TRAFFIC SAFETY RESEARCH
AN INTERDISCIPLINARY JOURNAL

Case report

Towards a safe system in low- and middle-income countries: vehicles that guide drivers on self-explaining roads

Hans Godthelp[1,2]*

[1]Road Safety for All, the Netherlands

[2]Netherlands Organisation for Applied Scientific Research, TNO, the Netherlands (retired)

*Corresponding author: hg@roadsafetyforall.org

Handling editor: **Stijn Daniels**, KU Leuven, Belgium, Transport & Mobility Leuven, Belgium

Reviewers: **Wouter Van den Berghe**, Tilkon Research & Consulting, Belgium
Marko Renčelj, University of Maribor, Slovenia

Received: 7 March 2023; Accepted: 17 May 2023; Published: 25 May 2023

Abstract: Road crashes cause a huge problem of public health in low- and middle-income countries (LMICs). The Safe System approach is generally considered as the leading concept on the way to road safety. Based on the fundamental premise that humans make mistakes, the overall traffic system should be 'forgiving'. Sustainable safe road design is one of the key elements of the Safe System approach. Road design and speed control should help prevent crashes with a high level of kinetic energy. However, the road design principles behind the Safe System approach are certainly not leading in today's infrastructure developments in most LMICs. Cities are getting larger with increasing motorization and expanding road networks. Existing through-roads in local communities are upgraded, resulting in heavy traffic loads and high speeds on places, that are absolutely not suited for this kind of traffic. Furthermore, a Safe System would require that functional design properties of vehicles and roads would be conceptually integrated, which is not the case at all. Although advanced driver assistance systems are on their way of development for quite a long period, their potential role in the Safe System concept is mostly unclear and at least strongly underexposed. The vision on future cars is dominated by the faraway concept of automation. This paper argues that the way to self-driving cars should take a route via the concept of guidance, i.e. vehicles that guide drivers, both on self-explaining roads and on more or less unsafe roads. Such an in-vehicle guidance system may help drivers to choose safe transport mode, a safe route and a safe speed, based on criteria related to safety and sustainability. It is suggested to develop driver assistance systems using relatively simple and cheap technologies, particularly for the purpose of use in LMICs. Such a guide may make roads self-explaining—not only by their physical design characteristics—but also by providing in-car guidance for drivers. In the future, the functional characteristics of both cars and roads may be conceptualized into one integrated Safe System, in which the user plays the central role. Such a guidance system may serve as the conceptual bridge between the roadway, the vehicle and the driver, and thus be considered as an indispensable component of the Safe System approach. It is argued that such a development is necessary to bring a breakthrough in road safety developments in LMICs and also give an acceleration towards zero fatalities in high-income countries.

Keywords: advanced driver assistance, low- and middle-income countries (LMICs), road safety, Safe System approach, self-explaining roads

1 Introduction

The number of road traffic fatalities in the Netherlands reached a peak value of 3 264 in 1972. After that year a long and steady period of safety programs followed. Passive safety measures reduced the consequences of accidents, and obligatory seat belt use may be considered as one of the most successful in this category. Strategies for law enforcement were introduced, not only to increase seat belt use but also to improve speed behavior and reduce alcohol use. All of these measures gave a first boost towards a reduction in the number of fatalities. A more or less definite breakthrough was reached in the 1990s by developing the so-called concept of Sustainable Safety, i.e. the notion that the traffic system should be resistant to human errors. As a result, the number of fatalities reached the level of 570 in 2014 (SWOV, 2022). Developments similar to the Netherlands took place in most of the Western European countries, and internationally the underlying approach has developed as the Safe System approach.

Nowadays the number of traffic fatalities in countries with emerging economies develops more or less similarly to that in Western Europe in the 1970s. Gururaj & Sukumar (2017) give an extensive overview of the situation in India and about policies needed to reach improvements. For their home country they show a number of fatalities of 150 000 in 2015. Like 50 years ago in the Netherlands safety belt use is promoted, road design improves and enforcement strategies on speed and alcohol use develop. And indeed casualty numbers for India after 2015 show a slight decline, although reliability still may be limited. Similar developments take place in many low and middle income countries (LMICs), particularly in case of emerging economies.

To stimulate and support these developments, in 2010 the UN General Assembly proclaimed the Decade of Action for Road Safety (WHO, 2010). The Decade of Action intended to reach significant improvements in road safety and worked with a program based on five pillars: (*i*) road safety management, (*ii*) safer roads and mobility, (*iii*) safer vehicles, (*iv*) safer road users, and (*v*) post-crash response.

To underline this development, the Brasilia Declaration on Road Safety was signed in 2015 (WHO, 2015). Countries agreed to halve road traffic deaths by the end of the decade—a key milestone within the new Sustainable Development Goal (SDG) target 3.6. As a follow up, the 2030 United Nations Agenda for Sustainable Development recognizes that road safety is a prerequisite to ensuring healthy lives, promoting well-being and making cities inclusive, safe, resilient and sustainable (UN, n/d).

Now that the First Decade of Action has come to an end some first positive results have become visible. Nevertheless, at the Third Ministerial Conference on Road Safety in Stockholm the conclusion had to be drawn that the goals for 2020 were by far not reached and that in fact the fatality numbers in many LMICs are still increasing (Ministerial_Conference, 2020). The WHO Global Status Report on road safety (WHO, 2018) shows the trend of increasing fatality numbers with a dramatic number of 1.35 million fatalities worldwide in 2016. The report also shows that the rates of road traffic death per 100 000 population in some African countries reaches 29.3, whereas this number is about 3.8 in the Netherlands.

These numbers make clear that extra efforts are needed to accelerate developments in LMICs. Although the Safe System approach is advocated as the universal solution for definite improvements, a systematic approach is lacking in many countries. Focusing on the five pillars as mentioned is very important but may not be sufficient to implement a safe traffic system in LMICs. The urgent question that arises is how LMICs might develop their own implementation strategy for the Safe System principles. And—as a part of that strategy—whether and how new visions on the use of connected vehicle and transport systems, anno 2023, may play a role in this process. One of the fundamental questions may be whether on a relatively short notice new technologies may become an integrated part of the Safe System approach. Making use of existing, cheap technology may stimulate LMICs to develop a policy towards a leapfrog strategy in order to improve their fatality numbers. This note gives some thoughts into this direction. Instead of focusing on self-driving vehicles, LMICs may benefit from intelligent cars, trucks, buses, motorcycles that are able to understand roads and traffic circumstances, and thus give guidance to the driver. This approach may be mixed with earlier concepts of self-explaining roads and vehicle safety technologies. Such a combination might help to further transfer road traffic into a safe system.

2 Safe System principles

Let us consider the road safety developments in some further detail. As noted above, road safety improvements in many Western countries accelerated in the 1970s and 80s through making both cars and roads *forgiving*. Programs of crash testing resulted in safer cars. Passive safety systems were developed, intending to limit the damage caused to driver and passengers in the event of a crash. Airbags, seat belts, and whiplash protection system are examples of these passive safety systems deployed in vehicles. In the same sense roads were made forgiving through guardrails, crash cushions, breakable posts, etc.

In the period after the 1990s, the awareness raised that safety systems should not only mitigate the consequences of crashes, but also should prevent crashes from occurring. The relevance of crash *prevention* was based on the fundamental premise that the road traffic system should take account of human limitations. The road traffic system is open to a variety of users of which children and elderly are a significant part. In addition, lots of factors may be the reason for human failures—fatigue, bad visibility, drivers being distracted, bus drivers speeding because of tight time schedules, etc. Unlike systems with professional users, such as aviation, all of these aspects are to be included in an approach for a safe system. Human limitations therefore are to be considered as one of the basic characteristics behind the system. Analysis of human skills serves as an important tool for the description of these limitations. To get a feeling about the traffic task, it has proven useful to make a distinction between a number of task behavioral levels (Michon, 1985):

- Modality level: deciding to travel by bus, car, bike, or as a pedestrian
- Network level: decisions about route choice and navigation
- Tactical level: decisions on lane changing, speeding, crossing, etc.
- Operational level: vehicle control.

A systems view on road user behavior—and thus on road safety—will take notice of the interactions between these different task levels. Development of a robust public transport system will serve as an important instrument to improve road safety. In future cities, the clever mix of public and private transport might be leading in mobility development. Dividing the road network in a set of clearly defined road categories will guide route choice behavior. Such a network might also be based on a view on the functionality of roads. Roads may thus be categorized as either through roads, distributor roads, or access-roads in a hierarchically structured road network. Each category will have its own rules and regulations on user behavior for both vehicle drivers and vulnerable road users, i.e. regulating speed and road user encounters. Traffic signs and signals as well as road design characteristics will thus give guidance to road users in order to make optimal decisions.

During the 1990s, this line of thinking received more and more attention in a number of European countries, ultimately resulting in the Safe System approach. Welle et al. (2018) give a nice overview of these developments, its results and potential role, also in low- and middle-income countries. The Dutch Sustainable Safety concept (SWOV, 2006) and the Swedish Vision Zero approach (Belin et al., 2012) served as important building stones of the safe system approach. Both concepts are strongly related. Table 1 gives a description of the principles behind the Sustainable Safety concept.

Table 1 Description of the five Sustainable Safety principles SWOV (2006)

Principle	Description
Functionality of roads	Monofunctionality of roads as either through roads, distributor roads, or access roads in a hierarchically structured road network
Homogeneity of mass and/or speed and direction	Equality of speed, direction and mass at moderate and high speeds
Predictability of road course and road user behavior by a recognizable road design	Road environment and road user behavior that support road user expectations through consistancy and continuity of road design
Forgivingness of the environment and of road users	Injury limitation through a forgiving road environment and anticipation of road user behavior
State awareness by the road user	Ability to assess one's capacity to handle the driving task

Practically in the period after 1995 the Safe System philosophy strongly stimulated the development of all kinds of active safety systems, i.e. systems that intend to prevent crashes to occur. These developments found their way both in road and vehicle design.

European *road* improvements after the 1990s were based on the awareness that the chances on high speed collisions—with high levels of kinetic energy—should be structurally limited through appropriate design. Road design should more or less naturally regulate the integration or the separation of vehicles and vulnerable road users. In the Netherlands, the *woonerf* was developed in these days as a place where cars, cyclist and pedestrians were assumed to share place at low speeds. These developments may be considered as an example of the notion that the road traffic system should be based on the awareness that human error is a part of the system. The philosophy of self-explaining roads (Godthelp, 1990; Theeuwes & Godthelp, 1995) serves as one of components of the sustainable safety recipe. The concept implies that the road network should be designed in such a way that roads more or less naturally give guidance to human expectations and thus traffic behavior. Self-explaining roads naturally impose correct speeds and clearly indicate what type of traffic participants are to be expected and how interactions between the different types of participants should take place. Speed management is considered as significant factor in modern road design. The 30 km/h regime in urban environments, as developed in the last decade, may be considered as an ultimate result of this way of thinking. On self-explaining roads the guidance process is more or less informal, but not without limiting conditions. Roundabouts and village gateways do clearly limit speed and thus give guidance to the process of interaction with other road users on the particular intersection. Similarly, speed humps and lifted intersections do limit speed in areas with a mix of cars and vulnerable road users. The concept of self-explaining roads has been advocated and applied on a broad scale (Theeuwes, 2021; Bekiaris & Gaitanidou, 2011; van Geem et al., 2013).

In the same period after the 1990s, *vehicle* safety technologies developed in new directions with promising results. Bhalla & Gleason (2020) analyzed the potential life-saving effects of nine proven vehicle technologies for the Latin American region. Their results show that electronic stability control (including anti-lock braking systems), the more frequent use of seat belts and child restraints, and better side/front impact systems would be very beneficial. Calculations indicated that improving these vehicle design features might result in 28% fewer deaths. Contrary to the popular belief, the authors argue that the vehicle fleet in LMICs—at least in the Latin America and the Caribbean (LAC) region—tends to be young. They estimate that almost three-quarters of vehicles in use in the Latin American region are less than 10 years old. They suggest that if vehicle safety technologies had been introduced in all new cars at the start of the UN Decade of Action for Road Safety 2011–2020, by now there would be approximately 21% fewer traffic deaths in the LAC region, leaving this region much closer to Strategic Development Goals of halving traffic deaths by 2020. Recent reports indicate that the situation in Africa deviates from LAC—many African countries suffer from high numbers of polluting and unsafe vehicles imported from high-income countries, particularly from Europe (FIA, 2020; UNEP, 2020). This implies that as compared to LAC even larger safety gains can be reached by African countries by (*i*) setting quality standards of both new and used cars, and (*ii*) regulating minimum age of imported vehicles.

Despite these promising findings it still should be realized that most vehicle safety features as considered by Bhalla & Gleason (2020) do primarily focus on mitigating the consequences of crashes and/or on regulating vehicle stability during extreme maneuvering. The question therefore remains whether and how new type of vehicle safety measures may be implemented in order to systematically *prevent* the potential occurrence of crashes and extreme maneuvers. Whether and how vehicles may have a guidance function for drivers, also in relation to the encounters with vulnerable road users, similar to that successfully provided by self-explaining roads. Principally the question is how the guidance role of vehicles may become a conceptual element within the safe system approach.

Taken together the question arises whether our expectations about the potential role of the Safe System approach in its present shape on a worldwide scale are realistic. In many countries in Africa, Asia and Latin America, roads and transport facilities may not be suited for a relatively quick transfer towards an orderly system and network. This may prevent a relatively quick 'leapfrog' towards the wished for situation with a reduction in the number of road traffic fatalities with 50% as intended for the coming decade towards 2030 (Ministerial_Conference, 2020). In order to reach that goal the safe system approach might need a new dimension. A dimension that would give a further boost towards the prevention of road crashes. The challenge in road safety developments, particularly in LMICs, may be to make a connection between safe road design issues and new technologies, i.e. combining the self-explaining philosophy of roads, giving speed and maneuvering guidance to drivers, with a similar guidance role of vehicles. Vehicles serving as a guide. This might also require a clever mix of vehicle and transport technologies with those in the area of communication and sustainable development.

3 Safety potential of driver assistance systems

Intelligent transportation systems are on their way of development for about 30 years. The development of roadside systems brought us quite a number systems that combine traffic flow improvement with road safety. Systems like traffic signaling on motorways, intelligent traffic control signals and vehicle activated signs do give guidance to drivers making traffic smooth and safer. Makwasha & Turner (2014) clearly show the effectiveness of vehicle activated signs that aim to guide drivers in choosing appropriate speeds when approaching curves and intersections. As such these systems serve as nice examples of road related transport technologies that help drivers to prevent crashes.

Regarding intelligent vehicle safety systems the automotive sector developed a long term view about the development of support systems ultimately resulting in the autonomous vehicle. The expectation has been and still is that in the course of time, subsequent levels of automation will appear ranging from no automation (level 0) to driver assistance (level 1), partial automation (level 2), conditional automation (level 3), high automation (level 4), and, finally, to full automation (level 5) (Michelin, 2014; SAE, 2018).

Although the development of autonomous vehicles do get a lot of publicity, realistic expectations and predictions indicate that during the coming decades humans drive the car. Vision papers, like those by PWC (2019) make a clear statement:

'*Various autonomous driving technologies already in use are designed to improve safety, such as rear-view cameras, automatic braking, adaptive cruise control, lane departure warning, etc. These options are increasingly implemented in autonomous vehicles of level 1 (function-specific) and 2 (combined function) and quickly become standard. The road to level 3 (limited self-driving) and level 4 (full self-driving) of autonomous driving is more difficult due to challenges that exist around high definition mapping, interaction with (and prediction of) human drivers and adaptation to changing infrastructures and circumstances. The complexity of this requires considerable investment and cooperation, the results of which will probably only be visible over time.*'

Instead of focusing in self-driving vehicles it seems sensible for the period till 2050 to promote the level 2 and 3 applications of driver assistance and some well-chosen partial automation. Wilmink et al. (2008) already made an estimate about the safety effects of 25 intelligent vehicle safety systems (see Table 2). Vaa et al. (2014) compared safety effects of different support systems, indicating the highest effects of speed adaptation systems. Kulmala (2010) developed a comprehensive framework for the safety assessment of intelligent transport systems.

Table 2 clearly shows the potential benefits of this sort of vehicle safety systems. Nevertheless, a more integrated vision about their role in the safe system concept is quite unclear and underexposed. Today 'automation' systems are introduced more or less in isolation as sort of precursors of what is called self-driving cars. In an analysis of the Human Machine Interfaces of adaptive driver support systems, as presently in use in modern cars, Carsten & Martens (2019) argue that in many respects, the current designs fall short of best practices and have the potential to confuse the driver. When designing this sort of safety systems from a conceptual safety perspective the effectiveness may appear to be larger. Carsten & Tate (2005) analyzed the effects of non-overridable intelligent speed adaptation and indicated that fatality numbers may be reduced by more than 50%. Hydén (2020) strongly argues that the use of in-vehicle speed support systems should be placed on the international road safety agenda. A study about the potential safety effects of advanced driver assistance systems by the European Road Safety Observayory (ERSO, 2018) gives a nice overview, indicating which systems deserve particular attention in future vehicles. The study also gives a prominent place to speed adaptation systems and asks for robust evaluation programs.

An early vision on the potential role of intelligent transport and driver support systems in road traffic was developed in the GIDS (Generic Intelligent Driver Support[1]) project (Godthelp & Beek, 1991; Michon,

[1]Note *gids* is the Dutch word for guide.

Table 2 Effects of 12 Intelligent Vehicle Safety System (IVSS) on the number of road fatalities in 25 EU member states in case of 100% fleet penetration by safety mechanisms, in % (Wilmink et al., 2008)

System	Safety mechanisms								
	1	2	3	4	5	6	7	8	9
Electronic stability control ESC	-21.1		+4.2	+0.4				+0.5	
Full speed range adapt, cruise control	-2.1		+0.9					-0.2	
Emergency braking	-7.2		+0.3						
Pre-crash protection of VRU’s	-2.5		+0.2						
Lange change assistance	-2.3		+0.2			+0.04			
Lane keeping support	-17.7		+2.8						
Night vision warning	-6.9		+3.5			+0.7	+0.3	+0.3	
Drowsiness monitoring/warning	-7.9		+2.2			+0.7	+0.6	+0.0	
Emergency eCall									-5.8
Intersection safety support	-8.6		+5.0						
Wireless local danger warning	-3.1		+0.2		-1.6				
Speed alert	-5.5	-1.0	-1.0		-1.0			-0.5	

Safety mechanisms:
(1) Direct in-vehicle modification of the driving task
(2) Direct influence of roadside systems
(3) Indirect modification of user behavior
(4) Indirect modification of non-user behavior
(5) Modification of interaction between user and non-users
(6) Modification of exposure
(7) Modification of modal choice
(8) Modification of route choice
(9) Modification of accident consequences only

1993). The project presented a system philosophy, in which a number of isolated support systems are transformed into one integrated, communication system. As such GIDS made the connection between intelligent support systems and the safe system approach. More recently Tinga et al. (2023) developed the Mediator system with a new vision on how the switch between automated and non-automated modes of driving may be safely presented to drivers. GIDS or Mediator types of driver support systems may conceptually integrate the levels of the driving task, i.e. modality choice, navigation, anti-collision, speed adaptation, and active vehicle guidance, etc. They may serve as a dialog control system that safely regulates the overall driver workload and task distribution between human and vehicle.

Now that the first versions of driver assistance systems are available in a more or less mature shape the challenge may be to use the basic version of this technology in LMICs. They may be implemented in new vehicles or applied in retrofit. Smartphones and their connectivity are widely spread out worldwide as is the functionality of systems like GoogleMaps. This makes the use of the elementary support functions within reach—also in LMICs. Relatively simple and cheap technologies may inform and guide drivers at the different levels of driving behavior. Navigation systems may get the functionality of guiding drivers along safe star-rated routes (EuroRAP, 2015). Speed can be influenced through enforcing and limiting, i.e. through the use of overridable or non-overridable intelligent speed adaptation systems (Hydén, 2020). Intersections may be controlled with the assistance of robust traffic sensors connected to the car. Connectivity can also bring in-car visibility of vulnerable road users. In other words—also in LMICs roads may become self-explaining, not only by their physical design characteristics, but also by guiding drivers and vulnerable road users through a clever mix with this sort of driver support systems.

4 In conclusion: vehicles that guide drivers on self-explaining roads

As stated above, the functional categorization of the road network serves as one of the crucial characteristics of the road system, indicating design characteristics and speed regime. Connecting vehicles to road categories means that speed limits are available for intelligent speed adaptation and optimal route guidance. Anno 2030 connected mobility will—or may—be available worldwide in a more or less definite form. This implies that the mixture of smartphones, navigation systems, intelligent speed adaption, anti-collision and lane keeping technologies, based on smart sensors and satellite communication can be transformed into a relatively modest traffic guidance system, also in LMICs. Integration of these basic components into a driver support system will not bring us in the world of the self-driving car or motorcycle, but provides a tool to safely guide drivers in the complex myriad of roads and road users. It will bring us in the world of vehicles that provide basic guidance to drivers.

Such a vehicle guide may have a broad functionality: it may help drivers optimize the driving task from the perspective of safety as well as sustainability. Also, it may influence driving at the different levels of traffic behavior, i.e. helping people to choose their optimal way of travelling and choosing the safest route and speed—dependent on road quality, road categories and local traffic conditions The guide may influence speed through enforcing and limiting speed support systems, with intelligent speed adaptation as integrated element. Note that speed is considered as one of the major—if not the major—cause of road unsafety, i.e. with an enormous safety potential. By regulating drivers anticipation and expectations through both road design and an in-car driver assistance road traffic will become safer at a more systematic level. Such an approach would mean that the functional characteristics of both vehicles and roads will be integrated into one safe system, in which the user plays the central role. Such a guidance system may give vehicles a conceptually integrated position within the Safe System approach.

Summarizing it can be argued that a breakthrough is needed to reach the goals as proclaimed by the United Nations General Assembly for the Second Decade of Action for Road Safety 2021–2030 (UN, 2020). The Safe System approach is considered as the leading framework for the actions needed. Now that the aspired goals of the First Decade have not been reached, new directions for such a safe system are to be explored. It is suggested that future road safety systems should focus even more on the prevention of crashes. To reach this the notion of self-explaining roads that regulates road user behavior might be integrated with that of vehicles giving guidance to drivers. This way of thinking may give a new dimension to the safe system approach. It would invite policy makers, road designers, automobile manufacturers, traffic and mobile app industry to integrate 'traditional' issues like safe roads and safe vehicles towards a concept in which vehicles understand roads and guide drivers in behaving safely. Instead of being self-driving, future vehicles might give intelligent assistance to drivers. For the purpose of use in LMICs, a basic version of a vehicle guide may be developed and explored using relatively simple and cheap technologies, some of which are available as mature navigation and intelligent speed adaptation systems. Research and development programs exploring such a vehicle guide concept may give a new dimension to the Safe System approach, which is necessary to provide the urgently needed breakthrough in road safety developments in LMICs. Moreover, a safe system approach based on functional integration of the guiding role of roads and vehicles will at the end not only be highly profitable for road safety in emerging countries. It may also give the ultimate solution for the remaining unsafety in high-income countries. The approach may give us a definite picture of a traffic world without accidents.

CRediT contribution statement

Hans Godthelp: Conceptualization, Resources, Writing—original draft, Writing—review & editing.

Declaration of competing interests

The author confirms that there have been no involvements that might raise the question of bias in the work reported or in the conclusions, implications, or opinions stated.

Acknowledgements

This work has not received any external funding.

References

Bekiaris, E., E. Gaitanidou (2011), 'Towards Forgiving and Self-Explanatory Roads', in Bekiaris, E., Wiethoff, M., & Gaitanidou, E. (eds), *Infrastructure and Safety in a Collaborative World* (Berlin, Germany: Springer-Verlag), https://doi.org/10.1007/978-3-642-18372-0_2.

Belin, M. A., Tillgren, E. Vedung (2012), 'Vision Zero - a Road Safety Policy Innovation', *International Journal of Injury Control and Safety Promotion*, 19(2), 171–179, https://doi.org/10.1080/17457300.2011.635213.

Bhalla, K., K. Gleason (2020), 'Effects of vehicle design on road traffic deaths, injuries, and public health burden in the Latin American region: a modelling study', *The Lancet Global Health*, 8(6), E819–E828, https://doi.org/10.1016/S2214-109X(20)30102-9.

Carsten, O., M. H. Martens (2019), 'How can humans understand their automated cars? HMI principles, problems and solutions', *Cognition, Technology & Work*, 21, 3–20, https://doi.org/10.1007/s10111-018-0484-0.

Carsten, O. M. J., F. N. Tate (2005), 'Intelligent speed adaptation: accident savings and cost-benefit analysis', *Accident Analysis & Prevention*, 37(3), 407–416, https://doi.org/10.1016/j.aap.2004.02.007.

ERSO (2018), 'Advanced driver assistance systems', European Road Safety Observatory, https://road-safety.transport.ec.europa.eu/system/files/2021-07/ersosynthesis2018-adas.pdf.

EuroRAP (2015), 'Road that cars can read', European Road Assessment Programme, Proposals for Consultation, https://www.eurorap.org/wp-content/uploads/2015/03/roads_that_cars_can_read_2_spread1.pdf.

FIA (2020), 'Promoting Safer and Cleaner Used Vehicles for Africa', Federation Internationale de l'Automobile Region I, https://www.fiaregion1.com/wp-content/uploads/2020/06/FIA-Report_Final-V3_HR.pdf.

Godthelp, J. (1990), 'Towards control in road traffic [in Dutch]', *Verkeerskunde*, 41(3).

Godthelp, J., F. O. D. Beek (1991), 'Driving with GIDS: Behavioural Interaction with the GIDS Architecture', *Advanced telematics in road transport: DRIVE conference*, Brussels, Belgium, 4–6 February 1991.

Gururaj, G., G. M. Sukumar (2017), 'Advancing road safety in India: Implementation is the key', National Institute of Mental Health & Neuro Sciences, Publication 137, https://nimhans.ac.in/wp-content/uploads/2019/02/UL_BR_m010-11_Main-rprt_FINAL.pdf.

Hydén, C. (2020), 'Speed in a high speed society', *International Journal of Injury Control and Safety Promotion*, 27, 44–50, https://doi.org/10.1080/17457300.2019.1680566.

Kulmala, R. (2010), 'Ex-ante assessment of the safety effects of intelligent transport systems', *Accident Analysis & Prevention*, 42(4), 1359–1369, https://doi.org/10.1016/j.aap.2010.03.001.

Makwasha, T., B. Turner (2014), 'Evaluating vehicle activated signs at rural roads', *26th Australian Road Research Board Conference*, Sydney, Austratlia, 19–22 October 2014.

Michelin (2014), 'Road safety and connected mobility: An overview report on the current status and implications of road safety and connected mobility', Michelin Challenge Bibendum.

Michon, J. A. (1985), 'A critical view of driver behavior models: what do we know, what should we do?', in L, E., & R.C., S. (eds), *Human behavior and traffic safety* (New York, USA: Plenum press).

Michon, J. A. (1993), *Generic intelligent driver support* (London, UK: Taylor & Francis).

Ministerial_Conference (2020), 'Stockholm Declaration', *3rd Global Ministerial Conference on Road Safety*, Stockholm, Sweden, 19–20 February 2020, https://www.roadsafetysweden.com/about-the-conference/stockholm-declaration/.

PWC (2019), 'The future of mobility', Price Cooper Waterhouse, https://www.pwc.nl/en/industries/automotive/the-future-of-mobility.html, accessed 2023-05-18.

SAE (2018), 'Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles', SAE International, 3016_202104, https://www.sae.org/standards/content/j3016_202104/.

SWOV (2006), 'Advancing Sustainable Safety: National Road Safety Outlook for 2005-2020', SWOV Institute for Road Safety Research (Leidschendam, the Netherlands), https://swov.nl/system/files/publication-downloads/advancing_sustainable_safety.pdf.

SWOV (2022), 'Road deaths in the Netherlands', SWOV, Institute for Road Safety Research, Fact sheet, https://swov.nl/en/fact-sheet/road-deaths-netherlands.

Theeuwes, J. (2021), 'Self-explaining roads: What does visual cognition tell us about designing safer roads', *Cognitive Research: Principles and Implications*, 6, https://doi.org/10.1186/s41235-021-00281-6.

Theeuwes, J., J. Godthelp (1995), 'Self-explaining roads', *Safety Science*, 19(2–3), 217–225, https://doi.org/10.1016/0925-7535(94)00022-U.

Tinga, A. M., I. M. van Zeumeren, M. Christoph, E. van Grondelle, D. Cleij, A. Aldea, N. van Nes (2023), 'Development and evaluation of a human machine interface to support mode awareness in different automated driving modes', *Transportation Research Part F: Traffic Psychology and Behaviour*, 92, 238–254, https://doi.org/10.1016/j.trf.2022.10.023.

UN (2020), 'Improving global road safety', United Nations, General Assembly, Resolution 74/299, 2 September 2020, https://undocs.org/en/A/RES/74/299.

UN (n/d), 'Sustainable Development Goals', United Nations, https://sdgs.un.org/goals, accessed 2023-05-18.

UNEP (2020), 'Used Vehicles and the Environment: A Global Overview of Used Light Duty Vehicles - Flow, Scale and Regulation', United Nations Environment Programme, https://wedocs.unep.org/20.500.11822/34175.

Vaa, T., T. Assum, R. Elvik (2014), 'Driver support systems: Estimating road safety effects at varying levels of implementation', Institute of Transport Economics (Oslo, Norway), TØI Report 1304/2014, https://www.toi.no/getfile.php?mmfileid=35912.

van Geem, C., S. Charman, A. Ahern, A. Anund, L. Sjögren, A. Pumberger, G. Grayson, S. Helman (2013), 'Speed Adaptation Control by Self Explaining Roads (SPACE)', *16th Road Safety on Four Continents Conference*, Beijing, China, 15–17 May 2013, http://vti.diva-portal.

org/smash/get/diva2:761032/FULLTEXT01.pdf.

Welle, N., A. B. Sharpin, C. Adriazola-Steil, S. Job, M. Shotten, D. Bose, A. Bhatt, S. Alveano, M. Obelheiro, T. Imamoglu (2018), 'Sustainable & Safe: a Vision and Guidance for Zero Road Deaths', World Resources Institute, https://thedocs.worldbank.org/en/doc/912871516999678053-0190022018/original/ReportSafeSystemsfinal.pdf.

WHO (2010), 'Decade of Action for Road Safety', World Health Organization, https://www.who.int/groups/united-nations-road-safety-collaboration/decade-of-action-for-road-safety-2011-2020, accessed 2023-05-17.

WHO (2015), in and others (ed.), *Second Global High-level Conference on Road Safety: Time for Results*, Brasilia, Brasil, 18—19 November 2015, https://cdn.who.int/media/docs/default-source/documents/un-road-safety-collaboration/brasilia_declaration_en.pdf.

WHO (2018), 'Global status report on road safety', World Health Organization (Geneva, Switzerland), https://www.who.int/publications/i/item/9789241565684.

Wilmink, I., W. Janssen, E. Jonkers, K. Malone, M. Van Noort, G. Klunder, P. Rämä, N. Sihvola, R. Kulmala, A. Schirokoff, G. Lind, T. Benz, H. Peters, S. Schönebeck (2008), 'Impact assessment of intelligent vehicle safety systems', eIMPACT, Deliverable D4.

About the authors

Hans Godthelp has been the Head of the Traffic Behavior Research Group at the Netherlands Organisation for Applied Scientific Research, TNO, and Professor in Traffic Safety Science at the University of Groningen, the Netherlands. As a researcher, he initiated the development of the self-explaining road concept, which serves as an important element of the international Safe System approach. His doctoral thesis was about the Time-to-Line-Crossing method, which describes driver visual attention needed when controlling a vehicle. He was one of the founders of the international GIDS project, which developed a first vision about the potential role of intelligent driver support systems in road traffic. As a research manager, he focused on the integration of human engineering knowledge in research and development programs, both in industry and in cooperation with governmental departments and universities.

Since his retirement in 2010, he serves as a partner at the Road Safety for All foundation with a focus on the development of road safety research and education in low- and middle-income countries. As a member of the Steering Committee, he supported the establishment and organization of the Delft Road Safety Courses, both at the Delft University of Technology, the Netherlands, and locally in LMICs. He also serves as co-chair of the PIARC working group on Special Road Safety Issues in Low- and Middle-Income Countries.