the private sector and civil society. As long as individual road users make decisions in traffic and the context of these decisions will be shaped by the

many stakeholders involved, the Safe System approach will remain a valid and effective approach. Strong leadership and institutional management remain needed.

Of course, Sustainable Safety have to adapt itself to new developments and opportunities in society. From this perspective we conclude that Sustainable Safety 4.0 is sooner to be expected than a paradigm shift. If a game changer like self-driving vehicles ("level 4 or 5 of driving automation") will be a reality, the question will be answered differently, perhaps. If we will ever reach that state in the Netherlands with the many bicycles everywhere, is still questionable. Time will learn.

References

Asmussen, E. (1983). *Van "heer in het verkeer" naar "beheerst verkeer"* (From a gentleman in traffic to controlled traffic). Delft: Inaugural speech. Delftse Universitaire Pers.

Bax, C. (2011). *Processes and patterns. The utilisation of knowledge in Dutch road safety policy.* Leidschendam: SWOV.

Davidse, R. J. (2003). *Op zoek naar oorzaken van ongevallen: lessen uit diverse veiligheidsdisciplines* ((Looking for causes of accidents: lessons from various safety disciplines). R-2003-19 [in Dutch]). Leidschendam: SWOV.

Doumen, M. J. A., & Weijermars, W. A. M. (2009). *Hoe Duurzaam Veilig zijn de Nederlandse wegen ingericht?* (Een vragenlijst studie onder wegbeheerders (How sustainable safe is the design of Dutch roads? Questionnaire studies among road authorities). D-2009-5 [in Dutch]). Leidschendam: SWOV.

Fuller, R. (2005). Towards a general theory of driver behaviour. *Accident Analysis & Prevention, 37*(3), 461–472.

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

Hagenzieker, M. P., Commandeur, J. J. F., & Bijleveld, F. D. (2014). The history of road safety research: A quantitative approach. *Transportation Research Part F, 25*, 150–162.

Hakkert, A. S., & Gitelman, V. (2014). Thinking about the history of road safety research: Past achievements and future challenges. *Transportation Research Part F, 25*, 137–149.

Harms, L., & Kansen, M. (2018). *Fietsfeiten. (Facts on bicycling). [in Dutch] Ministerie van Infrastructuur en Waterstaat*. Den Haag: Kennisinstituut voor Mobiliteitsbeleid KiM.

Harris, S. (1989). Eerst meer, toen minder; een historisch overzicht. [first more, then less; a historical overview]. In F. C. M. Wegman, M. P. M. Mathijssen, & M. J. Koornstra (Eds.), *Voor alle veiligheid: bijdragen aan de bevordering van de verkeersveiligheid* (pp. 9–18). 's-Gravenhage: SDU uitgeverij.

Hauer, E. (2020). Crash causation and prevention. *Accident Analysis & Prevention, 143*, 105528.

ITF/OECD. (2008). *Towards zero; ambitious road safety targets and the safe system approach*. Paris: International Transport Forum/OECD Publishing.

ITF/OECD. (2016). *Zero road deaths and serious injuries; leading a paradigm shift to a safe system*. Paris: International Transport Forum/OECD Publishing.

Johnston, I. R., Muir, C., & Howard, E. W. (2014). *Eliminating serious injury and death from road transport. A crisis of complacency.* Boca Raton: CRC Press\Taylor & Francis Group.

KiM Kennisinstituut voor Mobiliteitsbeleid [KiM Netherlands Institute for transport Policy Analysis]. *Mobiliteitsbeeld 2019. Ministerie van Infrastructuur en Waterstaat*. Den Haag: Kennisinstituut voor Mobiliteitsbeleid KiM.

Koornstra, M. J. (1978). Pechvogels en brokkenmakers. (Unlucky person and crash prone persons). In W. A. Wagenaar, P. A. Vroon, & W. H. Janssen (Eds.), *Proeven op de som. Psychonomie in het dagelijks leven* (pp. 148–162). Deventer: Van Loghum Slaterus.

Koornstra, M. J., Mathijssen, M. P. M., Mulder, J. A. G., Roszbach, R., & Wegman, F. C. M. (1992). *Naar een duurzaam veilig wegverkeer: Nationale Verkeersveiligheidsverkenning voor de jaren 1990/2010*. Leidschendam: SWOV. The Netherlands [Towards a sustainably safe road traffic: National road safety outlook for 1990/2010; in Dutch].

Koornstra, M., Lynam, D., Nilsson, G., Noordzij, P., Pettersson, H.-E., Wegman, F., & Wouters, P. (2002). *SUNflower: A comparative study of the development of road safety in Sweden, the United Kingdom and the Netherlands*. Leidschendam: SWOV.

Kuhn, T. (1962). *The structure of scientific revolutions. Phoenix books*. Chicago: The University of Chicago Press.

Ministerie van Verkeer en Waterstaat. (1997). *Aan de start* (Startprogramma Duurzaam Veilig Verkeer 1997–2000. Populaire versie van de intentieverklaring. (Go to the start. Starting-up programma Sustainable Safety 1997–2000) [in Dutch]). Den Haag: Ministerie van Verkeer en Waterstaat.

Ministerie van Infrastructuur en Waterstaat, Ministerie, v. J. V., Interprovinciaal overleg (IPO), Vereniging van Nederlandse Gemeenten (VNG), et al. (2018). *Veilig van deur tot deur* (Het Strategisch Plan Verkeersveiligheid 2030: Een gezamenlijke visie op aanpak verkeersveiligheidsbeleid. (Safe from door to door) [in Dutch]). Den Haag: Ministerie van Infrastructuur en Waterstaat.

OECD. (1984). *Integrated road safety programmes. Report pepared by a scientific expert group*. Paris: OECD.

OECD. (1997). *Road transport research: Outlook 2000*. Paris: OECD.

OECD. (2019). *Making decentralisation work. A handbook for policymakers*. Paris: OECD.

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

Rumar, K. (1985). The role of perceptual and cognitive filters in observed behaviour. In L. Evans & R. C. Schwing (Eds.), *Human behavior and traffic safety* (pp. 151–165). New York: Plenum Press.

Shinar, D. (2019). Crash causes, countermeasures, and safety policy implications. *Accident Analysis & Prevention, 125*, 224–231.

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

SWOV. (2009). *De balans opgemaakt* (Duurzaam Veilig 1998–2007. (The balance struck. Sustainable Safety in the Netherlands 1988–2007) [in Dutch]). Leidschendam: SWOV.

SWOV. (2018). *Sustainable safety 3rd edition – The advanced vision for 2018–2030. Principles for design and organization of a casualty-free road traffic system*. The Hague: SWOV.

SWOV. (2019). *Serious road injuries in the Netherlands. SWOV fact sheet*. The Hague: SWOV.

Tavasszy, L., & Ruijgrok, K. (2013). Freight transport demand: Indicators, determinants and drivers of change. In B. Van Wee, J.-A. Annema, & D. Banister (Eds.), *The transport system and transport policy. An introduction*. Cheltenham: Edward Elgar Publishing Limited.

Theeuwes, J., & Godthelp, H. (1993). Self-explaining roads. In J. L. Kroes & J. A. Stoop (Eds.), *Safety of transportation*. Delft: Delft University Press.

Van der Knaap, P. (2017). Positive evaluation and learing: Looking for 'success' in Netherlands road safety policy. *Evaluation, 23*(4), 432–443.

Wegman, F. (2010). *Putting people at the Centre: How to improve road safety in the 21st century? The 20th Westminster lecture on transport safety. Parliamentary Advisory Council Safety.* London: PACTS.

Wegman, F & Aarts, L. (red.) (2005). *Denkend over Duurzaam Veilig (thinking about sustainable safety)* [in Dutch]. Leidschendam: SWOV.

Wegman, F., & Aarts, L. (Eds.). (2006). *Advancing sustainable safety: National Road Safety Outlook for 2005–2020*. Leidschendam: SWOV.

Wegman, F. C. M., Mathijssen, M. P. M., & Koornstra, M. J. (1989). *Voor alle veiligheid. Bijdragen aan de bevordering van de verkeersveiligheid* (For everyone's safety. Contributions to improving road safety). 's-Gravenhage: SDU uitgeverij.

Wegman, F., Johnston, I., Kroj, R., & Pain, R. (2007). *Road traffic safety research and education in Israel*. Ramat Hasharon: The Ran Naor Foundation for the advancement of road safety research.

Wegman, F., Aarts, L., & Bax, C. (2008). Advancing sustainable safety. National road safety oulook for the Netherlands for 2005-2020. *Safety Science, 46*, 323–343.

Weijermars, W. A. M. & van Schagen I.N.L.G. (red.). (2009). *Tien jaar Duurzaam Veilig* (Verkeersveiligheidsbalans 1998–2007 [in Dutch] R-2009-14). Leidschendam: SWOV.

Weijermars, W., & Wegman, F. (2011). *Ten years of sustainable safety in the Netherlands. An assessment* (Transportation Research Record No 2213) (pp. 1–8). Washington, DC: Transportation Research Board of the National Academies.

Weijermars, W. A. M., Dijkstra, A., Doumen, M. J. A., Stipdonk, H., Twisk, D. A. M., & Wegman, F. C. M. (2013). *Duurzaam Veilig, ook voor ernstig gewonden* ((Sutainable safety, also for serious injuries). R-2013-4). Leidschendam: SWOV.

Wijnen, W., & Stroeker, N. E. (2009). *Uitgaven aan verkeersveiligheid. Een schatting voor 2007* (Expenditure for road safety. An estimate for 2007). R-009-17 [in Dutch]). Leidschendam: SWOV.

World Commission on Environment and Development. (1987). *Our common future* (also known as the Brundtland Report). Oxford: Oxford University Press.