



Motorway Safety in Korea Learning From International Best Practice for an Action Plan to 2030



Case-Specific Policy Analysis

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The International Transport Forum

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International Transport Forum 2 rue André Pascal F-75775 Paris Cedex 16 contact@itf-oecd.org www.itf-oecd.org

Case-Specific Policy Analysis Reports

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Abbreviations and Acronyms

- AADT annual average daily traffic
- ADAS advanced driver assistance system
- ALR all-lane running
- ANPR automatic number-plate recognition
- ATC automatic traffic counter
- CAV co-operative automated vehicle
- CCMTA Canadian Council of Motor Transport Administrators
- C-ITS Co-operative Intelligent Transport Systems
- DHS dynamic hard shoulder
- DTG digital tachograph
- ELD electronic logging device
- ETSC European Transport Safety Council
- FMCSA Federal Motor Carrier Safety Administration (United States Department of Transportation)
- FPN fixed penalty notice
- HGV heavy goods vehicle
- ISAD Infrastructure Support levels for Automated Driving
- KEC Korea Expressway Corporation
- km kilometres
- KNPA Korean National Police Agency
- KoROAD Korea Road Traffic Authority
- KOTI Korea Transport Institute
- KOTSA Korea Transportation Safety Authority
- LUMS lane-use management system
- MOLIT Korea Ministry of Land, Infrastructure and Transport
- MVNO mobile virtual network operator
- NCAP New Car Assessment Programme
- OBU on-board unit
- SSES sectional speed enforcement system
- SVD Stopped Vehicle Detection
- UNRSTF UN Road Safety Trust Fund
- VMS variable-message sign
- V2I vehicle to infrastructure
- V2P vehicle to pedestrian
- V2V vehicle to vehicle
- V2X vehicle to everything
- VoSL value of statistical life
- VSL variable speed limit

Executive summary

What we did

Motorway crashes kill over 200 people in Korea each year. Matching the average safety performance observed across Germany, Japan, the Netherlands and the United Kingdom would halve the number of motorway deaths. This report reviewed international best practices in motorway safety across ten countries to determine which might be best suited to making Korea's motorways safer. It offers recommendations for an action plan to 2030, taking into account the expected uptake of connected and automated vehicles.

The International Transport Forum (ITF) engaged with over 40 experts and organisations in Korea and ten other ITF countries: Australia, Canada, France, Germany, Italy, Japan, Korea, Netherlands, Sweden, the United Kingdom and the United States. On the basis of expert interviews, stakeholder input and a literature review, the ITF developed recommendations for motorway safety in Korea specifically.

What we found

With 2.8 traffic deaths per billion vehicle-kilometres, Korean motorways have a significant margin of progress towards the safety performance observed in Germany, Japan, the Netherlands and the United Kingdom, whose motorway network fatality rates range from 0.9 to 1.7.

Vehicle design flaws or maintenance problems rarely contribute to motorway crashes. Yet, new vehicle design standards could compensate for weaknesses elsewhere in the transport system – in driver behaviour, for instance. The European Commission sets the most stringent vehicle standards in the world. It mandates systems such as Advanced Emergency Braking (AEB), Emergency Lane Keeping Assist (ELKS), drowsiness and distraction recognition (DDR) and Intelligent Speed Assistance (ISA). On heavy goods vehicles, most countries require the use of tachographs, devices that record driving times and help enforce rest periods.

Specific crash patterns are observed on motorways. Driver fatigue, distraction, insufficient headways and obstacles on the carriageway are crash factors that are over-represented on motorways. Heavy goods vehicles are involved in a third of motorway deaths in most countries, but up to 50% in Korea and Germany.

The relatively monotonous driving task on motorways leads to driver drowsiness and distraction. Motorways, meanwhile, offer the opportunity to automate the driving task. Road authorities are working to upgrade the physical and digital infrastructure that supports the adoption of connected and automated driving. However, until automated vehicles can handle all situations without driver supervision, on-board vigilance-monitoring equipment can make a significant contribution to motorway safety.

Motorways will benefit from the deployment of connected and automated vehicles. Having digital maps and digital information on the road environment could accelerate the uptake of such vehicles and maximise their road safety benefits. Truck platooning on motorways could rapidly and significantly transform motorway operations.

"Smart" motorways combine the continuous monitoring of traffic conditions with dynamic traffic management systems such as variable speed limits and lane-use management. The understanding of and

compliance with dynamic traffic management signals is critical to the safe operation of smart motorways. So are the design of emergency refuges and the deployment of stopped-vehicle detection systems in places where a traffic lane replaces the emergency stopping lane or hard shoulder.

Motorway fatalities decreased dramatically in several countries in the decade to 2010. In France, the most visible drop in fatalities was due to the introduction of automatic speed enforcement: non-compliance with 130 km/h limits fell from 36% to 13%. In Italy, the drop in fatalities coincided with the introduction of section speed control.

Australia, Italy, the Netherlands and Sweden impose financial sanctions ranging EUR 170 to EUR 695 to drivers caught driving 21 km/h above the speed limit on a motorway. The EUR 44 speed penalties applicable in Korea seem inadequate to induce compliance with speed limits. For exceeding the speed limit by 51 km/h on motorways, Korean drivers receive a EUR 67 ticket, which is disproportionately low compared to the fines of EUR 1000 and more imposed in France, the Netherlands, Ontario (Canada) and South Australia.

Australia, Canada, Italy, the Netherlands and Sweden have developed national road-safety strategies that adopt the Safe System approach: they seek to eliminate fatal and serious crashes with a systematic, multidisciplinary and multi-sectoral approach. Considering the wide range of factors that affect crash risk and crash outcome, motorway safety must not be considered as the responsibility of the road operator alone. This report makes recommendations to all relevant parties in Korea, including the Ministry of Land, Infrastructure and Transport (MOLIT), the Korea Transportation Safety Authority (KOTSA), the Korea Transport Institute (KOTI), the Korea Road Traffic Authority (KOROAD), the Korea Expressway Corporation (KEC) and the Korean National Police Agency (KNPA). It calls for an action plan towards 2030, to align with the road safety targets set by the World Health Organisation, and to account for the foreseeable rise of connected and automated vehicles.

What we recommend

Develop a proactive approach to motorway safety

Korean authorities and motorway operators should invest in research towards crash prediction models and towards the in-depth understanding of crash causes, so they can develop a proactive approach to road safety. In particular, the KEC should conduct research using surrogate safety metrics such as vehicle swerving or emergency braking in order to try to predict fatal and serious casualties. The KEC should ensure that its road safety research team is trained to make the most sensible use of AI and surrogate safety metrics. The Korean government should fund a permanent and independent in-depth crash investigation programme to understand safety weaknesses at their roots across the entire transport system. The MOLIT or KOTSA should initiate a research programme to quantify the influence of various factors and interventions on motorway safety performance in developed countries.

Promote work-related road safety in road haulage companies and in other sectors

Trucks are involved in over half of motorway fatalities in Korea. Work-related road safety is thus a priority for action. MOLIT should disseminate targeted information to employers about costs and benefits related to work-related road safety. Financial incentives should encourage employers to fit and purchase vehicles with in-vehicle technologies that have a high life-saving potential. MOLIT should also provide guidance for integrating work-related road safety, through incentives or requirements, into public procurement.

Review the cost-benefit evaluation of road safety investment

Korean authorities should review the guidance material that supports the economic appraisal of road safety projects. In particular, they should review a parameter called the *value of statistical life* (VoSL) and align it with OECD guidance. Such a shift would help more road safety actions get funded.

Create an observatory to map and monitor unsafe situations and behaviours

The KEC should fund and operate a robust and comprehensive statistical observatory that monitors driver behaviours and attitudes, using a range of techniques that include opinion surveys and roadside observations. The observatory could map this information by corridor or segment, to support the design of targeted interventions. The observatory would track progress over time and thus facilitate the impact evaluation of education and enforcement campaigns.

Review the legal and operational frameworks for speed enforcement

The experiences of other countries suggest that reducing speeds could deliver the best results in reducing motorway deaths. To do so, Korean authorities should review the legal framework that enables the enforcement of speed limits. Penalties should be higher and be complemented with non-financial sanctions, and the automated speed enforcement should cover the whole motorway network. The framework should give specific attention to the enforcement of variable speed limits. In addition, the Korean government should envisage and trial the decriminalisation of some traffic offences, shifting the enforcement authority from the police to motorway operators for offences related to average speed or lane-use management systems. Not waiting for a decision on decriminalisation, the KEC should use vehicle identification systems to compute the average speed of each vehicle trip on their network, for the monitoring of behaviours and the trial of a reward system for safe driving.

Set high vehicle safety standards inspired by those developed in the European Union

To take advantage of vehicle safety technologies, the Korean government should mandate the use of systems including advanced emergency braking, intelligent speed assistance, driver monitoring systems and digital tachographs. The European regulations for vehicle safety provide a source of inspiration for Korean authorities to match. Korean authorities should not only impose safety systems on new vehicles but also develop mandatory retrofit programmes for older vehicles, especially heavy goods vehicles. For the latter, the MOLIT should prepare legislation that requires that all trucks are equipped or retrofitted with digital tachographs and submit real-time data to KOTSA.

Upgrade the physical and digital infrastructure for the adoption of connected and automated driving

The KEC should upgrade the physical and digital infrastructure that supports the adoption of connected and automated driving. This includes making all dynamic and static infrastructure information available in digital form to automated vehicles, along with precise information on the traffic situation. The MOLIT should nevertheless require that all automated vehicles involved in live trials on motorways are capable of handling unexpected situations such as C-ITS outage and the presence of pedestrians, animals, obstacles and debris on the roadway.

Set guidance and standards for the rapid deployment of Co-operative-ITS services in Korea

C-ITS services are particularly relevant to the safety of motorways. Examples include emergency electronic brake light (EBL), traffic jam ahead warning (TJW), in-vehicle signage (VSGN) and in-vehicle speed limits (VSPD). In addition, probe vehicle data (PVD) helps the motorway operator collect real-time traffic

information on hazards such as slippery road surfaces, congestion and incidents. Korean stakeholders should consider road safety as the primary benefit of C-ITS services, which should be accessible to all vehicles by means of affordable retrofit programmes or smartphone integration. The MOLIT – together with telecommunication authorities, road authorities, and vehicle and technology industries – should work to frame and accelerate the deployment of C-ITS services.

The KEC should invest in solutions that protect road users, from the most traditional to the most innovative

The KEC should examine the life-saving potential of the installation or upgrade of roadside barriers and refuges. It should also examine the case for expanding lane-use management systems and automating high-risk road-maintenance tasks. The KEC should develop new tools for asset inspection, such as the use of 3D point cloud mapping using LIDAR sensors. It should also continue providing high-accuracy real-time information via all channels including C-ITS. This includes information on roadworks, congestion, incidents, variable speed limits, lane-use management, etc.

Why focus on motorway safety?

Motorways are typically three times safer than other road networks, based on the number of road deaths per unit of traffic (Figure 1). This is largely explained by their design, which eliminates at-grade intersections¹, physically separates vehicles travelling in opposite directions, and excludes pedestrians and cyclists.

Due to their relatively good safety record, motorways are rarely considered an immediate priority in national road-safety action plans. Motorway deaths in 2018 represented 8% of road fatalities in the European Union, 8% in Korea and 3% in Japan (ITF IRTAD database).

Motorways, however, also attract a large volume of traffic, allow vehicles to operate at high speeds, and include a high share of heavy goods vehicles. This makes motorway safety a sensitive topic and a very relevant and specific area of research.

Motorway safety benefits from a range of national and international road safety policies that are not specific to motorways; these include vehicle safety features and technical checks as well as drink-driving penalties. This report acknowledges such policies and promotes the elaboration of comprehensive national road-safety action plans – while focusing on measures that have a disproportionately positive effect on motorways or are specific to motorways.

This section explores the differences between motorway crashes and crashes on other roads, in order to suggest policies and actions that are targeted at motorway safety. It also compares motorway safety performance across selected ITF countries.



Figure 1. Road fatalities per billion vehicle-kilometres

Notes: Time period is 2018 for all roads, 2017-2019 average for motorways. UK data covers Great Britain alone. Source: ITF (2020).

Benchmarking the safety of motorway networks

Table 1 shows that motorway network length ranges from 3 700 kilometres in the United Kingdom² to nearly 78 000 kilometres in the United States. Korea has a motorway network length of 4 750 kilometres (km), which is comparable to that of Italy, the Netherlands and the United Kingdom. The annual average daily traffic ranges from 36 000 to 48 000 vehicles per day in most countries. With more than 48 000 vehicles per day on an average section, the Korean motorway network is among the most intensely used; it is most comparable to that of the United States and Germany in this regard. Only the British network is more intensely used, with an average of 82 000 vehicles per day.

Country	Network length (km)	Traffic volume (million vehicle-km per year)	Deaths per year	Deaths per billion vehicle-km	Annual average daily traffic (AADT)
Canada	38 098	141 046	290		10 143
France	11 826	157 980	271	1.7	36 599
Germany	13 039	249 467	396	1.6	52 419
Italy	5 784	84 205	236	2.8	39 866
Japan	11 630	100 840	127	1.7	23 755
Korea	4 750	83 495	235	2.8	48 155
Netherlands	5 400	72 120	76	1.1	36 593
Sweden	2 519		21		
United Kingdom (Great Britain)	3 706	110 783	104	0.9	81 907
United States	77 879	1 333 509	4 724	3.5	46 912
France (toll motorways)	8 970	96 997	154	1.6	29 626
England (smart motorways)	466	22 379	13	0.6	131 572
England (conventional motorways)	2 575	75 026	74	1.0	79 826

Table 1. Motorway safety statistics: Average for 2017-19

Notes: **Canada**: 2017 for network length; 2016 for traffic volume (*network length* refers to the National Highway System). **France**: scope consists of motorway concessions (73% of the network), interurban motorways (16%) and urban motorways (10%) and does not cover national roads with motorway characteristics. **Germany**: Network length and traffic do not include connector roads, exits and entries. Road crash data refer to fatalities within the boundaries of the motorway sign and on connector roads. **Italy**: 2019 for network length. Data refer to toll-pay motorways which cover 77% of motorway network. **Japan**: 2015 for traffic volume and deaths per billion vehicle-kilometres. **Netherlands**: Data include national motorways and highways where the speed limit is higher than 100 km/h; these roads are managed by Rijkswaterstaat. **Sweden**: 2019 for network length. **United Kingdom (GB)**: 2017-18 for network length, traffic volume and deaths per billion vehicle-kilometres; data also cover "upgraded A roads", also known as A(M) roads. **France (toll motorways)**: 2015-19. **England (conventional motorways)**: 2015-19.

Sources: **Canada**: Transport Canada. **France**: General Department for the Sustainable Development (CGDD) for network length and traffic volume; French Road Safety Observatory (ONISR) for deaths. **Germany**: Federal Ministry for Transport, Building and Urban Development (BMVBS) for network length; Federal Highway Research Institute (BASt) and the German Institute for Economic Research (DIW Berlin) for traffic volume; BASt for deaths. **Italy**: National Statistics Office. **Japan**: National Police Agency. **Korea**: the Ministry of Land, Infrastructure and Transport (MOLIT) for network length and traffic volume; Korea Transportation Safety Authority (KOTSA) for deaths. **Netherlands**: Central Bureau of Statistics (CBS) for network length and traffic volume; Institute for Road Safety Research (SWOV) for deaths. **Sweden**: Swedish Transport Agency. **United Kingdom**: Ordnance Survey Maps for network length; Department for Transport (DfT) for traffic volume and deaths. **United States**: Federal Highway Administration (FHWA) for network length and traffic volume; Fatality Analysis Reporting System (FARS) for deaths. **France (toll motorways)**: ONISR for network length and traffic volume; Association of French Motorway Companies (ASFA) for deaths. **England**: Highways England (2021).

The number of traffic deaths per billion vehicle-km ranges from 0.9 to 3.7 on the motorway networks in countries listed in Table 1. At the sub-national level, the lowest fatality rate is 0.6 and is observed on the smart motorway segments in England (a *smart motorway* is a section of motorway that uses active traffic management techniques to manage the flow of traffic). Using this metric, Korean motorways score 2.8 and have a significant margin of progress towards the safety performance observed in Germany, Japan, the Netherlands and the United Kingdom whose motorway network fatality rates range from 0.9 to 1.7. This shows that fatality numbers and fatality rates in Korea could be halved, saving the lives of more than 100 people each year.

None of the experts interviewed for this report could mention a published comparison of motorway safety performance across countries that would rigorously explain the differences in safety performance and separate the influence of various explanatory factors. Explanatory power may be found in the share of heavy goods vehicles, speed limits, market penetration of vehicle safety features, the number of access and exit ramps, the road safety rating of motorway sections, etc. A research programme in this area would cast a new light on the performance of each country, would help identify best practices, and would support efforts to develop a motorway safety programme with precise targets.





Source: ITF IRTAD database

As Figure 2 shows, motorway traffic deaths have flatlined over the last decade in most countries. A relatively low political priority combined with a background growth in traffic (especially commercial traffic) could explain this phenomenon. The first decade of the millennium, however, featured some dramatic decreases in motorway fatalities. The most visible was in France, where non-compliance with 130 km/h

limits fell from 36% to 13% following the introduction of automatic speed enforcement. The second most visible decrease happened in Italy and coincided with the introduction of section speed control.

The French and Italian experiences with speed enforcement are developed later in this report, in the section on safe road users. Annex A plots the motorway fatality numbers in ten countries and marks the dates of important motorway safety measures.

Specific challenges and opportunities

This section explores the differences between motorway crashes and crashes on other roads, in order to suggest policies that are targeted at motorway safety. Driver fatigue, distraction, insufficient headways and obstacles on the carriageway are crash factors that are over-represented on motorways. Heavy goods vehicles are involved in up to 50% of motorway casualties in Korea and Germany. In addition, this section considers the opportunity for roadside equipment to support the use of connected and automated vehicles on motorways.

Motorway crash types

Motorways are dual carriageways that physically separate traffic flowing in opposite directions, have no intersections, and exclude pedestrians, cyclists and low-speed vehicles. This naturally affects the types of crashes that occur on motorways. Experts mention rear-ending, also known as *shunt*, among the most common crash configurations. They also highlight the risk imposed by heavy goods vehicles when they crash into lighter vehicles.

French data (Box 1) highlights fatigue and insufficient headway (the gap between two consecutive vehicles in a traffic lane, often measured in seconds) as fatal crash factors that are over-represented on motorways in comparison to other roads. Human factors are involved in 90% of fatal motorway crashes. The same data reveals that infrastructure factors are involved in 17% of fatal motorway crashes, much less than on two-way roads outside urban areas. A safe infrastructure helps explain why motorways are safer than other roads, and this also represents an opportunity for those designing and operating motorways to learn from the rare instances where infrastructure factors contribute to road crashes.

It would be wrong to treat a motorway as a road asset that is free of pedestrian traffic. In 2019, pedestrians represented 18% of victims on French motorways, a figure that has been rising since 2014 (ONISR, 2020). While the majority of pedestrian victims exit their vehicles following a breakdown or a crash, Cerema (2021) found that one in three pedestrians killed on French motorways in 2015 came from outside the motorway premises. ONISR (2020) adds that 80% of pedestrian fatalities on motorways occurred at night. This observation reinforces the need for authorities and road operators to communicate the need for pedestrians to escape the carriageway and wear high-visibility vests. This observation also demonstrates the need for all automated vehicles, even those whose operational design domain is limited to motorways, to accurately detect pedestrians.

Heavy goods vehicles and driver fatigue

Heavy goods vehicles are involved in a large proportion of traffic deaths on motorway networks: one-third in France (ONISR, 2020) and over 40% in the United Kingdom (Figure 3), where they represent only 11% of the traffic³. On Korean motorways in 2019, more than 50% of road fatalities involved a truck (Table 2). In addition, the fatality rate of truck crashes on motorways is higher than other types of crashes. On average in Korea, 100 truck crashes result in 2.8 road fatalities, but the figure is higher (9.3) on the

motorway network. Driver fatigue is a major cause of crashes. Truck drivers on long-distance trips under tight schedules represent a systematic risk.



Figure 3. Share of motorway fatalities from crashes involving heavy goods vehicles

Sources: ITF IRTAD database (2017-2019 average, except for Netherlands 2014-2016).

Motorways in France account for 8% of road fatalities but 29% of work-related road fatalities (ONISR, 2020). This suggests that motorway safety would particularly benefit from a range of measures targeted at the specific context of professional trips. The European Transport Safety Council (ETSC) maintains a library of such measures, some of which are highlighted in Box 4 (in the next section, on road safety management).

Crashes and casualties in 2019		All roads	Motorways	Ratio
All crashes	Number of crashes	229 600	4 223	1.8%
	Fatalities	3 349	206	6.2%
	Number of fatalities per 100 crashes	1.5	4.9	-
Crashes involving	Number of crashes	29 908	1 139	3.8%
trucks	Fatalities	835	106	12.7%
	Number of fatalities per 100 crashes	2.8	9.3	-

Table 2. Involvement of trucks in crashes and fatalities on the Korean motorway network

Source: KOTSA (2021).

Opportunities

Motorways are often considered as the ideal test site for automated vehicles and for Co-operative Intelligent Transport Systems (C-ITS). To automated vehicles, motorways are an environment that is much simpler than other roads due to the absence of pedestrians, curb activity and intersections. Due to the high volume of traffic observed on motorways, road operators are more inclined to invest in any roadside equipment in support of connected and automated vehicles.

Experts interviewed by the ITF suggested that motorway safety will particularly benefit from the wider adoption of driver assistance systems, such as automated emergency braking and lane-keeping technologies. Connected and automated vehicles are expected to eliminate human error and prevent the majority of crashes. However, although one can speculate about these benefits, their scale will be limited

by the market penetration of the new vehicles. Over the next decade, they risk distracting policy makers from proven and more traditional road safety measures.

Box 1. French analysis of the factors contributing to motorway deaths

In France, Cerema* has developed a database with crash causation factors covering 85% of the fatal crashes that occurred in 2015. Factors are divided into four groups: human behaviour, vehicle, infrastructure and traffic conditions. The most frequent fatal crash factors are "excessive or inappropriate speed" (38%), "alcohol" (31%) and "drug use" (17%); these are observed on all roads in general and on motorways also.

Cerema extracted 227 motorway crashes from this dataset and compared the factors involved, looking at 137 trigger factors and 16 severity factors. Several factors are over-represented on French motorways, in comparison with rural two-way roads:

- obstacles on the carriageway (3 times more likely), including stopped vehicles, animals, tyres and lost loads
- insufficient headway (3 times more likely)
- fatigue (2 times more likely)
- distraction by or misuse of digital tools (2 times more likely).

Other factors are under-represented: infrastructure factors, in general, are involved in 17% of fatal motorway crashes but in 33% of fatal crashes on two-way roads outside urban areas.

The study remains cautious on the use of crash factors. One should bear in mind that the original coding of the contributory factor depends on the personal interpretation and level of training of the police officer. The factors coded by the police primarily seek to establish faults and responsibilities, potentially ignoring some underlying factors. The study sought to review police-coded factors whenever possible.



Source: Cerema (2021) and ITF IRTAD country chapter for France.

Report structure

The UN Road Safety Trust Fund considers that road safety requires five pillars, presented in Figure 5. The structure of this report aligns with these pillars. It begins with a section on Road Safety Management, in which particular attention is placed on the adoption of Safe System principles. Considering the motorway context, this section also focuses on the readiness for co-operative intelligent transport systems.

Then, the report examines road user behaviours, with a focus on speeding and on driver fatigue. Another section examines the role of safe vehicles, and especially the value of connected and automated vehicles in motorway safety. The last two pillars of the UN framework, namely safe roads and effective post-crash response, are merged into one section.

The final section draws from international best practice to elaborate a set of recommendations applicable to all Korean stakeholders for a motorway safety action plan towards 2030.



Figure 5. New global framework plan of action for road safety

Source: UNRSTF (2018).

Road safety management

Perhaps the most important pillar for road safety action is road safety management, which the UN describes as follows:

In the road safety management pillar, action needs to focus on target setting, vertical and horizontal management as well as monitoring. Further action under this pillar should focus on coordination with other efforts linked to ensuring high-quality living conditions and mobility of the population covered through land use planning policies and mobility policies. While the work across the pillars and areas will be done by specific bodies, coordination of their work through road safety management may be enhanced by setting up a lead agency for road safety or designating a ministry to coordinate road safety, or it may be ensured by the national government. (UNRSTF, 2018)

Leadership, resources and targets

Australia, Canada, Italy, the Netherlands and Sweden have developed national road-safety strategies that adopt the Safe System approach (Table 3). The Safe System seeks to eliminate fatal and serious crashes and requires a systematic, multi-disciplinary and multi-sectoral approach. It involves the implementation of system-wide measures that ensure, in the event of a collision, that the impact forces remain below the threshold likely to produce either death or serious injury.

In addition to the countries listed in Table 3, Chile, Cyprus, Czech Republic, Denmark, Estonia, Hungary, Lithuania, Luxembourg, New Zealand and Slovenia have published national road-safety strategies that adopt the Safe System approach or a Vision Zero approach, or both (NTUA, 2021).

Australia

Government responsibilities for road safety vary across jurisdictions in Australia's federal system. The national government regulates safety standards for new vehicles and allocates the infrastructure resources necessary to maintain safety on both national highway networks and local roads. It also funds, plans, designs and operates the road network – as well as managing the vehicle-registration and driver-licensing systems and regulations and enforcing road user behaviour. Local governments are responsible for funding, planning, designing and operating the road networks in local areas (ITF, 2020).

The Australian government's main role in road safety is supported by the Department of Infrastructure, Transport, Regional Development and Communications, which administers new-vehicle safety standards, the National Black Spot Programme (other road funding) and the keys2drive programme, and produces national road-safety statistics. The Department also co-ordinated the National Road Safety Strategy 2011-2020 (Australian Infrastructure and Transport Ministers, 2020).

In July 2021, the Australian government established a new Office of Road Safety within the Department of Infrastructure, Transport, Regional Development and Communications. The Office of Road Safety is tasked with delivering the government's new and existing road safety programmes, engaging with road safety stakeholders, and co-ordinating performance monitoring and reporting on the National Road Safety Strategy (Australian Ministry of Infrastructure and Transport ministers, 2020).

Country	Authority	Safe System Approach	Vision Zero	Target for fatal casualties	Target for serious injuries
Australia	Office of Road Safety	Yes	Yes	-50% per capita by 2030, from a 2018-20 baseline	-30% per capita by 2030, from a 2018-20 baseline
Canada	Council of Ministers Responsible for Transportation and Highway Safety	Yes	Yes		
Germany	Ministry of Transport and Digital Infrastructure (contribution of various stakeholders)		Yes	-40% by 2030, from a 2021 baseline	
Italy	Ministry of Infrastructure and Sustainable Mobility (drafted by five universities)	Yes		-50% by 2030	-50% by 2030
Japan	Japanese Government (Cabinet Office, Ministry of Land, Infrastructure, Transport and Tourism, National Police Agency (developed by Central Traffic Safety Counter)			2 000 by 2025	22 000 by 2025
Korea	Ministry of Land, Infrastructure and Transport (joint effort of various organisations)			2 700 in 2021 from 4 621 in 2015	54 000 in 2021 from 91 114 in 2015
Netherlands	Ministry of Infrastructure and Transport (joint effort of various organisations)	"Sustainable Safety"	Yes	0 in 2050	0 in 2050
Sweden	Swedish Transport Administration	Yes	Yes	-50% by 2030 from a 2017-19 baseline	-25% by 2030 from a 2017-19 baseline

Table 3. National Road Safety Strategies beyond 2020

Sources: own elaboration based on expert interviews and derived from NTUA (2021), ITF (2019c) and ITF (2020). Notes: France, the United Kingdom and the United States are not listed because they have no national road safety strategy.

The Office of Road Safety has prepared a new Strategy for 2021-2030 and supports a five-year rolling National Road Safety Action Plan, which are expected to be endorsed by each State. The Safe System approach to road safety is well documented and integral to the National Road Safety Strategy for 2021-2030. Over the next ten years, this strategy intends to reduce the number of people killed or seriously injured in road crashes and to support the long-term goal of zero deaths and serious injuries by 2050. Fatalities per capita will be reduced by 50%, and serious injury per capita will be reduced by 30% as targets by 2030 (Commonwealth of Australia, 2021).

Unlike the previous National Road Safety Strategy for 2011-2020, the strategy for 2021-2030 adopted an enhanced governance framework, together with systems for performance management and reporting. Improved performance monitoring will allow for a more in-depth investigation of what is functioning and the quickest feasible modifications. The Strategy's progress is rigorously monitored using a set of safety performance metrics that reveal whether measures are effective and whether the work being done is transforming not just roads, but all aspects of the safe system. Independent assessment and analysis, such as through an external advisory committee, will play a significant role in delivering an annual report to the Infrastructure and Transport Ministers Meeting.

The National Road Safety Strategy for 2021-30 highlights the necessity to regulate and promote technologies for heavy vehicle safety (Commonwealth of Australia, 2021). Since 2013, policies for the safety of heavy vehicles have been developed through the creation of the Heavy Vehicle National Law (HVNL) and the establishment of the National Heavy Vehicle Regulator. The Strategy also fosters an organisational safety culture that takes responsibility for any harm that could occur in road crashes.

The five-year action plan will strengthen operational regulations and enforcement for heavy vehicle traffic. A formal process for recognising operators who have appropriate safety management systems is provided by the National Heavy Vehicle Accreditation Scheme. In addition, the Industry Master Code is a risk-based safety and compliance framework developed by the industry, and it includes a set of national standards and procedures to help parties in the chain of responsibility identify and manage risks in order to satisfy their HVNL duties. For example, when anyone requires a permit or order to perform any transport tasks within Western Australia, the Western Australia Heavy Vehicle Accreditation is mandatory (Office of Road Safety, 2021).



Figure 6. At a glance: The Australian National Road Safety Strategy for 2021-2030

Source: Commonwealth of Australia (2021).

Box 2. Australian National Policy Framework for Land Transport Technology: Action Plan 2020-2023

In terms of introducing technology into the transport sector, Australia has a three-year *National Policy Framework for Land Transport Technology: Action Plan 2020-2023*, prepared by the Transport and Infrastructure Council, which brings together transport and infrastructure ministers from the Commonwealth, States, Territories, and New Zealand, as well as the Australian Local Government Association. This plan strategically incorporates the benefits that the new technologies could bring to improve safety, efficiency, sustainability and accessibility.

The plan promotes active traffic management solutions on motorways that combine systems – such as variable speed limits, on-ramp signalling, and variable message signs – that have enhanced traffic flow on motorways in Brisbane, Melbourne and Sydney. These investments are typically low-cost and high-return, and they can help to postpone the need for costly construction projects. The implementation of ramp metering on Melbourne's Monash Freeway, for example, increased throughput by 19% during the morning rush hour, obviating the need for widening.

Co-operative Intelligent Transport Systems (C-ITS) allow each vehicle to communicate with other vehicles (V2V), roadside infrastructure (V2I), and other devices, such as mobile phones (V2P). Given that a combination of connected and automated technology is needed to achieve the greatest possible reductions in traffic congestion and safety, the Australian governments are already preparing for the introduction of C-ITS-equipped vehicles. Automated vehicles may employ V2V to detect obstacles that are not in the line of sight.

The Co-operative Intelligent Transport Initiative (CITI) is one of the world's first large-scale test projects of vehicle-to-vehicle and vehicle-to-infrastructure communications in heavy vehicles. The study is taking place in New South Wales, on a 42-kilometre stretch of high-risk route where crashes often involve heavy vehicles. The EUR 0.88 million (AUD 1.4 million) project is funded by the Australian and New South Wales governments. The government of New South Wales aims to improve road safety on motorways through trials of V2I communications in heavy vehicles.

Source: Transport and Infrastructure Council (2020).

Canada

Canada has adopted the Vision Zero⁴ approach as an inspirational goal. This is evident in the country's fourth national road-safety plan, "Road Safety Strategy 2025", known as RSS 2025. In this plan, the vision of making Canada's roads the safest in the world is combined with a long-term vision towards zero fatalities and serious injuries on the roads. RSS 2025 (CCMTA, 2016) was put in place in 2016 and looks forward to 2025. It places greater emphasis on vehicle technologies and roadway infrastructure.

Among the key principles included in the RSS 2025 are adopting the Safe System approach and providing an inventory of proven and promising best practices to address key risk groups and contributing factors. As motorways have higher design standards and are considered safer, most best practices target vulnerable users and urban movements. Nonetheless, best practices for motorways include variable messaging signs, automated speed-enforcement cameras, variable/seasonal speed limits, de-icing techniques, designated truck lanes, rest areas and rumble strips. For each practice, literature is used to document the benefits provided by its application. In Canada, responsibility for road safety falls to the different jurisdictions, which makes them responsible for adopting Vision Zero targets. A number of municipalities and cities have developed strategies with the Vision Zero goal in mind, with Toronto, Ottawa, and Vancouver being the most prominent ones.

In the United States, different elements of road safety responsibility also fall at different levels. Therefore, the adoption of Vision Zero falls to the different levels of government, such as the state or city level. Nonetheless, federal authorities such as the National Highway Traffic Administration (NHTSA) and the Federal Highway Administration (FHWA) actively support efforts towards that goal. They also work to advance safety culture and a Safe System approach together with their partners at different levels.

The US federal government is responsible for setting standards for motorway design and vehicle technologies. Given the country's market size and the influence it has in manufacturing, it has the ability to significantly contribute to the Vision Zero goal by setting guidelines in line with the Safe Systems approach. For example, star-rating systems for new vehicles have been used to promote new safety systems. The authorities set a new safety feature as necessary to obtain a 5-star rating; vehicle manufacturers then add this safety feature in their new vehicles in order to get or maintain their rating.

Germany

Germany adopted Vision Zero on 2 June 2021, when the German Federal Cabinet approved the Road Safety Program for the period 2021-30 (BMVI, 2021). It is not seen as a rigid plan but as an adaptive process that should be regularly checked and adjusted. With this broad approach, the federal government wants to involve not only the federal states and municipal organisations but also relevant associations, institutions and companies. The areas of focus are the following:

- consideration of the potential of automated and new technology vehicles to improve road safety
- driver assistance systems
- improvement of the road infrastructure
- inclusion of traffic safety when designing cycling policies
- development of crash surveys and improvement of data quality
- continuous update of road safety programmes.

A target of reducing road fatalities by 40% by 2030 has been set from a 2021 baseline⁵.

The programme was anticipated by a Road Safety Pact agreed in 2020 (BMVI, 2020). The idea is that all actors should combine their efforts with a common strategy in order to improve road safety. The Federal Ministry of Transport and Digital Infrastructure developed the new approach together with federal states, municipalities and other stakeholders. For the first time, the federal, state and local governments decided on a joint road-safety strategy together. All the actors committed themselves to suitable measures in their respective areas of responsibility. The Federal Ministry assumes responsibility for the spheres of legislation, research and development funding and the road infrastructure under its competence; the Road Safety Program is the federal government's contribution to the strategy. The federal states and local authorities are responsible for the spheres of monitoring, road safety education and the road infrastructure under their competence. The industries develop the necessary technology, while trade associations and other players support the integration of road safety activities in the stakeholder groups as well as measures to improve road safety within their institutions. A total of 12 action areas establish priorities and identify the scope for improvement in road safety activities:

- safe mobility everyone is responsible, everyone joins in
- mobility of children and young people
- safe cycling
- safe walking and inclusion for everyone
- motorcycling fun and safe
- learning in an age of changing mobility
- emerging technologies, automation and the digital revolution
- freight transport and logistics
- mitigating the consequences of crashes
- future-proof standards and regulations from speed regulation through road design to vehicle development
- improving highway culture
- promoting and improving existing and effective measures and implementing them nationwide.

Italy

In January 2021, Italy published a *General Guideline for the Strategy Plan on Road Safety 2030* (Ministero delle Infrastrutture e della Mobilitá Sostenibili, 2021). The Safe System approach will be the basis of the new strategy, which has five pillars: road safety management, safer roads, safer vehicles, safer road users and post-crash assistance.

The plan sets a generic target of halving road fatalities by 2030 from a 2020 baseline level; as the estimated road fatalities for 2020 are 3 029, the target for 2030 will be to have less than 1 515 road fatalities. The generic target will also include the reduction of serious injuries. The final target is to eliminate road fatalities by 2050, in line with the European Union's Vision Zero approach.

In addition, the plan sets specific targets for cyclists, pedestrians, users of motorised two-wheelers, children and people over 65. For each category, the main risk factors and some specific guidelines have been identified; the plan will develop the necessary actions and policies accordingly.

The plan sets intermediate targets at three-year intervals. This will allow the authorities to evaluate the benefits of what is implemented and update the plan if needed.

The Strategy Plan on Road Safety 2030 will be approved by the end of 2021 and there will be five action plans, one every two years, starting in 2021.

Japan

In Japan, the National Cabinet Office oversees traffic safety policies. The National Police Agency is responsible for traffic enforcement, traffic regulation, safety facilities management and driving license administration within the 47 prefectures. The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) is responsible for building and maintaining safe-road infrastructure and managing safety vehicle standards. The Ministry of Education, Culture, Sports, Science and Technology (MEXT) is in charge of traffic safety education in schools.

The government of Japan formulates a Traffic Safety Programme every five years in accordance with the Basic Law on Traffic Safety Measures.

In order to improve the safety, reliability, and ease of use of expressways, the MLIT has adopted three goals:

- to realise the safest expressways in the world with the lowest road crash rates
- to ensure that expressways remain strong and resilient to all kinds of disasters
- to make expressways that are easy to use, comfortable, and safe for all drivers, especially elderly drivers (Japanese Cabinet Office, 2021).

The 11th Traffic Safety Programme was formulated by the Central Council for Traffic Safety Countermeasures, headed by the Prime Minister, in March 2021. The programme sets forth the direction of comprehensive and long-term measures for traffic safety and covers the fields of road traffic, railway traffic, traffic at level crossings, maritime traffic, and air traffic.

For road traffic, the programme sets clear targets: "the number of fatalities caused by road crashes within the 24 hours following the crash will be 2 000 or less by 2025, and the number of serious injuries will be 22 000 or less by 2025." The programme also highlights that there is a shortage of labour forces in a wide range of fields and occupations related to transport due to Japan's ageing society. In this context, the importance of training to ensure the quality of human resources, for instance, planners and road engineers, is highlighted. Considering the total number of fatalities caused by road crashes was 4 117 in 2015, this objective is ambitious (Japanese National Police Agency, 2015).

The programme acknowledges that human beings make errors, and seeks to prevent these errors from leading to crashes. As most road crashes involve driver error, automated driving has the potential to contribute to a dramatic improvement in road safety. Yet as the technology is still under development, it should not distract from the delivery of other traffic safety measures. The first international standards for automated navigation equipment (Level 3), cybersecurity and software updates were established by Working Party 29 (WP29) of the World Forum for Harmonization of Vehicle Regulations. In Japan, a similar standard for automatic guided vehicles came into force on 1 April 2020, prior to the adoption of this international standard (MLIT 2020c). This also limits lane-keeping functions that operate in traffic jams on motorways.

Basic plan for safety and security on motorways

The MLIT is leading the implementation of concrete measures to improve road safety on motorways. It formulated the "Basic Plan for Safety and Security on Motorways" in response to the "Basic Policy for Efforts to Improve the Safety, Reliability and Ease of Use of Motorways" compiled by the National Highways Division of the Roads Subcommittee of the Social Infrastructure Development Council in December 2019 (Japanese MLIT, 2019b).

The number of traffic crashes on motorways has decreased by approximately 30% since 2008 (Japanese MLIT, 2019b). In order to further reduce the number of traffic crashes, the MLIT has identified approximately 300 crash-prone points (covering approximately 10% of the total length of the motorway networks) where the rate of crashes resulting in death or injury is more than twice the average for motorways. It investigates the causes of crashes and implements countermeasures at those locations.

The plan outlines how motorways should accommodate automated vehicles. Creating dedicated space for such vehicles, promoting V2I technology, and developing high-precision three-dimensional maps are highlighted as ways to enhance road safety on motorways. The plan sets ambitious objectives, including:

- fully automated (level 4) driving of private cars on highways by 2025
- commercialisation of unmanned rear-vehicle convoy driving systems (between Tokyo and Osaka) from 2022 (Japanese MLIT, 2019b).

The plan acknowledges a shortage of parking space for large vehicles, especially late at night, combined with a shortage of rest facilities on motorways. It is also necessary to improve the spacing of rest facilities on motorways. The MLIT is also discussing how to promote the recharging of electric vehicles and refuelling of hydrogen vehicles at rest facilities.

Considering the severe shortage of truck drivers, the development of the infrastructure environment to promote the use of double-coupled trucks is another important topic. In 2019, the vehicle length of the special vehicle permit standard was relaxed, enabling logistics companies to use double-coupled trucks; and, in response to the needs of logistics companies, the MLIT expanded the number of routes covered (Japanese MLIT, 2019b).

The MLIT sets goals for the commercialisation of manned-convoy driving systems by 2021, and an unmanned convoy system between Tokyo and Osaka by 2022. In anticipation of the realisation of trucks driving in convoys on motorways, several motorways will be widened to accommodate six lanes⁶ (Japanese MLIT, 2019b).

National ITS plan for 2030: Public-private ITS concept and roadmap

Public-Private ITS Concept and Roadmap, a document outlining the direction of policies for ITS and automated driving, was first formulated by the Japanese government in 2014. Most recently updated in 2020, the roadmap is revised annually based on the latest social conditions and technological innovations. The roadmap aims to build the world's safest and smoothest road transportation society by 2030 (Japanese Cabinet Office, 2020).

In the roadmap, the targets to be achieved in each measure are listed for short-term (2020-22), mediumterm (2023-25), and long-term (2026-30) phases. Specifically, in 2020, (1) the market launch of automobiles capable of automated driving (Level 3) on motorways, and (2) the provision of unmanned automated driving services in limited areas (depopulated areas, etc.) should be achieved – followed by the market launch of Level 4 automated driving systems on motorways, the widespread introduction of automated driving systems in logistics, and the nationwide spread of unmanned automated driving services in limited areas by 2025.

Looking ahead over the next 5 to 15 years, this plan aims to build the "safest road transport society in the world" and to build and maintain the "world's safest and smoothest road transport society" by 2030, through the development and diffusion of automated driving systems and the improvement of data infrastructure. Japan plans to expand the overseas deployment of vehicles and infrastructure for ITS and automated driving through collaboration between the public and private sectors with the aim of remaining a world centre of innovation in automated driving (including the development of data infrastructure) beyond 2020 (Japanese Cabinet Office, 2020).



Figure 7. Scenario for the commercialisation and service of fully automated driving by 2025

Source: Japanese Cabinet Office (2019).

Initiatives for expressways

Realisation of Automated driving on motorways (level 4) by 2025: The market launch of cars with Level 3 automated driving systems on motorways by 2020 is expected to be followed by the market launch of cars with Level 4 automated driving systems on motorways by 2025. Level 4 allows automated driving from the entrance to the exit of the motorway, and automatically stops the vehicle on the shoulder in situations that fall outside the specific conditions under which automated driving systems are designed to function.

The MLIT has been conducting joint research with the public and private sectors since 2018 on a system to provide information from the roadside to support automated driving in complex traffic environments such as merging areas on expressways.

Widespread use of driver assistance systems: Because measures to prevent traffic crashes involving older drivers have recently become a particularly urgent issue, in 2017 the Japanese government published a report titled "Interim Summary of the Meeting of Deputy Ministers of Relevant Ministries and Agencies on the Promotion and Awareness of Safe Driving Support Vehicles". The report promotes the concept of "safe driving support vehicles", which are vehicles equipped with collision damage mitigation brakes. The MLIT promotes and raises awareness of safe driving support vehicles, expands automobile assessment, and establish standards for advanced safety technologies.

In 2020, The Ministry of Economy, Trade, and Industry and the MLIT began accepting applications for a "Support Vehicle Subsidy" that subsidises the purchase of vehicles that support safe driving and are equipped with collision damage mitigation brakes and pedal-misapplication control devices for drivers aged 65 or older, and the introduction of retrofit pedal-misapplication sudden-departure control devices. By the end of March 2020, a total of 215 models for which applications were submitted (by eight Japanese manufacturers) had been certified. In addition, a logo mark was created for automobile manufacturers to use in their public relations activities to promote the use of collision damage mitigation brakes. At the same time, in response to the entry into force of the international standard for collision damage reduction brakes in 2020, a domestic standard was formulated and the start date of the mandatory requirement for new vehicles was set (Japanese Cabinet Office, 2020).

Netherlands

The Sustainable Safety vision is an optimal approach for improving road safety shared by many road safety professionals. A sustainably safe road-traffic system prevents road deaths, serious road injuries and permanent injuries by systematically reducing the underlying risks of the entire traffic system. Human factors are the primary focus: by starting from the needs, competencies, limitations and vulnerability of people, the traffic system can be realistically adapted to achieve maximum safety.

There are five road-safety principles, three for design and two for organisation: functionality, (bio)mechanics, psychologics, allocating responsibility, and learning and innovating in the traffic system. The Netherlands also takes a risk-based approach in regards to safety. In this approach, authorities first determine the risks, then decide how to tackle them, using crash statistics and road safety performance indicators as a basis for action.

With regard to motorways, according to Sustainable Safety guidelines⁷, there should be a physical separation between driving directions, there should be no at-grade intersections, and there are guidelines for establishing obstacle-free zones for different speed limits. This is according to the biomechanics principle. Moreover, information (signs, markings, etc.) should be clear and understandable and drivers should not be overloaded with information (psychologics principle).

Within the Sustainable Safety vision, the Netherlands has a robust framework for motorway design and maintenance. In 2020, nearly EUR 3 billion was invested in the construction and maintenance of roads, with a significant share of that going to motorways. There are regular audits and road inspections, to address any issues before they become a concern for safety. Audits and inspections are a routine part of motorway design and safety management. Audits and inspections in the Netherlands follow the EU directive for road infrastructure safety management (Box 3).

Box 3. European Union: Directive for Road Infrastructure Safety Management

The European Directive 2019/1936 on Road Infrastructure Safety Management requires the establishment and implementation of procedures relating to road safety impact assessments, road safety audits, road safety inspections and network-wide road safety assessments by the Member States. It amends Directive 2008/96/EC on road infrastructure safety management.

The directive applies to all motorways in the European Union, whether they are at the design stage, under construction or in operation. The directive proposes to adopt the following definitions:

- "Road safety impact assessment" means a strategic comparative analysis of the impact of a new road or a substantial modification to the existing network on the safety performance of the road network.
- "Road safety audit" means an independent, detailed, systematic and technical safety check relating to the design characteristics of a road infrastructure project and covering all stages from planning to early operation.
- "Safety rating" means the classification of parts of the existing road network into categories according to their objectively measured in-built safety.
- "Targeted road safety inspection" means a targeted investigation to identify hazardous conditions, defects and problems that increase the risk of crashes and injuries, based on a site visit of an existing road or section of road.
- "Periodic road safety inspection" means an ordinary periodical verification of the characteristics and defects that require maintenance work for reasons of safety.
- "Network-wide road safety assessments" shall evaluate accident and impact severity risk, based on: (a) primarily, a visual examination, either on site or by electronic means, of the design characteristics of the road (in-built safety); and (b) an analysis of sections of the road network which have been in operation for more than three years and upon which a large number of serious accidents (in proportion to the traffic flow) have occurred.

The directive requests that member states conduct a network-wide road safety assessment at least every five years. The assessment should evaluate the risk of serious crashes based primarily on a visual examination, either on site or by electronic means, of the design characteristics of the road. For greater transparency, the directive requires the reporting, every five years, of the safety classification that results from the network-wide road safety assessment.

Source: EC (2008).

Sweden

The basis of Swedish road safety work is Vision Zero, a strategic approach towards a safe system, where no one is at risk of being fatally or seriously injured while using road transport. This approach was introduced in Sweden in 1997 and received strong political support at an early stage of its development, becoming widely established as a result of co-operation between the various players in the road safety sector. In 2004, the Swedish parliament confirmed their support for Vision Zero as a long-term strategy for road safety.

According to this approach, the main problem is not that crashes occur, but that crashes can lead to death or lifelong injury. The road transport system is an entity whose components – such as roads, vehicles and road users – must interact in a way that prevents death or serious trauma. In order to prevent serious results from crashes, it is essential for the roads, and the vehicles they carry, to be adapted to match the capabilities of the people that use them.

One of the main characteristics of Vision Zero is management by objectives and results. Traditionally, road safety work has focused too narrowly on road rules. With the new approach, legislators start by setting road safety objectives and then design and implement policies accordingly. Relevant indicators are measured, monitored and discussed at annual conferences. In 2018, the Swedish Transport Administration published an action plan to improve road traffic safety in 2019-22. The plan suggests 111 measures for the 14 authorities and stakeholders to implement, focusing on three areas: right speed, sobriety in traffic and safe cycling (Lindberg, 2019).

The Swedish government set new targets for 2030 of reducing (a) the number of fatalities by 50% between 2020 and 2030 based on the average number of fatalities for 2017-19 (corresponding to a maximum of 133 road deaths in 2030) and (b) the number of persons seriously injured by 25% during the same period.

United Kingdom

In July 2019, the government published the *Road Safety Statement 2019: A Lifetime of Road Safety*. It sets out a two-year action plan containing 74 action measures. The statement initiates a transition towards a safe-system approach as follows:

The statement emphasises the mentality shift towards a safe system approach, which commits the department to the idea that road deaths and casualties are not merely the result of poor driving but of a transport system as a whole, from signage to road user education, from enforcement to infrastructure design and construction. The effect of this approach should be to raise standards and improve co-ordination so that avoidable road deaths and injuries are reduced to an absolute minimum. Accordingly, national and local agencies, road safety charities, stakeholder groups, emergency services and other actors are integral to achieve safer roads. (ITF, 2020, UK chapter)

The UK Department for Transport works to support the safe testing, sale and use of connected and automated vehicles. The Department believes automated vehicles could make road transport safer and more accessible, as well as provide the UK with productivity and industrial opportunities. It is working with legal experts to identify where in the UK motoring laws may need to be changed to support the safe use of automated vehicles, and to provide potential solutions (DfT, 2019a).

Box 4. Addressing work-related road risk

The European Transport Safety Council (ETSC) has conducted several case studies and pieces of policy research on the reduction of work-related road risk, especially in the context of road haulage companies. ETSC reports make several government-level recommendations that could make a difference to motorway safety:

- Provide guidance and support to road haulage companies on how to conduct a work-related road risk assessment, with supporting examples and case studies. This includes work-related road risk management materials which are accessible and relevant for small and large organisations.
- Promote the business case through targeted information dissemination to employers about investing in and benefitting from work-related road safety.
- Oblige employers to reveal the identity of an employee if they committed a traffic offence that has been recorded by a safety camera.
- Encourage employers via financial incentives to fit and purchase vehicles with in-vehicle technologies that have a high life-saving potential.
- Dedicate resources to adequate enforcement for road haulage regulations, including through tachograph checks.
- Require periodic professional driver training that includes road safety topics, are up-to-date with the latest developments in technology and legislation, and are relevant to the driver.
- Require that the intensity of tachograph checks and associated penalties remain at a level that prevents fraud.
- Develop specific guidance for integrating work-related road safety, through incentives or requirements, into public procurement. Establish a centralised certification service for suppliers who are in compliance with work-related road risk management legal requirements and have safe work policies.
- Promote and schedule the mandatory adoption of in-vehicle safety technologies including Intelligent Speed Assistance, Alcohol Interlocks, Advanced Seat Belt Reminders on all seats, Autonomous Emergency Braking and Event Data Recorders.

Source: ETSC (2017 and 2020).

Evaluation, modelling and in-depth investigations

The United States has also developed a repository of countermeasures, similar to Canada. They are grouped together in a publication titled Countermeasures That Work (NHTSA, 2017). It compiles measures, policies, enforcement and other aspects of road safety, using evidence to demonstrate their effectiveness, and providing information on how they are used, costs, and timeframe. Regarding motorways, it includes measures such as variable message signs, divided highways, use of cameras for automatic enforcement, and speed limits.

Box 5. Current Road Safety Decision Support Systems Worldwide

Several resources exist that constitute a library of road safety countermeasures coming with an assessment of their effectiveness in various situations. Their use is recommended when seeking to reach ambitious road safety targets:

- SafetyCube, EU Road Safety DSS, <u>https://www.roadsafety-dss.eu</u>
- Safe Future Inland Transport Systems (SafeFITS), a global road safety model, <u>https://unece.org/safefits-road-safety-decision-making-tool</u>
- iRAP, Road Safety ToolKit, <u>https://toolkit.irap.org</u>
- PRACT repository, by CEDR, <u>https://www.pract-repository.eu</u>.
- PIARC, WRA Road Safety Manual, <u>https://roadsafety.piarc.org/en</u>
- US NHTSA/FHWA CMF Clearinghouse, <u>http://www.cmfclearinghouse.org</u>
- Austroads Road Safety Engineering Toolkit, <u>https://austroads.com.au/safety-and-design/road-safety/road-safety-tools</u>.

Source: Yannis (2018).

Modelling

Modelling the expected outcome of road safety policies and actions is one of the keys to a successful roadsafety action plan. It helps scale the resources to match the level of ambition. In 2019, the European Commission undertook a modelling exercise when assessing the benefits of policies that accelerate the uptake of connected vehicles (EC, 2019). In 2015, Highways England undertook the modelling of safety effects of all-lane running, finding that the tripled likelihood of live-lane breakdowns would be more than compensated by the benefits brought by variable speed management (Highways England, 2015).

Modelling the expected number of casualties avoided also helps make the business case for a road-safety action plan. Making the case for road safety interventions often involves a concept called the value of statistical life (VoSL). The concept helps authorities allocate resources to road safety actions in a way that is proportionate to the number of lives expected to be saved.

For the ITF (2016a), good-practice countries adopt a rational framework for resource allocation based on cost-effectiveness and cost-benefit analysis using the willingness-to-pay methodology to establish the VoSL and ensure life-saving solutions are funded and supported by a robust economic theory.

The OECD (2012) offers guidance on how willingness-to-pay surveys can be used to assess policies that affect mortality risks. It proposes a range for the average adult VoSL for OECD countries of USD (2005 USD) 1.5 million – 4.5 million, with a base value of USD 3 million.

For Korea, the OECD Environment Directorate has updated the figures for 2019 and suggests using a VoSL of KRW 3 590 million (EUR 2.75 million)⁸. Korean authorities use much lower values, however, which inevitably reduces the economic feasibility of road safety projects. KoROAD (2017) estimated the VoSL at EUR 320 000 using the "gross loss of output" approach (ITF 2020). KOTI (2021) later computed the VoSL at EUR 540 000. A review of the VoSL calculation methods in Korea seems appropriate and may close the gap between values suggested by the OECD and values used in practice.

In-depth investigation

Several countries fund permanent programmes of in-depth investigation based on a sample of crashes, focusing on fatal and severe crashes. Carried out by independent researchers, the programmes do not seek to establish criminal liability, but rather to identify the parts of the transport system that have failed and contributed to the crash. At times of rapid change in-vehicle technology, especially with driver assistance systems and vehicle automation, such programmes seem more important than ever. They can benefit from a legal framework that enables the analysis of black boxes found on vehicles (also known as event data recorders or EDRs) and ensures vehicles are fitted with such equipment.

In-depth investigation can uncover crash causation patterns thanks to the analysis of information that would not normally be reported to a national crash data system. In-depth investigation consists in collecting and analysing data from a road crash. This data is gathered by a team of crash investigators, usually at the scene of the crash. The team collects a predefined set of crash data by examining the road environment and vehicles involved and by interviewing the people involved in the crash, either directly (drivers, passengers, etc.) or indirectly (witnesses, emergency personnel, etc.). The objectives and methods used for the analysis are typically defined within a research study or a crash investigation programme.

In-depth investigations are usually conducted for specific types or very serious types of crashes. There have been several projects and programmes including in-depth analysis of various samples of crashes. Some are national (e.g. the German In-Depth Accident Study – GIDAS; the United Kingdom's On The Spot Road Accident Database; Swedish Traffic Accident Data Acquisition – STRADA), while some are EU- or US-funded projects (Motorcycle Accidents In Depth Study – MAIDS; European Truck Accident Causation – ETAC; Large Truck Crash Causation Study – LTCCS; Pan-European Co-ordinated Accident and Injury Database – PENDANT; SafetyNet).

To conduct timely and proper in-depth investigations, teams should be readily available to evaluate crashes that meet the sampling criteria. These teams should be unaffiliated with the national authority and the road operator, in order to provide an objective and non-biased assessment of the crashes and their causes. The investigators should collect all relevant data before proceeding with the analysis. Several methods of investigation can be employed to explain how the system behaves, how the different elements of the system (the vehicles, road, etc.) interact with each other, and what the possible factors are that may contribute to a system failure, i.e. a crash. Where possible, the data should be collected on-scene while the involved parties are present. The results of the analysis should be recorded both in a report and in a dedicated crash database, in order to facilitate further aggregated analyses. The report should contain at least the method of investigation and the evidence to support the conclusions; the identified crash causes and any factors that may have increased the severity of the crash; and recommendations designed to prevent the reoccurrence of similar crashes (SafetyNet, 2008). More details about in-depth investigations can be found in a report from ITF on road infrastructure safety management (ITF, 2015a).

Since its launch in 1999, the German In-Depth Accident Study (GIDAS) has performed an in-depth analysis of about 2 000 injury crashes each year. The programme seeks to collect comprehensive real-world crash data. GIDAS is a co-operative project between the Federal Highway Research Institute (BASt) and the German Association for Research in Automobile Technology (FAT). It involves many partners including vehicle manufacturers, equipment suppliers and universities. So that it can address all the technical, medical, psychological, infrastructural and legislative aspects of road safety, it is interdisciplinary. It helps the industry develop, evaluate and observe active and passive safety systems and automated driving functions. It is highly detailed yet anonymous. Its sampling frame makes it representative of crashes over the entire country and up-to-date with recent safety systems and trends. The team of investigators arrives

on the crash scene within 15 minutes on average, after they are alerted by police or fire services. Information is collated into a GIDAS database that is constantly evolving: since 2005, more than 100 changes have been made each year to the data model to address current aspects of active safety and topics like advanced driver assistance systems (ADASs), accident avoidance and mitigation, accident initiation, and causal factors (Liers, 2018).

Safe road users

Nine out of ten fatal crashes on the French motorway network involve one of several factors related to driver behaviour. Until the day when automated systems have replaced all human drivers, it remains critical to address factors such as speeding, distraction, fatigue, seat belt use and alcohol use.

Although solutions are largely known and well documented, their implementation across the world varies considerably. Enforcement and education should be delivered jointly and should match the level of ambition established in road safety plans.

Speeds and headway

In a review of the relationship between speed and crash risk, the ITF (2018a) found that a reduction in average speed from 120 to 115 km/h results in a 28% reduction in road deaths. This reveals an elasticity value of 8 for road deaths in relation to average speed. In other words, every 1% reduction in motorway speed results in an 8% reduction in motorway traffic deaths.

Each year, the UK Department for Transport (DfT) reports detailed figures on speeding and headways on motorways in Great Britain, using automatic traffic counters (ATCs) at 19 locations. Data collected in 2019 in free-flow conditions found 50% of car drivers and 1% of heavy goods vehicle drivers over the applicable speed limits, which are 113km/h (70mph) for cars and 97km/h (60mph) for heavy goods vehicles ⁹. Vehicle headway data is collected using ATCs on motorways' inside lanes¹⁰ which measure the time between two vehicles passing over the sensors. Data from 2019 shows that 15% of heavy goods vehicle drivers fail to maintain at least a two-second headway with the vehicle in front¹¹. The Highway Code (rule 126) states that all drivers "should allow at least a two-second gap between you and the vehicle in front on roads carrying faster-moving traffic", and "this should be at least doubled" in inclement conditions.

The UK DfT uses the same approach to release quarterly speeding statistics¹² that could prove useful in the evaluation of enforcement and education campaigns. Quarterly data reveals a record proportion (15%) of vehicles exceeding the motorway speed limit by 16km/h (10mph) or more from April to June 2020, probably due to the lower traffic volumes observed at times of the most severe travel restrictions related to the Covid-19 outbreak.

A French study of motorway driver behaviour found 29% of drivers adopting unsafe headways (less than two seconds) in the fast lane. The most recent automatic safety cameras in France are designed to enforce headways.

The enforcement of speed limits is, therefore, a cornerstone of a motorway safety policy. The French success with automatic speed enforcement is further evidence of this. The efficacy of enforcement is determined by two factors combined:

- 1. The intensity of police controls, and the use of automatic tools
- 2. The level of sanctions typically the cost of financial penalties, but also the use of non-financial penalties (seizing a vehicle, license ban, community work, demerit points, etc.).
Figure 8. Comparison of speeding penalty ranges across countries



Penalty (EUR) for speeding 21 km/h above the speed limit on motorways

Penalty (EUR) for speeding 51 km/h above the speed limit on motorways



Note: These figures were calculated on June 2021.

Figure 8 shows that Australia, Italy, the Netherlands and Sweden impose financial sanctions of between EUR 170 and EUR 695 to drivers caught driving 21 km/h above the speed limit on a motorway. The lower fine imposed in Korea stands as an outlier that could undermine the efficacy of police activity and discredit any communication campaign on safe speeds. Norway has the highest speeding tickets of all European countries at EUR 640 for speeds 21 km/h above the speed limit on motorways¹³.

For exceeding the speed limit by 51 km/h on motorways, Korean drivers receive a EUR 67 ticket, which is disproportionately low compared to the ten-times-higher fine imposed in Japan and the fines of EUR 1 000 and more imposed in France, the Netherlands, and the states of South Australia and Ontario. The

United Kingdom, together with Switzerland and Finland apply so-called "progressive punishment" to speeding fines. The cost of a speeding ticket In the United Kingdom can reach 175% of a driver's weekly income but is capped at EUR 2 900 (GBP 2 500)(McKenna, 2018).

In order to ensure safe working space in motorways, countries often increase speeding fines when works take place. For example, in several US states, speeding fines are doubled in construction zones. This is one of the reasons why Figure 8 shows a range of values for the speeding penalty in US states.

Another reason why speeding penalties vary within the same country is because of discounts offered for early payment. This is the case in France, where penalties paid within 30 days are discounted by 33% (conversely, penalties are nearly tripled if not paid within 60 days).

The role and powers of motorway operators

In France, Delahaye (2017) recommends that authorities use motorway tolling equipment to enforce average speed limits. Already tested in 1999 by motorway operator SAPRR, the solution was announced in 2002 by the French Inter-Ministerial Road Safety Committee but never implemented. One should bear in mind that some additional costs would accrue for the type approval of tolling equipment in light of this new enforcement purpose.

Toll motorway operators do not need any police support to know how many and which vehicles are speeding: toll collection equipment collects timestamped, geolocated vehicle identifiers and can easily compute an average speed between two points. According to interviews conducted in more than ten countries, it appears that no motorway operators are taking action on this basis to deter speeding. Experts believe that motorway operators have no interest in doing so, and are under no pressure from the regulators.

In a safe system, however, one would not miss such an opportunity to address speeding – a behaviour that risks the lives of innocent road users and operational staff. One could envisage at least two routes: (a) operators collaborate with the police to integrate their entire tolling system with the police enforcement systems or (b) operators seek the powers required to enforce speed violations. The latter comes with several drawbacks, however, namely the lack of interest in speeding enforcement and the inability to connect with the demerit point system.

The UK has acquired decades of experience with civil enforcement of parking and moving-traffic offences (e.g. the use of bus lanes). Across England, over 12 million penalties are delivered by local authorities for such offences each year¹⁴. In some areas, the questionable use of incentives and targets by local authorities has generated a sense of distrust among the population (Snow, 2017). Adjudication courts have been created to mitigate such problems.

In London, local authority leaders are calling for speeding offences – up to a certain speed threshold – to be decriminalised. This would relieve pressure on police resources that are already stretched while generating revenue for local authorities to spend on traffic and safety management. The change would require legislative change as well as a system that continues giving demerit points, regardless of the civil or criminal nature of the offence¹⁵.

One lesson from the UK experience is that police powers can be reviewed in situations where other stakeholders (such as local authorities or transport operators) are likely to perform civil enforcement more efficiently than police forces perform criminal enforcement.

Section speed control

Several countries in Europe, including the Netherlands, Italy, the Czech Republic, Great Britain, Austria and Belgium use automatic "time over distance" cameras on motorways and in tunnels (ETSC, 2015). This helps to make drivers adhere to speed limits along entire sections and results in more fluid traffic. Section speed control in Belgium has reduced crash numbers by 15% – while also reducing speeds further downstream, a phenomenon known as a "halo effect" (TML, 2015).

In the UK, a total of 410 km of roads were already equipped with average-speed cameras in 2015, including the 160 km stretch of the A9 in Scotland. On average, the permanent average-speed camera sites analysed by Owen, Ursachi and Allsop (2016) saw reductions in injury collisions, especially those of a higher severity: fatal and serious collisions fell by 25-46% while personal injury collisions fell by 9-22%. The results are not specific to motorways, but authors found no statistically significant difference in the effect on fatal and serious casualties between sites with high and low speed limits.

On the KEC network, conventional spot-speed cameras are installed on 794 spots – that is, every km on average. In addition, sectional speed enforcement systems (SSESs), which check the average speed of a vehicle in an enforced section, were introduced in 2007 to make up for the shortcomings of conventional spot speeding detection systems. Drones and undercover patrols are also playing a role in enforcement. Among these measures, SSES has proven effective and has been expanded to 61 segments covering 676 km in total (8% of the KEC network). According to research conducted on nine sections with an SSES, the SSES contributed to a 42% reduction in the number of fatal and serious crashes. According to a before-and-after analysis on 15 SSES-enforced sections conducted by the KEC Research Institute, the average travel speed decreased from 101 km/h to 95 km/h and the standard deviation of vehicle speed substantially decreased from 8 to 6 km/h. This shows that the SSESs make traffic more homogeneous, with smaller speed differences among vehicles (Jung et al., 2014).

It is technically possible to have the entire KEC network under sectional speed enforcement with current technology. Because the Korean motorways are equipped with cameras and dedicated short-range communications (DSRC), the motorway operators can calculate the average speed of an entire trip on the motorway. (The time spent in service areas can be subtracted as cameras and DSRC around the service area can identify vehicles.) Public acceptance is perhaps the main barrier to implementation. Drivers would be more likely to accept the solution if it was part of a "nudge" framework that rewards motorists for adopting the correct behaviour. In the long term, however, it seems unethical to imagine a system that does not sanction road users who break the law and consciously put the life of others at risk.

Section control of speed in Italy

Automated section control of speed allows authorities to calculate a vehicle's average speed over the controlled segment, and to automatically process an offence report and the related fine, by registering the vehicle's number plate. This system encourages compliance over distances longer than those observed where spot enforcement technologies have been in place.

Section control of speed, known in Italy as Safety Tutor, was introduced for the first time on the Italian motorway network at the end of 2005. By 2014, the system included 230 speed-camera sites covering about 40% of the Italian motorway network managed by Autostrade per l'Italia, one of Italy's motorway operators, for a total length of 2 900 km. In 2018, the system was temporarily abandoned because of a technology patent issue, but it was reintroduced soon after. By 2020, there were 134 segments under control for a total length of 1 400 km.

Montella et al. (2012a) carried out an evaluation of the safety benefits of the Safety Tutor system installed on the A1 motorway in 2007, performing an empirical Bayes observational before-and-after study. An estimated 31% reduction in total crashes was observed, due mainly to a decrease in severe crashes and crashes at curves. However, the reduction was most pronounced in the first semester after the system's activation and declined over time. This declining effect may be due to a reduction of speed enforcement (the system was not always activated) and to drivers' corresponding behavioural adaptation. This underlines the need for a high level of enforcement, and perhaps even more importantly the need to maintain popular support for speed control.

These conclusions were confirmed by another study that analysed the average driving speeds on the Italian A3 motorway over two different periods, finding that non-compliance with speed limits increased from 50% in 2010 to 57% in 2011. The decrease in driver compliance over this time suggests that a weak enforcement strategy was applied (Montella et al., 2012b).

Montella et al. (2015) evaluated the system on the A56 urban motorway. The study first conducted a before-and-after analysis of speed data, including the effects on non-compliance with speed limits. To evaluate the safety effects, an empirical Bayes observational before-and-after study was then carried out. The point-to-point (P2P) speed enforcement led to a reduction in the mean speed, the 85th percentile speed, the standard deviation of speed, and the proportion of drivers exceeding the speed limits. The decrease of speed variability and excessive speeding behaviour were the most significant results. With regard to safety effects, the P2P system yielded both a 32% reduction in total crashes in the controlled segment and a 21% reduction in total crashes in the part of the motorway where it was not activated. This spillover effect may be due to the fact that drivers are not always sure where the speed enforcement cameras are.

Automated speed cameras in Australia

Automated speed limit enforcement is used across Australia' motorway network. In the state of Victoria, the road safety strategy recognises the need to address high-risk behaviours on the roads, rather than waiting for technology (such as automated driving) to solve the problem in the longer term. Victoria is increasing its automated camera operations over the next few years in response to the continued involvement of speeding in fatal and serious injury crashes. (Victoria State Government, 2020)

In New South Wales, average-speed cameras are used for heavy-vehicle speed enforcement. These cameras have the capacity to enforce speed limits between two points of the network, which are typically 5 km apart. The 2018 speed camera review found a 44% reduction in the number of fatal casualties in crashes involving a heavy vehicle along the network covered by average-speed cameras. The same report found a reduction in fatal crashes and injury crashes at fixed speed-camera locations since the cameras were installed, compared with the five-year period prior to installation. Specifically, at the location of fixed speed cameras, there was a 32% reduction in casualty crashes, 80% reduction in fatalities, and 37% reduction in injuries (Transport for NSW, 2018).

Automated speed cameras in France

Introduced in 2003 under the leadership of President Chirac, who made road safety a national priority, the automatic speed-camera and penalty-processing system is the single most important road-safety intervention of the last 20 years in France (Figure 9). ETSC (2015) compared European countries and found the best progress in reducing mean speed on motorways was achieved in France – and that the progress

was prompted by the deployment of safety cameras coupled with stricter sanctions like penalty point systems, including speed offences and higher fines.



Figure 9. Increased compliance with speed limits on French motorways since 2003

Source: adapted from ETSC (2015).

Page et al. (2011) estimated that 75% of the drop in road deaths between 2002 and 2005 could be attributed to improved speed management following the deployment of safety cameras and the introduction of a fully automated speed-enforcement scheme. Of all fixed spot-speed safety cameras, about 266 were located on the motorway network in 2016 (Delahaye, 2017). This equates to about two pieces of equipment per 100 km of motorway network. About one-quarter of the income from automated safety cameras is dedicated to funding the programme itself; this includes the maintenance and upgrade of the safety camera equipment.

The results may have eroded in recent years due to the widespread use of navigation devices that alert drivers about the presence of fixed cameras. In response, authorities have developed alternatives such as automated section control as well as mobile and floating systems.

Close to 400 unmarked vehicles in France are now fitted with automated "floating" safety cameras that are capable of in-motion speed enforcement. Introduced in 2013, this solution resulted in 180 000 penalties in 2014 and over a million in 2019. It represents close to 10% of the total number of radar-observed speed penalties¹⁶. The technology primarily captures oncoming traffic and is particularly relevant to the high-risk bidirectional road network. It is also valuable on the motorway network where other safety camera equipment is unavailable. Because the technology relies on the automatic reading of speed limit signs, it remains rarely used in urban environments, where signage is often incomplete.

However, floating safety cameras consume valuable police officer time. As a result, the French interministerial committee for road safety has approved the gradual outsourcing of the probe-driving task to contractors, so the police can focus on other tasks, such as alcohol and drug testing. By the end of 2021, the government expects contractors to operate over half of the speed enforcement vehicles fleet.¹⁷

Stunt driving sentences in Canada

Each of Canada's provinces has its own level of autonomy. Like most policies and regulations, speeding is handled at the provincial level. While creating discrepancies in the handling of speeding offences, this also offers room for some provinces to introduce stricter sanctions for speeding. In 2018, across the entire

country, approximately 23% of fatal crashes on all roads involved speeding (ITF, 2020). In Ontario, for example, driving 50 km/h above the speed limit is considered "stunt driving" under the Highway Traffic Act of Ontario (Ontario Regulation 455/07). When found guilty of such offence and convicted, a driver is liable to:

- a fine of EUR 1 400 6 800 (CAD 2 000 10 000)
- imprisonment for up to six months
- a suspension of the driving license up to two years for a first conviction; up to ten years for a subsequent conviction.

In 2015, 5 628 charges were brought to court for stunt driving across the entire province of Ontario, compared to 563 698 for regular speeding (Province of Ontario, 2016).

Driver retraining in the United Kingdom

Across England and Wales, the police detected 2.6 million speeding offences in the year 2019-20, of which 97% were detected by speed cameras (RAC Foundation, 2021). This represents 43 500 speeding offences per million people, resulting in:

- 32% dealt with by fixed penalty notice (FPN)
- 45% dealt with by speed awareness courses
- 12% cancelled (e.g. in cases where the police were unable to identify the driver of the vehicle, or when the vehicle belonged to the emergency services)
- 10% taken to court (Lam and Snow, 2020).

An FPN is a prescribed financial penalty that may be issued to a motorist as an alternative to prosecution. They can be issued for a limited range of motoring offences, such as speeding offences and using a handheld mobile phone while driving. An FPN can be either endorsable (accompanied by points on a driving licence) or non-endorsable (not accompanied by points on a driving licence).

Driver retraining in the UK is a generic term that includes speed awareness courses, motorway awareness courses and other types of training that can be imposed on drivers.

Over one million speed awareness courses are taken each year in the United Kingdom. Participation in the National Speed Awareness Course (NSAC) reduces speed reoffending. It has a larger effect on reoffending than the penalty points and fines associated with FPNs. However, due to insufficient data, it has not been possible to demonstrate a statistically significant effect of participation in the NSAC on the likelihood of involvement in injury collisions (Ipsos MORI, 2018).

Police forces in the UK can invite drivers to take the National Motorway Awareness Course (NMAC). This course is aimed at drivers who have been caught committing an offence on smart motorways (sections of motorway that use active traffic-management techniques to manage the flow of traffic). The course is offered in particular to drivers who have been detected exceeding the active variable speed limit or who have passed through a mandatory Red X lane-closure signal or committed infringements on hard shoulders and in emergency refuge areas.¹⁸

Variable mandatory speed limits are used across all three types of so-called "smart motorways" in the UK: controlled motorways, hard-shoulder running motorways and all-lane running motorways. Indeed, all three types come with variable-message signs capable of displaying a temporary speed limit that is lower

than the national motorway speed limit. Enforcement of variable mandatory speed limits involves a combination of gantry-mounted and cantilever-mounted speed-enforcement equipment and traditional (mobile) enforcement by the police. Variable mandatory speed limits are linked to enforcement cameras that automatically adjust to suit the limits displayed on signs that are remotely activated by traffic control centres. Enforcement usually involves average-speed cameras, using automatic number-plate recognition (ANPR) equipment.

Distractions, alcohol, drugs and fatigue

Driver attention is negatively affected by the monotonous tasks and long distances that are typical of driving on motorways. Vigilance is further reduced by driver assistance systems, a phenomenon that is particularly problematic on vehicles whose level of automation requires driver attention at all times. It is, therefore, necessary for the automotive industry to develop trustworthy monitoring technologies to detect drowsy or distracted driving. Delahaye (2017) observes that drowsiness recognition systems are already on the market and recommends that authorities encourage their development and testing:

- movement sensors, which are supposed to detect changes in eye rhythm or head nodding and, in the event of an anomaly, trigger audible and visual alerts to indicate to the driver that it is time to take a break
- anti-drowsiness rings, which analyse the electrical activity of the middle finger and index finger and emit a ringing tone combined with a vibration in the event of a significant drop in attention.

According to a recent study by the Belgian Institute for Road Safety (formerly IBSR, now the Vias Institute), the effectiveness of these systems is far from optimal. Even so, the development of these devices, which cost less than EUR 300, should be encouraged.

Systems that track the eye movement of drivers could also detect when a satnav, on-board entertainment display or smartphone is distracting the driver (ITF, 2019a). Similarly to seatbelt reminders that emit an audible alert when a vehicle occupant is unbelted, such eye trackers could warn the driver when they have lost sight of the road and could prime autonomous emergency-braking systems for the heightened likelihood of driver error.

The RAC's (2020) *Report on Motoring* found that 23% of all drivers in the UK – the equivalent of just under ten million motorists – confess to making or receiving calls on a handheld phone while they are driving, at least occasionally. Among drivers aged between 17 and 24, this rate is 51%. Meanwhile, 17% of all drivers – and 35% of under-25s – say they check texts, email or social media while driving, despite the heightened level of risk involved in looking away from the road, even for seconds at a time. One-quarter (24%) of motorists say they usually leave their phones switched on with the sound on when driving, rather than putting the device on silent or switching to some form of safe-driving mode. The same report found that 79% of drivers support the introduction of camera technology to identify illegal mobile phone users – something that has been trialled in other countries.

Since 1988, the UK Department for Transport has commissioned roadside observation surveys on seatbelt use by vehicle occupants on the national road network. Since 2002, similar surveys for driver mobile phone use have also been undertaken. In 2017, 1.1% of drivers were observed using a hand-held mobile phone while driving on weekdays in Great Britain, of whom 0.4% were observed holding the phone to their ear and 0.8% holding the phone in their hand (DfT, 2019).

The survey of seatbelt and driver mobile phone use did exclude motorway sites due to the difficulty of making observations in high-speed traffic. However, the French motorway operator SANEF performs such surveys using video recordings. Guidelines from the European Commission for the monitoring of distractions include a methodology for making observations on motorways. (Boets et al., 2021)

In a recent survey of French motorists, 20% of drivers report sending text messages or emails when driving on motorways. The figure reaches 40% among people aged 18-35¹⁹.

Australia

In Australia, road safety authorities seek to reduce illegal smartphone use while driving. In March 2020, New South Wales (NSW) became the first jurisdiction in Australia to implement a state-wide camera programme – in collaboration with the private sector – after rapidly developing and testing the cutting-edge technology involved, which includes artificial intelligence (AI) (Transport for NSW, 2021). Automated enforcement can detect more motorists for offences including speeding and, now, mobile phone offences – although it may not immediately stop the behaviour from continuing.

This programme is a key initiative in the context of the Australian national government's target of reducing road fatalities and serious injuries by 30% by 2021 (compared to 2009-2010 levels) and to zero by 2056 (NSW, 2021). The programme is being expanded over three years from 2019-20, with a target of more than 135 million annual vehicle checks by 2022-23. To help reach this target, it is anticipated that approximately 45 cameras will be operating across NSW, incorporating both fixed and transportable units. Taking after the effective rollout of the mobile phone location cameras, Transport for NSW has started testing whether the same cameras can identify seatbelt offences.

In Australia, the drivers of heavy vehicles take mandatory rest breaks. They must take at least one rest break lasting 15 continuous minutes in every 5 ¼ hours of work time, 30 minutes of rest time (in blocks of 15 continuous minutes) in every 7 ½ hours of work time, and 60 minutes of rest time (in blocks of 15 continuous minutes) in every ten hours of work time. Also mandatory are 7 continuous hours of stationary rest time per 12 hours of work time and 24 continuous hours of stationary rest time per 72 hours of work time Regulator, 2021.

Austroads provides *Guidelines for the Provision of Heavy Vehicle Rest Area Facilities*²⁰, as heavy-vehicle drivers tend to be required to work for long hours. To help drivers manage fatigue and comply with driving hours regulations, motorway networks include heavy-vehicle rest areas (HVRAs) (Austroads, 2019). For example, in the Sydney area, according to recent Senate hearings on the importance of a viable, safe, sustainable and efficient road transport industry (Parliament of Australia, 2021), there are requirements for road authorities to provide sufficient areas, and possibly to construct a suitable area adjacent to the motorway network to allow truck drivers to stop for a rest break and/or fuel.

Canada

In 2018, statistics from the National Collision Database showed that approximately one in five fatal collisions were reported to have alcohol involvement as a contributing factor (Transport Canada, 2021). This figure has declined significantly since 2010, when it was nearly one in three (ITF, 2018b). This reduction is a result of the work that Canadian authorities have done to raise awareness of the dangers of impaired driving.

Since the mid-1990s the Canadian Council of Motor Transport Administrators (CCMTA) has had a Strategy to Reduce Impaired Driving (STRID), which was an integral part of the Road Safety Vision and remained a key component of the Road Safety Strategy 2015 (CCMTA, 2011).

Most jurisdictions in Canada have implemented the major STRID interventions to address driving while impaired. All jurisdictions have a 90-day administrative license suspension, and most have vehicle impoundment programmes, alcohol ignition interlock programmes, and assessment/rehabilitation programmes. In addition, police services conduct periodic roadside enforcement programmes in their jurisdictions during the year, particularly during the holiday season in December.

In most Canadian jurisdictions, convicted impaired drivers can choose to have an alcohol ignition interlock placed on their vehicle in order to get their license back before the end of the suspension period imposed by the court. Many drivers refuse the ignition interlock, claiming they will complete their suspension, but may continue to drive anyway. Ignition interlocks are mandatory in some Canadian provinces for offenders who have above a certain limit of alcohol in their blood, are repeat offenders, or are criminally convicted.

Driving under the influence of cannabis and/or other drugs is also a significant concern. Canada was one of the first major countries to legalise the medical and recreational use of cannabis products. In 2014, 42% of fatalities came from crashes involving individuals who were positive for drugs; and in 2019, 13.2% of cannabis users with a valid driver's license reported driving within two hours of using cannabis (Statistics Canada, 2020).

Legislation passed in 2018 established new federal laws and penalties for driving while impaired by cannabis and other drugs²¹.

Rest areas

A survey of commercial vehicle drivers in Canada (Trepanier et al., 2010) found that the lack of rest stops contributed to drivers' exceeding their allowable hours of service. More than 60% of truck drivers surveyed indicated that they frequently had trouble finding parking or places to rest and that basic amenities such as telephones, washrooms, adequate lighting and drinking water were lacking from existing public rest areas. Overall, 88% of drivers surveyed indicated that there were insufficient rest areas, roadside pullouts or turnouts.

Rest areas for commercial motor vehicles address the issues of driver fatigue and load securement, while also reducing roadside stopping that may pose hazards to other road users. Yet a comprehensive literature review about truck parking at rest areas in Canada, the United States, and Australia (Montufar et al., 2009) revealed a shortage of commercial vehicle parking in Canadian and US jurisdictions – a problem that is expected to escalate in both countries because of increasing truck traffic flows. The report noted that shortages in truck parking capacity may contribute to drivers parking illegally or driving while fatigued, both of which can cause collisions. The report also found limited information on which specific benefits result from the provision of parking for commercial vehicles. Short- and long-term strategies proposed by the authors included developing national-level guidelines for the spacing and design of public truck parking facilities, addressing driver security concerns at parking facilities, and providing additional truck parking spaces where needed and financially and/or commercially feasible.

Researchers conducted a benefit-cost analysis to determine the value of public rest areas, including welcome centres, along freeways and other major roadways in Michigan. The benefits associated with rest areas included travel diversion cost savings, comfort and convenience benefits, increased tourism spending, and crash reductions. The costs associated with rest areas included amortised construction costs, operating costs, and routine maintenance costs. The benefit-cost ratio for all rest areas and welcome centres combined was estimated at 4.56:1. Most of the benefits came from a combination of comfort and convenience (i.e. the "value" to users), a reduction in fatigue-related crashes (estimated at 3.37 crashes per facility per year), and tourism. The study found evidence of major night-time truck capacity issues at

both rest areas and truck stops along a number of interstate highways, which suggested the potential need for additional facilities along extremely busy routes (Gates et al., 2012).

In Canada, the federal government is collaborating with the CCMTA to strengthen measures and policies aimed at increasing safety for commercial vehicle drivers. This includes finalising a national standard for entry-level training for commercial drivers, which represents an important milestone for road safety in Canada and will help ensure drivers have the necessary knowledge and skills to safely operate commercial vehicles. In addition, Transport Canada helped develop a North American Fatigue Management System for commercial drivers to address the issue of driver fatigue with a comprehensive approach²².

Tachographs

An electronic logging device (ELD) is a device that is integrated with a commercial vehicle's onboard electronic systems and is used to track, collect and record electronic data on a driver's compliance with hours-of-service (HOS) regulations. By improving the accuracy of recorded driving times, ELDs reduce the potential for driver fatigue and ultimately improve road safety by reducing collisions involving commercial vehicles where driver fatigue is a contributing factor.

In December 2015, the United States Department of Transportation's Federal Motor Carrier Safety Administration (FMCSA) announced the final rule requiring commercial truck and bus drivers who currently use paper logbooks to record hours of service records to adopt ELDs within two years. Motor carriers who were already using compliant "automatic onboard recording devices" (AOBRDs) were allowed to continue using the devices for an additional two years beyond the compliance date. Canadian-domiciled drivers were also required to use ELDs when operating on American roadways. The FMCSA estimated that the implementation of this rule would result in 26 lives saved and 562 injuries and 1 844 crashes avoided annually. The regulatory impact analysis for the rule indicated that annualised benefits exceeded the costs of introducing ELDs (FMCSA, 2015).

The Canadian Trucking Alliance cited the results of research carried out by the American Transportation Research Institute demonstrating that truck drivers driving over the prescribed hours-of-service limits were 45% more likely to be involved in a crash than drivers who were in compliance. Furthermore, carriers that exhibited a pattern of frequent hours of service violations had a crash rate 90% higher than the average (Canadian Trucking Alliance, 2014).

In Canada, the federal government and provinces and territories have collaborated through the CCMTA to strengthen commercial motor vehicle safety regulations, including measures to prevent fatigue and distracted driving. In June 2019, the department published a regulation mandating ELDs for commercial carriers to reduce the risk of fatigue-related collisions. This system is similar to the one in place in the United States, with one major difference: In the United States, ELDs are certified by their manufacturers, which has enabled a large number of different ELDs to enter the market. In Canada, ELDs need to be certified by a third party that is accredited by the Standards Council of Canada. This reduces the number of eligible ELD devices but also reduces the probability of device tampering so as to alter the recorded data. Canada's ELD mandate started in June 2021, with a "progressive enforcement period" lasting up to one year (Ziemkowska, 2018).

France

The French motorway concessions provide just over 1 000 areas where drivers can take a break or a nap: 638 rest areas and 364 service areas (ASFA, 2020b). Cerema (2021) notes, motorway concessions impose the provision of frequent rest areas, which contribute to the relatively low number of fatal motorway

crashes that are caused by driver fatigue. ASFA (2020) finds fatigue and sleepiness to be involved in 21% of crashes on the French motorway concessions.

Most motorway operators in France design regular campaigns to raise awareness of risky behaviours. Whether the benefit of such campaigns is measured depends on the existence of a behavioural observatory. SANEF, one of the private companies operating sections of the French toll-motorway network, has run such an observatory since 2012, with technical support from Cerema. Their findings reveal the substantial potential for progress towards safe behaviours and attitudes among drivers:

- 4% of drivers observed at speeds above 150 km/h on sections limited to 130 km/h
- 31% of drivers on the middle lane not maintaining a two-second headway
- 21% of truck drivers encroaching on the hard shoulder
- 15% of truck drivers holding their mobile phones in their hands

All figures result from a video survey conducted from a bridge (SANEF, 2019).

Japan

Japan's revised Road Traffic Law was promulgated in June 2019 and, from December of the same year, the penalties for "talking on the phone while driving" were strengthened (National Police Agency, 2021), as follows:

- Holding the mobile phone while talking or gazing at the screen:
 - The new penalty is imprisonment for up to six months and the maximum fine has been raised from EUR 385 (50 000 yen) to EUR 770 (100 000 yen).
 - The number of demerit points will increase from one to three points.
- If the use of a mobile phone causes a crash or otherwise causes a traffic hazard:
 - The offence becomes subject to a criminal penalty.
 - Penalties can include up to one year of imprisonment and fines of up to EUR 2 300 (300 000 yen).
 - The number of demerit points will be increased to six points and the license will be suspended.

To reduce the number of people driving while using a smartphone, the Japanese government conducts communications campaigns to inform the public that penalties for talking on the phone while driving have tripled, the fines are higher, and one even can get a one-time suspension of the driving license (Japanese Government, 2021). Furthermore, after a 2019 crash killed 16 children, all motorway companies began raising awareness of the need for traffic safety, supported by the prefectural police and local governments. For example, in the western region, the three expressway companies²³ started to conduct "Stop! Nagara [distracted] Driving Campaigns" in 2019 in collaboration with FM radio Osaka and artists (Nexco West, 2021). The three companies signed an Agreement on Mutual Co-operation for Traffic Safety Awareness Activities on Expressways, and awareness-raising events are now organised regularly in parking areas on the motorways and drivers are invited to register as campaign supporters (Honshu-Shikoku Bridge Expressway Company Limited, 2021).

To raise awareness on the risks associated with driver fatigue, Japanese motorway operator Nexco West, in collaboration with private companies Nestle and Kenpal Corporation, organised a campaign called "Drive & Love". With this campaign, the operator aimed to change the way society as a whole thinks about driving – through communication with not only drivers but also other stakeholders. Nexco West organised events

at parking areas to check drivers' fatigue levels through an application named "Drive Score", which uses an EEG sensor and a smartphone app to measure brain waves to determine the state of sleepiness. Those who register as "supporters" receive a free coffee. (NEXCO West, 2019)

Ensuring traffic safety for the elderly

From the age of 70, people in Japan must take a specific cognitive test and training course to renew their driver's license (Japanese National Police Agency, 2020). From the age of 71, the renewed license is valid for a three-year period. Under the revised Road Traffic Act, drivers aged 75 and over who have committed certain traffic violations are required to undergo a cognitive test. Those whose test results have deteriorated compared to the immediately prior test results are required to take a traffic safety class for elderly drivers. Moreover, drivers aged 75 and over who are deemed as possibly having dementia (based on the cognitive test taken when they renewed their licenses), or who have committed certain traffic violations (Japanese National Police Agency, 2017).

In light of the current status of fatal traffic crashes caused by elderly drivers, a ministerial council on measures for the prevention of traffic crashes by elderly drivers was organised by former prime minister Shinzo Abe in 2016. Since then, the National Police Agency held expert advisory council meetings to discuss the issue. The council emphasised the need for health checks among elderly drivers and the need to improve the system of traffic-safety classes for them, as well. The council also emphasised the necessity of (a) promoting measures to raise awareness about the voluntary surrender of driver's licenses and (b) ensuring alternative transportation means for the elderly. The council sees value in advanced safety technologies such as automated emergency braking, considering the effects of ageing on reflexes, muscular strength and visual acuity, as well as the risk of dementia. The police will work to deliver traffic safety education to elderly drivers who continue to drive (Japanese National Police Agency, 2017).

In 2020, the Road Traffic Law was amended to enhance and strengthen measures for elderly drivers. It introduced an on-street driving test to assess driving skills when renewing a driver's license from the age of 75. It also established a new type of driving license for the elderly that would allow them to only drive vehicles equipped with advanced safety features, such as automatic brakes and acceleration control systems, that mitigate the consequences of pedal confusion (Japanese National Police Agency, 2020).

Korea

Drowsy driving has been a major cause of motorway crashes in Korea. According to a KEC analysis, of the 1 193 crashes occurring during 2013-17, 380 (32%) were caused by drowsy driving (KEC, 2018a). The provision of more places to rest has been suggested for some time as a way to address drowsy driving. However, it was not an easy task for Korean motorways as the entire network is charged with tolls. Drivers currently pay more toll charges if they leave the network to rest and get on again as there is a base rate for entering the motorway (in addition to a proportional mileage rate). Building more service areas is not always viable considering the costs of land purchase and construction. Consequently, smaller parking areas called "drowsiness shelters", featuring basic facilities such as prefab toilets and vending machines, have started to gain attention as a viable alternative.

While the service areas provide diverse services from dining, filling gas to shopping and sightseeing, they are on average more than 40 kilometres apart from each other. In 2011, the KEC began building drowsiness shelters between regular full-scale service areas. It started by converting unused bus stops on the motorways into parking spaces with toilets.

Road users welcomed this as a much-needed improvement. The KEC tripled the number of such shelters from 37 in 2011 to 107 in 2012, and by 2020 there were 230 shelters. Drivers can now park on average at 19.5-kilometre intervals, which represents around 12 minutes of driving time in standard traffic. Therefore, road users can more easily access rest areas when they feel tired.

In a 2015 survey of 543 users of drowsiness shelters, 505 replied that the shelters are "very helpful" for preventing crashes. In 2017, the MOLIT officially released guidelines for the installation and management of drowsiness shelters, standardising the design of ramps to the shelters and setting minimum requirements for facilities (Figure 10). According to the KEC's internal analysis, following the installation of the drowsiness shelters, the number of crashes caused by drowsy driving decreased by 15% and the number of deaths by 38%.

Figure 10. Comparison between a regular service area and a drowsiness shelter



Regular service area

Drowsiness shelter

Source: images provided by the KEC.

Truck driver fatigue

In Korea, although overall casualty numbers are declining, a growing percentage of road deaths involve trucks. During the past five years (from 2016 to 2020, deaths from truck crashes have decreased annually by 4.8%, while total deaths from car crashes have decreased by 8.0% (KOTSA, 2021). The Korean government is trying to curb fatigue-related truck crashes by mandating regular periods of rest. The KEC also encourages truck drivers to take breaks by providing loyalty rewards and more dedicated service facilities.

To identify the road segments on which fatigue is most likely to occur, and thus where action is most needed, the KEC has developed a mapping tool whose input data is provided by T-map, a popular navigation system provider. T-map aggregates information that comes from drivers using navigation services, showing the proportion of drivers who have been driving for more than two hours. This is part of a fruitful data exchange with private navigation companies, similar to the exchange discussed in Box 10 for the co-operative crash-response service.

Mandatory break for commercial vehicles: enforcement and encouragement

To prevent crashes resulting from truck driver fatigue, the enforcement rule of the Trucking Transport Business Act stipulates that a 15-minute break after two hours of continuous driving should be guaranteed for truck drivers. Enforced since March 2021, this is stronger than the previous rule, which mandated a 30-minute break after four hours of driving. However, this regulation is hard to monitor and truck drivers often ignore break time in order to complete their deliveries, which are usually very tightly scheduled. In Korea, since 2011 the Traffic Safety Act has required trucks to be equipped with a digital tachograph (DTG). The truck drivers either submit records every six months or use a DTG that has a telecommunication module that automatically transfers records to the KOTSA. However, it is still impractical to conduct real-time monitoring for minimum-break violations.



Figure 11. Loyalty rewards system for truck drivers

Source: graphic provided by the KEC.

The KEC has been encouraging truck drivers to take the required breaks by providing "loyalty rewards" and building truck drivers' lounges. Simple and easy to implement, the loyalty-rewards scheme rewards drivers for each break the truck drivers register. The KEC has installed kiosks at which truck drivers can check in (using a QR code) to receive free coupons for coffee and snacks that can be used at service areas.

Truck drivers' lounges

Trucks account for 25% of motorway traffic in Korea (KEC, 2018c). However, not enough dedicated service areas currently exist for them. In 2018, only 21 out of 195 service areas (10.7%) were dedicated to trucks. In addition, 33% of truck traffic takes place at night (from 21:00 to 06:00), which leads to more frequent crashes from drowsy driving. In 2018 and 2019, trucks were involved in over 50% of motorway fatalities (Table 4).

Year	2017	2018	2019	Total	Average
Total deaths	214	227	176	617	205.6
Deaths from truck crashes (number)	96	116	91	303	101
Deaths from truck crashes (percentage)	45%	51%	52%	49%	49%

Table 4. Deaths fro	m truck crashes c	on KEC networks	(2017-2019)
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Source: KEC (2020).

The concept of a "truck driver's lounge" was recently introduced to provide more resting space and amenities for truck drivers. Although dedicated service areas for truck drivers already have service facilities such as shower booths, sleeping rooms and laundry, standard service areas (which serve more passenger cars than trucks) have more basic facilities for truck drivers, and in smaller spaces.

In 2018, the KEC started a pilot programme to build truck drivers' lounges at selected, regular service areas and to equip them with the same level of service facilities as the dedicated truck-driver service areas. While there was no increase in parking space for heavy goods truck drivers, the truck drivers' lounges could provide better services to the truck drivers using the service areas (Figure 12).

Figure 12. A truck driver's lounge and its facilities



Outside



Resting room

Source: images provided by the KEC.

Shower room



Laundry

According to an analysis conducted in 2020 (KEC, 2020), on the 50 km sections after the service areas with the truck drivers' lounges, fatalities decreased by more than 70%, which is five times greater than the fatality reduction occurring in the overall KEC networks. The KEC plans to increase the number of truck drivers' lounges to 39 by 2022. Considering that there were 21 dedicated service areas before the truck drivers' lounge was introduced in 2018, the number of facilities dedicated to truck drivers will have almost doubled by 2022.

Table 5. Deaths on Korean motorways from truck crashes (before and after the introduction of the truck drivers' lounges)

Before / After introduction of the truck drivers' lounges	Year	Up to 50km after truck drivers' lounges	Entire KEC network
Before	2017	16	96
	2018	11	116
	Average	13.5	106
After	2019	4	91
	Changes	-70%	-14%

Source: KEC (2020).

Other dangerous behaviours

Commercial vehicles come with many more challenges than driver fatigue. Trucks that are overloaded or carry a load that is not safely secured illustrate one of these challenges. Stopping such vehicles so that police checks can be performed is particularly difficult on motorways. According to Austroads, lane-use management systems (LUMSs) can facilitate safe enforcement and compliance operations. LUMSs can slow down approaching traffic and close a number of lanes to create a safe environment for the police to stop and inspect vehicles on a motorway.

Wrong-way driving is another dangerous behaviour; measures to mitigate it are discussed in Box 6 in the context of Japan.

Seat belt use is particularly critical on motorways where vehicle speeds are highest. More than in urban areas – where pedestrians and two-wheelers make up the majority of victims – seat belts are a priority for road safety on motorways. In Canada for instance, more than 30% of occupants killed in 2018 were unbelted at the time of the crash. Seat belt use is encouraged through periodic selective traffic-enforcement programmes, which combine heightened police enforcement and public awareness campaigns. Other methods include incentive programmes (which reward seat belt users with a gift), feedback signs at the roadside, and night-time enforcement programmes.

Seat belt laws contribute heavily to reducing fatalities and serious injuries. In Ontario for instance, motor vehicle drivers can face a fine if they or any passengers under the age of 16 are not wearing a seat belt. Fines range from EUR 135 to EUR 675 (CAD 200-1 000) accompanied by two demerit points on the driving record. Passengers over the age of 16 are responsible for buckling themselves up and will be held liable for not using or wearing a seat belt properly.

Box 6. Measures against wrong-way driving in Japan

In Japan, using technologies developed by the private sector in 2015, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) launched measures to prevent wrong-way driving on motorways. This involved identifying areas where serious wrong-way crashes are most likely to occur. In this case, it was determined that 50% of such crashes occur near interchanges and 70% involve drivers aged over 65, who are more likely to suffer from dementia.

To develop the required technologies, specialists in dementia and traffic psychology collaborated with an expert group developing measures against wrong-way driving. The MLIT subsequently incorporated physical and visual countermeasures, such as rubber balls, high-intensity arrowheads, large arrowhead road markings, and colouring (photos).



Source: Provided by the Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT).

As a result, the number of crashes involving wrong-way driving on motorways fell by around 40% from 2016 to 2018, mainly due to the completion of measures at junctions and entrances.

Source: Japanese MLIT (2015, 2019b).

Since 1988, the UK Department for Transport has commissioned roadside observation surveys on seat belt use by vehicle occupants on the national road network. Among car drivers, 98.6% were observed using a seat belt in Great Britain in 2017. Across all vehicle types, 96.5% of drivers were seen using a seat belt. Without continued enforcement, however, good habits can fade. In 2018, 21 626 seat belt offences resulted in fixed penalty notices (FPNs), driver retraining courses or court action, across England and Wales²⁴.

Safe vehicles

Traditionally, discussions of vehicle safety have focused heavily on *passive* safety, which is about protecting vehicle occupants and third parties in the event of a crash. The vehicle safety concept has expanded over time, however, to include *active* safety – the prevention of crashes. This transition has been enabled by the advancement of vehicle automation and vehicle communication technologies, such as advanced driver assistance systems (ADAS). These technologies have in turn given rise to new possibilities of co-operative automated vehicles (CAVs), which will enhance road safety by reducing human errors, the dominant cause of crashes. The motorway environment is regarded as one that can benefit from the early stages of CAV deployment. To exploit the full safety potential of these new technologies, motorway operators may need to provide a more-accommodating environment equipped with appropriate physical and digital infrastructure.

Vehicle design and regulatory framework

Vehicle design is bound to a complex set of rules and regulations. Most countries have vehicle safety standards that mandate design, performance, and safety requirements for vehicles registered and traded in their jurisdictions. At the same time, as vehicles are one of the most globally traded products, there has been co-operation at the global level to harmonise national safety standards. The UNECE World Forum for Harmonization of Vehicle Regulations (WP.29) is a platform through which countries can collaborate in setting internationally agreed regulations on vehicle safety. There are three regulations managed by the UNECE WP.29. The UN regulation (UNR) based on the 1958 agreement and the global technical regulation (GTR) based on the 1998 agreement provide vehicle safety regulations that the contracting parties of each agreement can adapt to their respective national safety standards. The UN rules based on the 1997 agreement provide similar international rules on periodic inspections.

The UNECE WP.29 has several working parties that specialise in specific safety aspects of vehicles. In accordance with the development of vehicle automation and communication technology, the UNECE WP.29 created a working party on automated and connected vehicles in 2018. The first new regulation concerning automated driving (UN regulation 157)²⁵ was adopted in June 2020. This regulation allows the use of a Level 3²⁶ automated lane-keeping system (ALKS) at speeds up to 60 km/h on motorways.

Although the UNECE WP.29 establishes international regulations, it is national governments that incorporate them into enforceable national regulations; and as national governments can decide whether to adopt a certain regulation, the actual national vehicle safety standards may vary by country. According to WHO (2015), only 40 countries have adopted the seven key UN safety regulations recommended by the Global New Car Assessment Programme (Global NCAP)²⁷. In this regard, Korea is not only one of the countries that has adopted all the key safety regulations surveyed by WHO; it is also working to adopt new developments in automated vehicles more proactively than the pace of the international rulemaking process. For instance, based on its own assessment, the MOLIT revised its vehicle safety standard in

December 2019 to introduce the Level 3 automated lane-keeping function without explicit conditions on speed limit – thus becoming the first country to legalise the Level 3 ALKS on its roads.

The Global NCAP is another regulatory framework designed to enhance vehicle safety. In contrast to vehicle safety standards that set out minimum criteria vehicles must satisfy to be commercially available, regional and national NCAPs evaluate new vehicles and provide star ratings that consumers can use when they make purchase decisions. NCAPs incentivise vehicle manufacturers to invest in safety functions so that their vehicles can receive a more positive response in the market. From a policy perspective, an NCAP is effective because it encourages the adoption of a certain safety functions that are not crucial enough to become mandatory for all vehicles but still have life-saving potential. There are several national and regional NCAPs reflecting regional differences such as US NCAP and Euro NCAP. Global NCAP was established in 2011 as a harmonisation platform for the different NCAPs.

Both vehicle safety standards and NCAPs affect the design of new vehicles. By contrast, periodic vehicle inspection is a tool for ensuring compliance with safety standards over the lifetime of existing vehicles. It is more important for commercial vehicles and buses, which record a higher annual mileage compared to private cars and also pose a greater risk in terms of road safety when failing to comply with vehicle standards. Vehicle inspection is also a useful way to enforce the mandatory retrofit of onboard safety features such as digital tachographs (DTGs).

The swift development of automated-driving technology in recent years poses a challenge to the existing vehicle regulatory framework. Unlike conventional functions and features – whose performance can be fully tested in safe, closed environments with a view to developing quality requirements and standardised test procedures – automated driving technology intrinsically requires driving in a live-traffic environment to assess its capabilities and limitations. This creates a dilemma for vehicle safety authorities, who – in order to develop the rules with which the new vehicles should comply – must allow public-road deployment of vehicles that are not yet fully compliant with existing vehicle safety standards. Even though CAVs are expected to have safety benefits over human-driven vehicles, they possess a certain degree of uncertainty that might lead to crashes in so-called "corner" cases – rare situations in which CAVs cannot properly react. Therefore, the governments must tread a fine line between a risk-averse approach that hinders innovation and a permissive approach in which unproven technologies result in additional casualties.

Regarding safety benefits and regulation, Alonso Raposo et al. (2021) argue that "The safety levels that CAVs will eventually achieve on the road will depend on the type-approval framework that will be established." This represents a major new challenge for national authorities, who have to develop a robust regulatory framework without slowing down the uptake of this technology. ITF (2015b) recommended that policy makers allow some regulatory flexibility, including circumscribed uses such as motorway platooning. Considering the potential safety benefits of automated driving, governments should be proactive and allow trials with management measures that compensate for the increased uncertainty. At the same time, motorway operators may need to explore ways to capitalise on the safety potential of CAVs – and consider how to prepare their infrastructure to accommodate the specific needs of those vehicles.

Advanced driver-assistance systems and the path towards vehicle automation

Advanced driver-assistance systems (ADASs) are electronic safety systems that assist drivers by providing warnings or fulfilling certain tasks automatically. These technological developments aim to minimise human error, which is a major contributing factor to crashes. Today, some of the features that can be

grouped under the context of driver assistance are already resulting in quantifiable improvements to road safety. In Canada, for example, vehicles with automatic emergency braking are involved in 38% fewer rearend injury crashes compared to vehicles without this system (Transport Canada, 2019a).

The European Union currently considers Electronic Stability Control (ESC), Intelligent Speed Adaptation (ISA), Collision Avoidance Systems (CASs), lateral control/support, blind-spot detection, side-collision avoidance, driver monitoring, Adaptive Cruise Control (ACC), route guidance and navigation, vision enhancement, Anti-Blocking Systems (ABSs), alcohol interlocks, seat belt reminders and post-crash systems (black box and eCall) as core systems for vehicle safety, and is gradually making such safety systems mandatory²⁸. According to ETSC²⁹, "the European Union will have, by far, the most stringent vehicle safety standards in the world with systems including Advanced Emergency Braking (AEB), Emergency Lane Keeping Assist (ELKS), drowsiness and distraction recognition and Intelligent Speed Assistance (ISA) all mandatory." While Korea has been slower than the EU in making ADAS mandatory, it has caught up to some extent by making the Lane Departure Warning System (LDWS) and Advanced Emergency Barking System (AEBS) mandatory for both new and existing heavy goods vehicles from July 2021. However, there is still room for improvement, as the Korean government has not yet set out a clear timeline for Intelligent Speed Assistance (ISA).



Figure 13. The six levels of driving automation

There are on-board safety systems that are not regarded as ADASs but have important roles in enhancing safety. The most notable example is a digital tachograph (DTG), which records speed, sudden braking, sudden acceleration, etc. It may not assist with driving tasks, but it provides valuable information that road safety authorities can aggregate and analyse. Experts interviewed by ITF mentioned that even though it is

Source: SAE International (2021).

mandatory for trucks to install a DTG in Korea, there is no legal obligation for truck drivers to submit information to KOTSA, the public authority in charge of managing DTGs. As a result, drivers tend to install the device but do not bother to turn it on. KOTSA has started to promote the use of a smart DTG featuring a telecommunication module that transmits real-time data to KOTSA, but as of July 2021 only 5 300 trucks were using one. To fully capitalise on the potential safety benefits of the DTG, Korea may need to consider making real-time smart DTGs mandatory.

In addition to the development of ADASs and other onboard safety systems, the development of CAVs opens up new possibilities in motorway safety. The key difference between ADASs and the automated driving systems used in CAVs is whether the system merely *assists* drivers in performing dynamic driving tasks as opposed to performing dynamic driving tasks *without* the engagement of a driver. Some ADASs, such as the seat belt reminder, assume the existence of a human driver as a basis of its functioning. However, functions like the Lane Keeping Assistance System (LKAS) are on the continuum of technological development from driver assistance to automated driving. According to the classification of SAE International (2021), features at Level 3 and above that drive the vehicle under limited conditions (called operational design domain, or ODD) without the constant supervision of a human are classified as "automated" driving features, and features that requires constant supervision are classified as "driver support" features (Figure 13).

When making decisions on driving tasks, it is important for CAVs to know their exact location in their local environment and to be able to predict the movements of objects surrounding them. CAVs are equipped with various sensors to perceive their environment, and digital maps and other information on the road environment substantially increase their capability. Thus, if infrastructure can provide this supportive information, the areas where CAVs can operate can be expanded and their performance level will improve.

The European Road Transport Research Advisory Council (ERTRAC, 2019) has developed the concept of Infrastructure Support levels for Automated Driving (ISAD) (Table 6). Motorway operators can enhance their support levels by providing static and dynamic digital information such as location, road-sign types, and variable-message sign (VMS) messages (ISAD Levels C and D). Going further, motorway operators will be able to provide digital information on real-time traffic (Level B) and guidance (Level A) for co-operative driving with Co-operative Intelligent Transport Systems (C-ITS).

The motorway environment is expected to be one of the most important places in which CAVs can be deployed early, regardless of different technology-development strategies. As presented in ITF (2015b), there are two strategies in the development of automated vehicle technology: "something everywhere" and "everything somewhere". The "something everywhere" strategy is to incrementally improve low-level automated driving features that can be operated in almost all driving conditions. For example, in March 2021, Honda released the first Level 3 vehicles with traffic-jam assist features. Most major manufacturers that have wide existing customer bases prefer this approach. Vehicle safety standards need to be updated in tandem with incremental development of these features to maintain the safety of the vehicles that will be sold to the general public.

By contrast, the "everything somewhere" strategy involves developing an automated vehicle capable of higher-level automated driving in selected, well-defined geo-fenced areas. The most widely known example is Waymo's driverless vehicle fleet operation in Phoenix, Arizona, but there many such projects across the world, including low-speed shuttles (unmanned delivery vehicles that operate in specific environments). Because they are limited to certain areas, the government can allow them as pilot projects rather than creating overarching vehicle safety regulations that apply to all the newly registered vehicles. It is expected that both approaches will eventually converge at a higher level of automation in the general driving environment.

Level	Name	Description	Digital map with static road signs	VMS, warnings, incidents, weather	Microscopic traffic situation	Guidance: speed, gap, lane advice
Digital	Infrastructure					
A	Co-operative driving	Based on the real-time information on vehicle movements, the infrastructure is able to guide AVs (group of vehicles or single vehicles) in order to optimise the overall traffic flow	х	х	x	x
В	Co-operative perception	Infrastructure is capable of perceiving microscopic traffic situations and providing this data to AVs in real-time	Х	Х	Х	
С	Dynamic digital information	All dynamic and static infrastructure information is available in digital form and can be provided to AVs	Х	Х		
Conve	ntional Infrastru	icture				
D	Static digital information / Map support	Digital map data is available with static road signs. Map data could be complemented by physical reference points (landmarks signs). Traffic lights, short-term road works and VMSs need to be recognised by AVs.	X			
E	Conventional infrastructure / no AV support	Conventional infrastructure without digital information. AVs need to recognise road geometry and road signs.				

Note: AV = automated vehicle; VMS = variable-message sign. Source: ERTRAC (2019).

Motorways play an important role for both strategies because they provide a simpler environment without at-grade intersections, without curb activity, and with access limited to motor vehicles alone. For the first approach ("everything somewhere"), Level 2 lane-keeping assistance systems (LKASs) like Tesla's Full Self-Driving (FSD) function are already on the market and used on motorways. Some vehicles execute lane-changing under the driver's supervision. The manufactures may be reluctant to release models with Level 3 and above features due to legal liability implications rather than technical difficulties. However, with the progress in UNECE WP.29 rulemaking and more experience with Level 2 features, manufacturers will eventually go for wide commercial release of new models with Level 3 and above motorway driving functions.

For the second approach ("something everywhere"), while many pilot projects are operated in an urban environment, applications such as truck platooning are being developed to make truck operation on motorways safer and more economical. The concept of truck platooning involves (virtually) connecting several trucks, which drive themselves but follow a lead vehicle, much like a train. Compared to human-driven trucks, automated truck platoons can have shorter headways and thus reduce aerodynamic drag, thereby saving fuel. Drivers in the following vehicles of a platoon can relax, thereby reducing fatigue-related safety risks. Due to these clear economic and safety advantages, truck platooning is expected to be one of the most readily adopted business applications of CAV technology.



Figure 14. Korea: Truck platooning demonstration in real traffic

However, this will pose new challenges to motorways. They may need to be equipped with wireless communication facilities capable of supporting seamless communication among and between platoons. They may also need to provide lane-closing and other information using V2I communication with the leading vehicle, if the leading vehicle is also driving in automated mode. There is a possibility that the platoon can interfere with vehicles trying to off-ramp at an exit. It is desirable for motorway operators to proactively participate in truck platooning pilots to assess the various safety implications of the technology. Since 2019, the US Department of Transport has conducted a programme³⁰ to develop truck platooning technology. In Korea, the KEC is participating in a similar truck-platooning project commissioned by MOLIT; in September 2021 the project successfully demonstrated three-truck platooning at 90km/h on a motorway section in real traffic conditions (Figure 14).

Communication technologies and co-operative intelligence

As shown in the example of truck platooning, communication has an important role to play in ensuring the safety of CAVs. As such, it is becoming an indispensable part of co-operative, connected and automated mobility. There are many ways to classify vehicle communications. One way is to incorporate the target objects with which vehicles communicate, such as V2I (vehicle to infrastructure), V2V (vehicle to vehicle) V2P (vehicle to pedestrian) and as the overarching term V2X (vehicle to everything).

The other important classifications are telematics and Co-operative Intelligent Transport Systems (C-ITS). Telematics is a more general term for vehicle communication that supports passenger infotainment and vehicle performance functions such as over-the-air (OTA) software updates. C-ITS is a dedicated safety purpose communication to ensure the exchange of time- and location-sensitive safety information, such as signal phase and lane closure. For infotainment and OTA use, existing telecommunication technology enabling one-to-one large-capacity data transmission is sufficient. These purposes tolerate delays of a few hundred milliseconds. Currently, many OEMs are registered as mobile virtual network operators (MVNO) to provide telematics to their customers. However, for road safety purposes, it is important to allow many-

Source: photograph provided by MOLIT.

to-many communication with very short delays to ensure real-time exchanges of safety messages. The largeness of data transmission capacity is secondary in importance. Because these requirements differ from those of conventional telecommunications, dedicated technologies are being developed and implemented and dedicated frequency bands are being allocated.

Motorway operators play a key role in the delivery of C-ITS, not least as a primary source of safety information and as the enabler of V2I communications. V2I is expected to come first, before V2V is taken up. The ability of a vehicle to perform V2V communication delivers more value when more vehicles also have this ability, a network effect described by Maeng et al. (2020). If the situation is left entirely to the market, it can result in a negative situation where everyone waits for others to invest in such equipment first. The provision of V2I information by motorway operators would represent a good initial push toward encouraging manufacturers to install C-ITS on-board units (OBUs).

The other possible approach for resolving the chicken-and-egg problem of network effects is to make OBUs mandatory. The EU has been considering this option: "Mandatory deployment of V2V communication will significantly increase overall C-ITS deployment. High levels of uptake of V2V services are also expected to trigger enhanced C-ITS infrastructure deployment because the guaranteed uptake in vehicles will increase the certainty and attractiveness of infrastructure investments" (EC, 2019). Not all connected vehicles must be recent models: depending on various policy scenarios, 114 to 178 million vehicles in the EU could be retrofitted with personal C-ITS devices by 2035, making up about one-half of the connected vehicle fleet (EC, 2019). Countries that have a low value of statistical life (VoSL) may not be able to justify mandatory equipment of OBU; for these countries, investing in V2I first could be a good alternative strategy.

Because these two approaches can easily co-exist, national governments could employ a mixture by providing V2I infrastructure while making OBUs mandatory for heavy goods vehicles or multi-passenger vehicles.

Table 7 offers a selection of C-ITS services that are relevant in the context of motorway safety and that could deliver benefits in the short- to mid-term (Day 1 and Day 1.5^{31}).

V2V/V2I	Service and description
V2V	Emergency electronic brake light (EBL). Aims to prevent rear-end collisions by informing drivers of hard-braking vehicles ahead. Drivers will be better prepared to adjust their speed accordingly.
V2V	Emergency vehicle approaching (EVA). Gives an early warning of approaching emergency vehicles, prior to the siren or light bar being audible or visible. This should allow vehicles extra time to clear the road for emergency vehicles and help to reduce the number of unsafe manoeuvres.
V2V	Hazardous location notification (HLN). Gives drivers advance warning of upcoming hazardous locations in the road, such as a sharp bend in the road, steep hill, pothole, obstacle, or slippery road service.
V2V	Slow or stationary vehicle(s) (SSV). Intended to deliver safety benefits by warning approaching drivers about slow or stationary/broken down vehicle(s) in the road ahead that may be acting as obstacles. The warning helps to prevent dangerous manoeuvres.
V2V	Traffic jam ahead warning (TJW). Alerts the driver on approaching the tail end of a traffic jam at speed. This gives drivers time to react safely to traffic jams by giving them more time to react.
V2I	In-vehicle signage (VSGN). Informs drivers of relevant road signs in the vehicle's vicinity, giving advance warning of upcoming hazards and increasing driver awareness.
V2I	In-vehicle speed limits (VSPD). Intended to prevent speeding and bring safety benefits by informing drivers of speed limits. Speed limit information may be displayed to the driver continuously, or targeted warnings may be displayed in the vicinity of road signs.
V2I	Probe vehicle data (PVD). The purpose of probe vehicle data is to collect and collate vehicle data, which can then be used for a variety of applications. For example, the data can be used to inform drivers about adverse road or weather conditions.
V2I	Road works warning (RWW). Enables road operators to communicate information about road works and restrictions to drivers. This allows drivers to be better prepared for upcoming roadworks and potential obstacles in the road, thereby reducing the probability of collisions.
V2I	Shockwave damping (SWD). Aims to smooth the flow of traffic by damping traffic shock waves.
V2I/V2V	Weather conditions (WTC). Aims to increase safety by providing accurate and up-to-date local weather information. Drivers are informed about dangerous weather conditions ahead, especially where the danger is difficult to perceive visually.

Table 7. Safety relevant Day 1 and Day 1.5 C-ITS services

Source: adapted from EC (2019, Vol. 2, p.39).

Supportive infrastructure would be an effective tool for accelerating the deployment of CAVs. Motorway operators could provide digital maps for automated vehicles and V2I C-ITS services that will provide safety benefits to road users regardless of adoption level.

Safe roads, operations and post-crash response

This section discusses a selection of measures that experts have identified as particularly important for motorway safety. It covers a wide area of action in a manner that is not exhaustive but seeks to learn from a number of high-impact examples.

Standards for design, maintenance and signage

Motorway design has barely changed over several decades. However, operators have introduced and evaluated the benefit of seemingly minor design changes, including changes to roadside barriers, interchange design, signage, night lighting policy and lane allocation. Operators are also investing in new equipment for co-operative ITS, tunnel safety and 3D point cloud mapping.

Germany

The passive safety of roads has been steadily improved over the last 15 years through the use of new safety barriers, tested in accordance with EN 1317. Compared to the protective devices previously required in the German regulations, the containment level of the barriers was significantly increased, thereby preventing breakthroughs in the central reservation – and, on bridges, avoiding endangering uninvolved third parties below the bridges. In the central reservation, protective devices of containment level H2 are now required as standard; at the edge of bridges over areas with a particular risk to third parties, containment level H4b is required to protect even 38-tonne trucks from falling.





Source: ERF (2012).

Created in 1998, the European norm (EN) 1317 for Road Restraint Systems established common requirements for the testing and certification of road restraint systems in all countries of the European Committee for Standardization (CEN). The introduction of EN 1317 represented a significant change in terms of safety and quality for European drivers. However, while EN 1317 guaranteed common testing methods for road restraint systems across EU Member States, the decision on the level of protection was up to national governments. Therefore, European drivers were confronted with different levels of road

restraint systems protection. However, the German standard stands out as the most widely adopted (La Torre, 2016).

In Germany, the requirements of EN 1317 were taken into consideration by Working Committee 3.7 of the German Research Society for Road and Transportation (FGSV) in the development of new *Guidelines for Passive Protection on Roads using Road Restraint Systems* (Research Society for Road and Transportation, 2009). It regulated the use of road restraint systems on German roads, stipulating the conditions under which safety barriers, crash cushions, transition structures and terminals may be utilised for protection against lane departure.

Japan

Japan has experience in dealing with various difficulties such as severe topography and construction conditions; disasters such as earthquakes and typhoons; traffic congestion due to the concentration of population in urban areas; crashes; environmental problems; and ageing structures. In order to reduce the cost of maintenance and renewal of roads, road authorities invest in preventive maintenance using the latest technology for inspection, diagnosis and repair.

On the Tokyo Metropolitan Expressway, a system to support the maintenance of roads and structures uses the Geographic Information System (GIS) and 3D point-cloud data. The 3D point-cloud data acquired by the laser scanner and the video images acquired at the same time are centrally managed in the cloud. In addition, by viewing omni-directional video and measuring in three dimensions, users can immediately check asset conditions without having to go on-site. By further utilising GIS and 3D point-cloud data with various extended functions – such as drawing, detection of pavement and wall deformation, creation of safety regulation drawings, and 3D simulation – maintenance management becomes more efficient (Japanese MLIT, 2019a).

Korea

In terms of geometric design and physical facilities, Korea's motorways maintain one of the highest global standards. Since Korea set up its first road design standard in 1965, the physical design of motorways has been continuously upgraded. Black spots have been redesigned to improve safety. Rumble strips and longitudinal grooving are widely used to prevent unintended lane departures and to improve friction, respectively. Rigid safety barriers are installed at most of the applicable locations. The KEC introduced innovative and cost-effective colour-coded guidelines: vertical and horizontal signage to help drivers navigate complex interchanges. Significant attention is given to tunnels, some of which have now been turned into "smart tunnels" with smarter signage and warning systems.

Safety barriers

Korea's motorways are well equipped with safety barriers. Currently, 82% of the entire KEC network is divided using 129-cm-high median barriers (Figure 16**Error! Reference source not found.**). The remaining 18% comprises tunnels and bridges that are built as dual carriageways or equipped with wider medians featuring clear zones. Therefore, the entire network is physically separated from the opposite direction. Concrete median barriers are designed to withstand the impact of buses and trucks. Rolling rubber barriers are used on the side of curved sections. Various types of roadside barriers are fitted, and 54% of the network is equipped with guardrails.

Besides constructing so-called "forgiving roadsides", a road network operator must also know which vehicle restraint system (e.g. roadside barriers) is most appropriate for each road segment. A project called

SAVeRS (Selection of Appropriate Vehicle Restraint Systems) has helped operators select the most appropriate vehicle restraint systems for different road and traffic configurations (La Torre et al., 2016).



Figure 16. Median barriers installed on Korean motorways

Note: concrete median barrier (left) and rubber roller barrier on a curved section (right). Source: images provided by the KEC.

Colour-coded guidelines

The KEC introduced colour-coded guidelines in 2011 to reduce confusion at exits and intersections (KEC, 2018a). These consist of vertical and horizontal colour-coded signage to help drivers navigate complex interchanges. The new road marking consists of two different-colour lines on diverging lanes. Drivers can simply follow the colour for their direction. When the first one was installed at a pilot interchange, annual crash numbers decreased from 20 to 3. According to an internal study conducted on 76 segments, there was a 27% reduction in crash frequency (KEC, 2017). The measure was well received by both road users and the government as a cost-effective way to reduce crash risk resulting from road user confusion. The Korean government standardised the colours and shapes in 2017 and incorporated colour-coded lines into official road safety marking in 2021. The installation is warranted in four kinds of locations:

- at all motorway junctions
- where two interchanges are located within one kilometre of each other
- at interchanges that include black spots
- where parking areas are located on sharply curved sections.



Figure 17. Colour-coded guidelines and road signs employing colour-coded arrows

Source: KEC (2017).

Smart tunnels

Tunnels have more safety risks due to limited sight and limited space. It is difficult to notice and react when traffic slows down in tunnels, which leads to a higher collision risk. In addition, if a fire results from a collision, the smoke can hinder evacuation and rescue operations. In comparison to crashes on ordinary motorway sections, crashes in tunnels are more dangerous: they are over twice more likely to be fatal (KEC, 2018a).

To address this higher risk, the road traffic law prohibits lane changing in all but a few tunnels with the most advanced facilities³². The KEC has elaborated measures to "nudge" drivers to abide by the rule and be more attentive when driving in tunnels. First, rumble strips have been widely used in tunnels since 2014; these cause noise and vibration when a vehicle leaves its lane, thereby discouraging lane-changing behaviour and awakening distracted or drowsy drivers who are crossing the lane unintendedly. Second, an automatic incident-detection system was introduced from 2010 to 2014 in 45 KEC branches. The system can analyse CCTV images and inform monitoring staff of incidents such as stopped vehicles, vehicles driving in the reverse direction, and people and dropped objects on the road.

However, notwithstanding ongoing efforts to enhance safety in tunnels, there were several high-profile tunnel crashes in 2016. One serial bus collision inside a tunnel left four people dead and 35 injured. On

another occasion, a bus collided with five passenger cars at the entrance to a tunnel, killing four people and injuring 37.

After these incidents, the concept of a "smart tunnel" was introduced. The smart tunnels are equipped with variable-message signs (VMSs) and lights at the entrance that inform drivers of the traffic situation inside the tunnel (the light is green when traffic is smooth but turns red when traffic has slowed or stopped inside the tunnel). This helps drivers prepare, if necessary, to suddenly slow down inside the tunnel, thus reducing the risk of rear-end collisions (Figure 18**Error! Reference source not found.**).



Figure 18. Tunnel entrance light signal indicating situation inside the tunnel

Green light when traffic is good



Red light with "broken car ahead" message

Source: provided by the KEC.

The other element of smart tunnels is an acoustic warning system in which hyper-directional speakers direct whistling sounds at approaching vehicles to prevent drowsy driving.

The smart tunnel system was applied to two consecutive tunnels regarded as major black spots in 2017. When the KEC compared crash numbers before and after the installation of the smart tunnel features (KEC, 2019), it found that the number of crashes decreased from ten to four between the 12-month period ending August 2016 and the 12-month period ending August 2019. The contrast was even clearer in terms of fatality: While there were five deaths and 23 injuries during the 2015-16 period, there was no death and injury during the 2018-19 period.

Netherlands

In general, a reduction of the illuminance level on motorways results in a decrease in road safety. The effect on road safety does depend, however, on the degree of the reduction and the road circumstances, such as traffic flow and the complexity of the road design. Therefore, there is no consensus about the impact of dimming or switching off public lighting on motorways.

Public lighting in motorways in the Netherlands is sometimes dimmed or switched off, in order to reduce energy costs or for environmental reasons (SWOV, 2018). Lighting on urban ring roads, motorways with high traffic flow, or sub-optimally designed motorways is dimmed from 11 pm to 5 am, whereas it is completely switched off on other motorways.

An international meta-analysis of crashes in different illuminance conditions shows that a 50% reduction of the illuminance level, by switching off every other lamp post along (mostly) motorways, involves a 17% increase in injury crashes and a 27% increase in crashes resulting in material damage only (Elvik et al.,

2009). However, a study by Rijkswaterstaat (Netherland's Directorate for Public Works and Water Management) shows that completely switching off public lighting on Dutch motorways with a low traffic flow and a safe road design hardly affects road safety (Schepers, 2011). According to the study, which compiled international research, the negative consequences of switching off public lighting depend on the traffic flow along the motorway section; on motorways with low traffic volumes, switching off public lighting has no negative effect on road safety. Reducing illumination by 50% has no negative consequences for driving behaviour, perceived safety and subjective workload.

Another option is dimmable public lighting, which allows for two or more illumination levels depending on traffic or weather conditions. One Dutch study examined the effect of dynamic public lighting on driving behaviour, perception and public acceptance of slightly reduced driving comfort in exchange for energy-saving technologies (Hogema and Van Der Horst, 1998). The authors conclude that when the situation allows (e.g. low traffic flow, dry weather) a much lower level of illuminance (e.g. 20% of the normal level) will not lead to any problems.

Sweden

The introduction of rumble strips at the shoulders of Swedish motorways in the 1990s represented a big step towards improving road safety. Rumble strips are composed of tactile materials laid along the length of traffic lanes as a road safety measure. In addition to providing visual delineation, longitudinal rumble strips can also be heard and felt by drivers and riders. This alerts a sleepy or distracted driver when their vehicle starts to leave the road. According to Botteghi et al. (2017), their presence improves road safety levels by reducing the number of total crashes and the number of encroachments across the edgeline.

Vadeby and Björketun (2016) evaluated the shoulder rumble strips on motorways. They found that the total number of killed and seriously injured decreased by 16%. In single-vehicle crashes, the number of killed and seriously injured decreased by 25%. Correcting for regression to the mean gave very similar results.

Box 7. Co-operative Intelligent Transport System (ITS) in Germany and Sweden

In 2016, the European Commission adopted a European Strategy on Co-operative Intelligent Transport Systems (C-ITS), a milestone initiative towards co-operative, connected and automated mobility. The deployment of C-ITS is an evolutionary process that began with less-complex ITS applications. These are referred to as "Day 1 services" and, in most cases, are applicable to motorway environments. The purpose is mainly to improve traffic safety and traffic flow efficiency. There are three essential operation tasks that C-ITS services serve:

- to provide information to road users to improve road safety and comfort during a journey
- to inform road users of specific obligations, restrictions or prohibitions
- to warn road users about crashes ahead and their exact nature.

Day 1 services have currently become much more comprehensive than initially planned, and they include a range of wireless communication technologies. Day 1.5 and Day 2 services are still in the process of definition.

Since 2016, C-Roads Germany has been one of 19 national pilots that have been testing C-ITS services in a real traffic environment. It implements eight different Day 1 C-ITS services that use ETSI ITS-G5 short-range communication³³ on motorways in two different pilot sites, Hessen and Niedersachsen. In the first site, the pilot consisted in expanding the existing services, road works warning and probe vehicle data and in implementing five new C-ITS services. In Niedersachsen, the activities focused on three new C-ITS services on the A2 motorway, the connection between three roadside stations and the Traffic Management Centre and the future connection of a further 12 roadside stations along the A39 motorway.

Sweden was part of the NordicWay 2 project (2017-20) and is currently part of the NordicWay 3 project (2019-23) together with Denmark, Finland and Norway. The main objective is to deploy pilot studies in order to further develop interoperable Day 1 and Day 1.5 C-ITS services and support infrastructure readiness for connected and automated vehicles. The Swedish NordicWay 2 pilot covered the design, implementation, testing and evaluation of relevant Day 1 and Day 1.5 services in urban and suburban areas. It was based on the use of a set of passenger cars, public transport buses and heavy goods vehicles equipped with appropriate driver interfaces and connected through clouds by cellular and ETSI ITS-G5 communication technologies. The aim was to demonstrate the possibility of communicating between vehicles, infrastructure and clouds and to show the interoperability, scalability and flexibility of the NordicWay interchange network with connected clouds.

Source: AustriaTech (2021).

United States

On most motorways, trucks may be restricted to certain lanes but other vehicles are not. Truck-only lanes are motorway lanes that are used exclusively by trucks in order to enhance safety and/or stabilise traffic flow. Truck-only lanes are uncommon in the United States. On the I-5 freeway in California, for example, they add up to a combined length of 8 km. Truck-only lanes may contribute to improved road safety on roads with specific characteristics.

Truck-only lanes are advised on roads with steep grades. In one study, the installation of a climbing lane on roads where large differences exist between car and truck speeds was estimated to reduce injury crashes by 33% (US Department of Transportation, 2008).

Several studies have been conducted to measure the effectiveness of restricted lane use on motorways in the United States (Liu and Garber, 2007; Qi, 2009). There is evidence that truck-only lanes may negatively affect safety on motorways with a higher traffic volume (Fontaine et al., 2009). An analysis of Virginia's truck lane restriction showed that there is a breakpoint in safety performance at approximately 10 000 vehicles per day per lane. In motorways with lower volume, total crashes and fatal and injury crashes were reduced by 13% and 32%, respectively. Motorways with higher volume had an increase in total crashes and crashes causing deaths and injuries by 28% and 23%, respectively.

Interchanges are often the most dangerous parts of motorways, as traffic splits and merges and vehicles slow down and accelerate. In the United States, the use of the diverging diamond interchange (DDI) has been very effective in mitigating these risks, as well as in reducing traffic accumulation on non-motorway roads. It is considered to be the safest interchange design as conflict points are fewer and less severe. It is promoted by the Federal Highway Administration for new motorways/freeways. (Cunningham et al., 2021)

The DDI, also known as a double-crossover diamond interchange, is a relatively new design in the United States. DDIs were first built in France, but never became very common; they have since found increased prominence in the United States. A DDI eliminates the need for vehicles turning left to cross paths with vehicles coming from the opposite direction. It can also facilitate the safe movements of pedestrians and cyclists. (ibid.)



Figure 19. Main characteristics of a diverging diamond interchange

Note: RTOR = Right turn on red Source: Cunningham et al. (2021)

Smart motorways

The definition of *smart motorways* varies across countries but typically includes a dynamic trafficmanagement system based on the continuous monitoring of traffic conditions. Traffic management systems such as variable speed limits and all-lane running are often seen on smart motorways. The proportion of national motorways that can be considered "smart" varies across countries, reflecting differences in traffic intensity and road investment strategies; in the Netherlands, for instance, smart motorways account for about 40% of the motorway network.

Australia

In 2016, Austroads published a *Guide to Smart Motorways* that describes *smart motorways* as motorways where information, communications and control systems have been incorporated in and alongside the road. These technology-based systems are deployed to actively manage traffic flows and improve road capacity and safety, as well as deliver other important outcomes for road users such as better travel reliability and real-time traveller information. Smart motorways are made up of a collection of ITS (intelligent transportation systems) interventions, co-ordinated ramp signalling, speed and lane control, traveller information (through variable message signs), and network intelligence. The goals of smart motorways are to get the most out of Australian road infrastructure, to enable a more productive and sustainable transportation network, and to suit the demands of road users and communities (Austroads, 2016).

Australia's progress in vehicle-safety technology focused initially on occupant protection (airbags, vehicle crumple zones and occupant safety cells) and later on crash avoidance (electronic stability control, electronic brake distribution, automated emergency braking, blind-spot warning and lane departure warning). Such innovations in vehicle safety have reduced the number and severity of crashes on the country's motorways. (See Box 8 for examples of smart motorways in the states of Victoria and New South Wales.)

New materials technology has also improved road safety through the use of wire rope barriers. Many motorways across Australia now use these barriers to prevent vehicles from colliding with fixed infrastructure such as signs or vehicles travelling in the opposite direction. A 2020 audit found that wire rope barriers and other safety measures have most likely reduced fatalities and serious injuries by 46.5% on the treated sections (VAGO, 2020).

When road works are scheduled, a full suite of traffic management measures is implemented prior to work being undertaken. Police do not have this luxury when working on the roadside, enforcing speed limits and other offences. In Australia, laws associated with work health and safety (WHS), formerly known as occupational health and safety (OHS), require senior officials to consult with workers who are affected by their decisions. Those workers may work for other organisations, in which case the duty to consult is a joint responsibility between those organisations. Put simply, road authorities must consult, by law, with affected workers such as the police who are required to work on their road network and do what is reasonably practical to ensure their safety. There are cases where such consultation is taking place and road authorities are constructing areas where police can perform duties safely.

In the states of NSW and Victoria, the Transport Management Centre (TMC) monitors and manages the state road networks 24 hours a day by working together with police and emergency services to confirm the exact location of every incident. The TMC co-ordinates the attendance of "traffic commanders" and Traffic Emergency Patrol (TEP) crews. These resources assist the police on a daily basis with incident management on state roads. TMC traffic commanders also attend incidents, liaise with the police and assist in the ongoing traffic management around the incident on both the immediate approaches and the wider network. The TMC has a network of thousands of cameras it can use to monitor road conditions and look for breakdowns or crashes. They also operate a call centre and receive information from the public and emergency services. This allows for public messaging and the implementation of detours. It usually is

the police who divert traffic off the motorway until the TMC and or other road crews can attend and install a suitable traffic layout.

Box 8. Victoria's Managed Motorways toolkit

Since the 1990s, when the M80 Western Ring Road was opened, smart (or "managed") motorways have contributed to the economic development of the state of Victoria, while diverting traffic away from streets and areas where its impact is the most negative (VicRoads, 2013b and 2017). Following Victoria, the government of the state of New South Wales (NSW) invested EUR 374 million (AUD 600 million) in the M4 Smart Motorway project, which is upgrading the M4 Motorway with intelligent technology (Transport for NSW, 2021).

VicRoads provides a managed motorways toolkit for operators, which includes various technologies and control strategies for delivering different levels of active management. Table 8 lists the tools available in the Framework guidelines.

Contro	l Tools	Foundation Tools		
Network Optimisation Control	Intervention Control	Information	Intelligence	
City Wide Coordinated Ramp Metering (CWVRM) system Dynamic variable speed limits (DVSL) ¹ Arterial road interface system Arterial road management system ² Exit ramp management system End-of-motorway management system ²	Lane use management system (LUMS) including variable speed limits (VSL) Entry ramp management system Wide area network dispersion (WAND) ² Motorway dynamic re- configuration (including entry and exit ramp mgt systems) ²	Variable message signs (VMS) External information publication for third party use	Traffic detectors (primarily speed, volume and occupancy – SVO – data) CCTV Automatic incident detection (AID) ¹ Congestion alarms ² Real-time graphical user interface (GUI) Weather and environmental monitoring system	
Source: VicRoads (2019).				

Table 8. Elements of managed motorways in Victoria, Australia

Although attempts have been made throughout Australia to force motorists to slow down to 40 km/h when passing emergency vehicles, these laws created safety risks. When first introduced in the state of NSW in 2018, a series of incidents occurred when police officers, police vehicles and civilian vehicles were hit by out-of-control vehicles. The drivers of those vehicles apparently panicked when seeing stationary police vehicles and lost control in a sharp braking attempt. Since September 2019, the requirement to reduce speed to 40 km/h was removed for those higher-speed roads and replaced with a requirement to slow down, and, where possible, move over to give space (Transport for NSW, 2019b).

Box 9. Austroads guidance for Emergency Stopping Bays (ESBs)

Emergency stopping bays (ESBs), also referred to as emergency refuge areas, provide a space next to a motorway for accommodating vehicles clear of trafficable lanes in the event of an emergency or breakdown. When stopped in the ESB, a driver may contact the designated responder by either roadside help phone, if provided, or by using a personal mobile phone.

ESBs may be provided on motorways with and without emergency stopping lanes in order to improve road user safety during incidents or a breakdown, and for use by on-road response and maintenance services. Road users may be encouraged to use ESBs over emergency stopping lanes due to enhanced safety from increased separation and protection from traffic.

The provision of ESBs on a motorway section should be driven by a risk-assessment approach that considers the:

- level of safety risk associated with stopping on the motorway at that location considering the availability of an emergency lane or mountable curb, as well as other measures to improve the safety of stopped vehicles (i.e. LUMS and VMS)
- users of the route for example, allowance for heavy vehicles to use an ESB area; and their needs, including their ability to be able to enter and exit the facility safely
- needs and requirements of incident responders, roadside assistance services, the police and other stakeholders for using ESBs including for enforcement/inspection purposes
- opportunities for co-location with maintenance bays for roadside ITS (e.g. LUMS gantries), particularly at mid-block sections where this may benefit maintenance access without negatively impacting safety, and sufficient space is available.

For motorways without an emergency stopping lane for an extended length (i.e. over 1 km) on a full- or part-time basis, ESBs should be provided at a typical spacing of 500 m, up to a maximum spacing of 1 km.

The ESB may include a help phone, vehicle detectors to alert road operators when the bay is used, and CCTV providing unobstructed coverage of the entire bay.

It is advised that ESBs do not resemble laybys on other routes that can be used for non-emergency purposes.

Source: Austroads (2016).

United Kingdom

Over 80 000 vehicles per day are counted on an average motorway section in the United Kingdom, making it the busiest network across the ten ITF countries analysed for this paper (see Table 1). In 2018, smart motorways accounted for 525 kilometres or 17% of the motorway network in England (DfT, 2020).

The country's high traffic volumes, the fear of congestion and the excessively high cost of road widening explain the early adoption of smart motorways in England. For Highways England (2021), "Smart motorways have greatly increased the capacity of the country's most important roads, and therefore provide more space for drivers who would otherwise be on less safe roads." According to the UK Department for Transport (DfT, 2020), smart motorways in England have resulted in fewer people killed and seriously injured per unit of traffic.
Highways England (2016) lists three types of smart motorways:

- Controlled motorway: First established in 1995, controlled motorways have three or more lanes with variable speed limits. On these sections, the hard shoulder should only be used in a genuine emergency.
- Dynamic hard shoulder (DHS) running: First used in 2006, a DHS motorway opens the hard shoulder at busy times and reduces the speed limit. The hard shoulder must not be used unless overhead signs show that road users are permitted to do so.
- All-lane running (ALR): First operated in 2014, ALR motorways have no hard shoulder and road users are required to obey variable speed limits and must not stop on the motorway. In the event of an emergency, road users are required to use an emergency area or motorway service area or to leave at the next junction. In comparison with the DHS design, permanently removing the hard shoulder eliminates the complex operational processes associated with dynamically opening and closing it.

In DHS and ALR setups, to mitigate the loss of the hard shoulder, emergency refuge areas are added and the roads monitored by CCTV. If traffic operators detect a crash, they can close the lane using "X" signs on overhead gantries. Sensors detect when traffic is slowing down and automatically lower the speed limit; this is called the Motorway Incident Detection and Automatic Signalling system (MIDAS). The system reduces the number of injury crashes by 13% (Tucker et al., 2006).

There is, however, considerable debate in society over the risks involved in hard-shoulder running and alllane running. Franklin-Wallis (2021) reported that in one instance, a driver and passenger were killed when, after they stopped on a live motorway lane, motorway operators failed to close that lane in time to prevent a truck from crashing into them six minutes later. In response to this risk, a Stopped Vehicle Detection (SVD) system is currently being installed at a number of locations. SVD is designed to detect stationary vehicles within 20 seconds and inform the relevant control room so that a lane can be closed. Otherwise, detecting a stationary vehicle in a live lane takes an average of 17 minutes where SVD is not in place (Highways England, 2016b).

The UK's experience with smart motorways has yielded three main lessons:

- Dynamic lane closure and dynamic speed limits should be enforced through the use of automatic number-plate recognition (ANPR) cameras.
- Frequent and visible emergency areas are essential. A distance of 1.6 kilometres between such "refuges" should be considered a maximum.
- DHS motorways create confusion among motorists and should be replaced by ALR motorways.

Variable Speed Limits in other countries

The French motorway network has about 1 500 km equipped with variable speed limit (VSL) signs. Automatic speed enforcement systems, however, do not enforce limits that are lower than the default limit.

Currently, smart motorway features such as all-lane running, variable lane systems and VSL systems are employed on Korean motorways. However, the VSL is not utilised at its full potential as it is used only on limited occasions. The KEC has been operating the VSL on 342 km of its network on sections that frequently get foggy or icy during the winter season. There is not yet a robust logic or algorithm informing the VSL

operation that would automatically reduce the speed of traffic that is approaching risky locations (the location of an incident or obstruction, for instance).

The other shortfall in Korea is the lack of enforcement. Even though there is a legal framework supporting the enforcement of VSL, actual enforcement has been conducted on just one privately owned motorway after a tragic accident under foggy weather involving more than 100 vehicles. For all other sections, there has been no enforcement so far. As a result, drivers consider the lowered speed limit as a recommendation rather than a mandatory traffic rule.

Incident detection and post-crash response

Korea

CCTV and ITS technologies are widely used for real-time incident detection in Korea. The KEC has deployed 2 448 sets of inductive loop detectors and 2 504 CCTV cameras on its network, meaning there is now one camera and one set of traffic detectors for every 1.7 km on average. When vehicle detectors and other sensors detect changes in traffic speed or volume, the CCTV system automatically turns to the point where changes started and transmits the situation to the regional and central traffic monitoring centres, which operate 24/7 (Figure 20). The KEC has recently begun co-operating with private navigation companies to supplement its own sensors with data collected by vehicles (Box 10).



Figure 20. Incident detection process of the KEC

Source: provided by KEC.

Once the incident is verified at the traffic monitoring centre, the information is immediately shared with relevant authorities such as police and fire stations so that a response can be initiated. The KEC dispatch their own patrol cars to support response activities and, if necessary, free tow-truck service is provided. Variable-message signs (VMSs) located on the upstream segments display alert messages to prevent secondary crashes. The VMSs are set up at 4.14 km intervals on average on KEC motorways.



Figure 21. Emergency escape call service and free tow-truck service

Source: adapted from material provided by the KEC.

Recently the KEC initiated an emergency escape call service and free two-truck service to enhance its crash response and minimise the risk of secondary crashes (Figure 21). The emergency escape call is designed to provide escape routes via phone call to drivers with registered Electronic Toll Collection (ETC) membership. When the plate number of a vehicle is recognised by the CCTV camera verifying an incident, the KEC is able to check whether the vehicle is equipped with ETC and, if so, the KEC can call the phone number linked to the ETC account. In Korea, almost 87% of motorway users pay tolls via ETC and, in most cases, the driver of a vehicle is the account holder of the ETC on that vehicle. As a result, the chances that the call reaches the driver are fairly good.

Box 10. Korea: Real-time information sharing with navigation companies

In 2019, the Korea Expressway Corporation (KEC) started a "motorway congestion warning service" that provides real-time audible and visual alerts to drivers through their onboard or smartphone-based navigation systems when congestion occurs on a section ahead. Through an Intelligent Transport System (ITS) that features a vehicle detection system (VDS) and CCTV cameras at every 1- or 2-km interval, the KEC monitors whether congestion emerges. Once the KEC identifies congestion, it updates the situation on its traffic management system. Then, the partner companies disseminate the information through their own navigation systems.

The service was the result of co-operation between the KEC, the public motorway operator and private companies operating navigation services. After starting with two navigation providers, it has since expanded to major navigation and digital map providers including Naver, LGU+ and T-map.

According to the Ministry of the Interior and Safety (MOIS), a crash on a frequently congested motorway section is 2.5 times more likely to result in a fatality. As the motorway-congestion warning service alerts drivers before they reach the back of a queue, one could expect a reduction in motorway fatalities.

The KEC also started a "co-operative crash-response service" with private navigation companies (Figure 22). This service employs a co-operative two-way information sharing mechanism that takes information from the users of navigation apps to identify crash risks. When a user stops suddenly or stops on the road shoulder, the situation is transmitted to the KEC's traffic information centre. The KEC checks the situation with its CCTV to confirm whether it is an emergency and, if needed, calls the police and fire station for emergency service. The information is disseminated to the navigation apps on the vehicles upstream via the system for the "motorway congestion warning service" to prevent secondary crashes.



Note: 1. Incident detection, 2. Sharing incident location, 3. Verifying the incident with CCTV, 4. Initiating crash response, 5. Sharing incident information, 6. Providing information to road users.

Source: information and infographics provided by the KEC.

United States

On crash scenes, lives are often saved by the rapid intervention of medical professionals supported by the appropriate equipment. In the US, 40% of fatal road victims were still alive by the time emergency medical personnel arrived. The emergency response must, however, be proportionate to the needs of the victims, making the best use of available resources. Such needs can be either under-estimated or exaggerated at times when incidents are inaccurately reported.

In the United States, the 911 programme was designed to provide a universal, easy-to-remember number for people calling for help³⁴. It is housed within the National Highway Traffic Safety Administration at the US Department of Transportation (DOT). The current system, however, does not benefit from the capabilities brought by smartphones, such as the exchange of text, photo, video and data. US states, technology providers, public safety officials, and 911 professionals are working on the "Next Generation 911 (NG911)", a DOT-led project to upgrade the system and benefit from these newer forms of communication technologies³⁵.

Crash prediction modelling

Crash prediction modelling is a term used to describe a variety of methods that use mathematical models, historical data and other inputs to estimate an expected crash frequency on a given road segment, intersection or network. One of the most important publications on the subject is the *Highway Safety Manual* (HSM) developed by the American Association of State Highway and Transportation Officials (AASHTO, 2010). Beyond this and beyond the United States, a number of research projects have also created crash prediction models (Yannis et al., 2017).

One can build a crash prediction model using simple statistical methods such as linear regressions. But increasingly complex methods have also been explored, ranging from Poisson and negative binomial to random-parameter models and neural networks. In recent years, machine-learning algorithms have been used in research projects and in practice, taking advantage of bigger datasets as inputs, making faster and more accurate predictions (Caliendo et al., 2007; Katrakazas et al., 2016).

Crash prediction models can be developed for all types of road networks, including motorways. Motorways (or *freeways*, as they are called in the United States) were not originally covered under the first edition of the HSM but were included in a supplement edition (AASHTO, 2014). A research project has adapted the methodology proposed by the HSM, developing a crash prediction model for Italian motorways (La Torre et al., 2019).

These models can be used to give motorway operators insights as to when, where and how crashes may happen, based on patterns found in historic data. The road operator can use this information to make permanent changes to their network or activate temporary responses and thus prevent crashes. These and other active motorway-management measures can be used to dynamically reduce the risk profile of motorways. To reach Vision Zero, such predictive models and proactive operations are needed. The proactive management of road risk is one of the components of a Safe System approach.

Crash prediction models can be differentiated in many ways, but this report will focus on a grouping based on the type of data used in the model. One uses static historic data and the other dynamic real-time data.

Crash prediction models using static historic data

It is often said that history repeats itself. Using historical data, a crash prediction model can identify areas and periods of concern. An example of such a model was developed in the United States by the Volpe Center, a research centre in the Department of Transportation. This approach has been used on several occasions, notably in the highway system of the state of Tennessee and in the city of Bellevue, Washington (Flynn and Sudderth, 2019). Although neither of these case studies specifically addresses freeway/motorway systems, the method is transferable and applicable to a motorway-only network.

This type of model uses machine-learning algorithms to predict crash propensity and guide decision making. To create such a prediction model, a detailed historical crash database is required, with the exact location and time of each crash, as well as severity information. Exposure data – i.e. the volume of vehicles travelling on the different segments of the road network – is also required. This data is broken down by hour of the day, day of the week, and month in order to create an annual profile of traffic patterns. The model can be further enhanced using more data inputs such as speed and weather.

Volpe found that using all crashes (including property-damage-only crashes) could increase the prediction power of the model. In order to capture all incidents, the model incorporates crowdsourced information from Waze, a widely used navigation application whose users can actively report traffic events. Historical weather data did not significantly improve the model, probably as this information was already incorporated by the exposure and incident data. This historical data is then used to train the model.

To make a forecast for a set period of time (e.g. a week), the model uses the historical information about exposure and incident rate for the upcoming period, coupled together with other variables, such as weather forecasts and any upcoming events (music concerts, sports events). These extra inputs are used to explain traffic volume increases beyond historical values. Combining this information, the model makes predictions for that period and identifies risky times and locations.

The outputs of the model can be used in two different ways. As authorities identify the locations and times with higher risk, they can then take appropriate measures. For example in the two case studies undertaken by Volpe, the authorities used the information to increase police presence at the high-risk times and locations (Tennessee) or to guide road-safety investment decisions (Bellevue).

This method has both advantages and disadvantages when it comes to a potential application on motorways. The essential data needed for creating such a crash prediction model should be readily available to a motorway operator. It can be created relatively easily, and could yield actionable information. On the other hand, it relies mostly on historic information, which may or may not be replicable in the future. To ensure that the outputs can be acted upon with a certain degree of certainty, significant post-processing is required.

Crash prediction models using static data are commonly used on other roads with mixed traffic, especially rural ones, to identify high-risk locations. Motorways, having high design standards and separated traffic, have few such high-risk locations. Crashes on motorways are often caused by a combination of traffic, bad weather, speeding and human error, and the latter two factors cannot be predicted. Even if such crash prediction models can be useful for motorways, they seem much less useful than models taking advantage of real-time information.

Real-time crash prediction models

Some crash prediction models can also predict the probability of a crash on a specific road segment using real-time data on traffic conditions. These models compare real-time traffic conditions with historical data, including observations made when crashes actually occurred.

Real-time crash prediction models try to identify the conditions that led to each individual documented crash and to alert authorities when those conditions reoccur (Abdel-Aty and Pande, 2007). Hossain et al. (2019) provide an extensive summary of real-time crash prediction models, describing the state of the art and breaking down the different components required.

Real-time crash prediction models first establish baseline traffic conditions – the traffic patterns on days when no crash was recorded – from the historical data. They then identify differences in these patterns on days when crashes actually happened, especially in the minutes leading to them (typically up to 30 minutes). Then, by monitoring real-time traffic conditions, they can identify whether these same variations/differences are happening, therefore signalling that there is an increased probability of a crash in the next few minutes. This allows the actors (road operator, road authority) to take the appropriate measures to reduce this probability.

Multiple different categories of data are required to build a robust real-time prediction model. Historical exposure data (traffic volumes) are perhaps the most important kind of data needed, with the data broken down by day, time of day, and road segment. Depending on the source used to obtain these data, further attributes of the traffic (e.g. speed, headway, volume by lane, occupancy) can also be gathered. The other historical information needed is crash data with accurate geo-location and timestamps. With this, traffic conditions before the crash can be identified. Data coming from the infrastructure itself (geometry, pavement conditions, etc.) can also be used. These data sources are combined to train the model to determine the baseline traffic conditions against which any changes happening before a crash occurs can be measured.

Motorways have significant advantages when it comes to building a real-time crash prediction model. There are limited entry and exit points, which makes traffic counts and analysis easier. Furthermore, large segments of motorways, especially in urban areas, are usually monitored via cameras. This enables the identification of the exact time and location of crashes. Finally, the high design and construction standards of motorways provide homogenous infrastructure data and the ability to easily monitor traffic conditions.

A key consideration for real-time crash prediction models is how the real-time data are gathered. The sensing equipment determines the type, volume and quality of the data, but also the associated cost. The most commonly used method is induction loop-detectors, a typical instrument for traffic flow measurements. In recent years, there has been an increased use not only of microwave detection systems but also of systems using ANPR and Bluetooth detectors (Yasmin et al., 2018; Ahmed et al., 2012; Yuan and Abdel-Aty, 2018). These methods are more expensive but offer additional and more-detailed traffic information. Microwave detection systems show the most promise; they are installed easily in the roadside and unaffected by temperature, humidity, colour or background noise.

These models use real-time traffic conditions to predict whether there is an increased probability of a crash. This enables operators to employ a range of countermeasures that can reduce that probability. For motorways, these countermeasures can take the form of variable message signs (Al-Ghamdi, 2008), variable speed limits (Lee and Abdel-Aty, 2008), or ramp metering (Abdel-Aty and Gayah, 2010). By applying these measures, the operator tries to return traffic conditions closer to safe (baseline) values, reducing the probability of a crash. It is important to point out that the individuals tasked with monitoring traffic conditions (i.e. those who will receive the inputs from the real-time crash prediction model) must

be properly trained. This will enable them to take the appropriate response in each situation, effectively reducing crash risk.

Several experts have expressed scepticism about the feasibility of developing accurate motorway fatality prediction models, mainly due to the statistically small number of motorway traffic deaths. The predictive power of models should be the subject of intense scrutiny before such tools are allowed to influence decision making.

An action plan for the Korean motorway network

Korea's motorway safety has improved steadily over the years but progress has stalled since 2015 (Figure 2 and Annex A, Figure A6). In this report, the ITF investigated best practice in motorway safety management in Korea and ten other developed countries. It reveals that the Korea Expressway Corporation (KEC) follows best practice in most areas and demonstrates leadership in some aspects. Having integrated road safety into its strategic vision, it describes itself as "a corporation providing a safe and convenient platform for future mobility".

However, further progress is possible. Fatality numbers on Korea motorways could be halved, saving the lives of more than 100 people each year. Doing so would align Korea with the average fatality rate on motorways in Germany, Japan, the Netherlands and the United Kingdom. Yet, without the support of other stakeholders, especially national authorities and agencies, the KEC alone will not be able to reduce the number of motorway traffic deaths significantly. For this reason, this report makes recommendations to all relevant parties including MOLIT, KOTSA, KOTI, KOROAD and the Police Agency.

In 2016, the ITF made a number of recommendations to improve all aspects of road safety in Korea (ITF, 2016). Some have been implemented, such as mandatory seatbelt-wearing on rear seats and rest periods for truck drivers. Korean experts however believe that compliance with such regulations could still improve. This report, therefore, includes a number of recommendations towards enforcement and education.

Other recommendations from the earlier ITF report have not been fulfilled. For instance, the governance system is more or less the same as it was in 2016, and higher speed penalties have not been introduced. This report does not make an inventory of whether and how previous recommendations were implemented, but instead focuses precisely on the actions and policies that have the most direct impact on motorway safety.

What follows is a list of precise recommendations, together with notes that can support their implementation.

Road Safety Management

The KEC should conduct research using surrogate safety metrics such as vehicle swerving or emergency braking in order to try to predict fatal and serious casualties and to make full use of such metrics in their road safety management practices. An earlier report (ITF, 2019a) recommended that all stakeholders should continue to conduct research on surrogate safety metrics to identify those metrics that predict road traffic crash numbers most successfully and can specifically predict the number of people killed and seriously injured. Research should also explore how surrogate safety metrics could include factors such as the fragility of a crash victim as well as speed, mass and crash angle. The KEC already collects relevant data from navigation service providers. This includes hours of continuous driving, which may predict the number of crashes due to fatigue. This also includes sudden vehicle stops through the "co-operative crash

response service". The KEC could further develop such data partnerships for both real-time and aggregate surrogate safety metrics.

The KEC should ensure that its road safety research team is trained to make the best use of AI and surrogate safety metrics. The adoption of surrogate safety metrics and the use of AI to identify crash-prone situations require core statistical competencies among road safety professionals. A good understanding of key statistical concepts is essential to prevent the misinterpretation and misuse of data. Strengthening links between transport safety experts and specialised academic researchers could be beneficial. The KEC should invest such skills in the development of crash prediction models and in the proactive management of crash risk to realise its vision of providing a safe and convenient platform for future mobility. The organisation should strengthen its capability for the collection and analysis of real-time traffic data that is generated by the infrastructure, the vehicles and the drivers.

The Korean government should fund a permanent and independent in-depth crash investigation programme to understand safety weaknesses in the entire transport system. Several countries, including the Netherlands and Germany, fund a permanent programme of in-depth investigation on a sample of crashes, focusing on the fatal and most severe crashes. Delivered by independent researchers, such an investigation does not seek to establish criminal liability, but rather to identify all the parts of the transport system that have failed and contributed to the crash. At times of rapid change in vehicle technology, especially with driver assistance systems and vehicle automation, such a programme seems more important than ever. It should be enhanced by a legal framework enabling the examination of vehicles' black boxes (also known as event data recorders or EDRs) and a legal obligation that vehicles are fitted with such equipment. The legal framework should ensure that personal information remains protected.

MOLIT should promote work-related road safety in road haulage companies and in other sectors where appropriate. Trucks are involved in over half of motorway fatalities in Korea. The MOLIT should consider work-related road safety as a priority for action, and consider implementing several measures proposed by the European Transport Safety Council (ETSC):

- Promote the business case through targeted information dissemination to employers about investing in and benefitting from work-related road safety.
- Encourage employers via financial incentives to fit and purchase vehicles with in-vehicle technologies that have a high life-saving potential.

• Develop specific guidance for integrating work-related road safety, through incentives or requirements, into public procurement. Establish a centralised certification service for suppliers that comply with the legal requirements for work-related road-risk management and have safe work policies.

The MOLIT or KOTSA should initiate a research programme to quantify the influence of various factors and interventions on motorway safety performance in developed countries. No published comparison of motorway safety across countries yet exists that rigorously explains the differences in safety performance and separates the influence of various explanatory factors. Explanatory power may be found in the share of heavy goods vehicles, speed limits, market penetration of vehicle safety features, geometric constraints, the number of access and exit ramps, the road safety rating of motorway sections, etc. A research programme in this area would cast a new light on the performance of each country, would help identify best practice and would support efforts to develop a motorway safety programme with precise targets. Rigorous quantitative research employing econometrics methods would be preferable. A partnership between MOLIT, KOTSA, the KEC and other organisations and research agencies is essential because of the

need for quality data across several fields. Global NCAP could advise on vehicle safety, iRAP could provide infrastructure star-ratings, the ESRA consortium could bring data on attitudes, etc.

The Ministry of Economy and Finance and the Korea Development Institute need to review the Value of Statistical Life for the fair economic assessment of road safety projects. Currently, the Value of Statistical Life (VoSL) in Korea is exceptionally low and does not align with OECD recommendations. This inevitably reduces the economic feasibility of road safety projects. A review of current VoSL calculation methods is essential for Korea to invest in road safety and deliver the UN road safety targets. The OECD (2012) offers guidance on how surveys can help assess the willingness to pay for policies that reduce mortality risks.

Safe Road Users

The KEC needs to fund and operate an observatory for dangerous behaviours on the motorway network. Across developed countries, it is common for motorway operators and national authorities to design and run regular campaigns to raise awareness of risky behaviours. Whether the benefit of such campaigns is measured depends on the existence of a behavioural observatory. SANEF, one of the private companies operating sections of the French toll-motorway network, has run such an observatory since 2012, based on video surveys, with technical support from the national experts group Cerema. Their findings reveal substantial room for progress towards safe behaviours and attitudes among drivers. For instance, 31% of drivers in the middle lane did not keep a safe headway, and 21% of truck drivers encroached on the hard shoulder. The KEC needs to fund and operate such an observatory to monitor behaviours, attitudes and perceptions among drivers on motorways. It would measure speeds, headways, distractions, seatbelt use, driving time between breaks, etc. The observatory would help measure the effect of future enforcement and education campaigns, as well as helping to set targets for such campaigns.

The KEC and relevant government agencies need to co-operate to create a robust enforcement system that enables the automated enforcement of variable speed limits and lane-use management systems. Variable speed limits and lane-use management systems impose dynamic rules that require clear and visible signage. Korean authorities thus need to elaborate a legal and regulatory framework specifying the exact signage requirements. The police and the motorway operators then need to co-operate to set up appropriate enforcement measures. Automated enforcement is the most cost-effective method to stimulate compliance. Creating a system that provides VSL information to drivers' navigation systems and smartphone apps would prevent confusion and increase the compliance rate. Until such systems are put in place, poor compliance levels will deprive the KEC of effective solutions towards traffic management and traffic safety.

The Korean government should envisage a 10-year trial for the civil enforcement of some motorway traffic offences by the KEC, helping the police better focus on offences that remain criminalised. Some countries like the UK have successfully decriminalised a number of offences in an urban context, giving civil enforcement power to local authorities. Parking offences and several moving-traffic offences (such as driving in bus lanes) are now enforced in this way. Considering the state-of-the-art equipment managed by the KEC for traffic monitoring and tolling, and the KEC's interest in keeping their staff and customers safe, the ITF recommends a trial for the civil enforcement of section speed limits, including dynamic speed limits, and of lane-use management systems, especially in respect of lane closures. This requires amending the Road Traffic Act and the funding of an independent adjudication court.

The KEC should use vehicle identification systems to compute the average speed of each vehicle trip on their network, for the monitoring of behaviours and the trial of a reward system for safe driving. It is technically possible for the motorway operator to track the average speed of a vehicle from its entry to its departure. The KEC could thus apply discounts or penalties through their toll collection system, in order to stimulate greater compliance with speed limits. Giving penalties may not be feasible without decriminalisation, but rewarding compliance with a discount would be technically and politically possible. Such nudges could contribute to building public support for section speed enforcement on the entire motorway network.

The National Police Agency should review the level of penalties and sanctions for moving traffic offences, especially for speeding, and evaluate the benefit of mandatory driver education courses. The enforcement of speed limits is the cornerstone of a motorway safety policy. The French success with automatic speed enforcement is evidence of this. The efficacy of enforcement is determined by two factors combined:

- the intensity of police controls, and the use of automatic tools
- the level of sanctions typically the cost of financial penalties, but also the use of non-financial sanctions.

Financial penalties for moving traffic offences should align with international best practice and be consistent with the ambitions of the national road safety plan. Non-financial sanctions deserve particular attention and a robust cost-benefit evaluation. Non-financial sanctions include mandatory training, community work, license suspension and vehicle impoundment. They should complement financial penalties whose effect on the compliance of wealthier road users may be negligible. They can also make the enforcement of speed limits more socially acceptable.

Safe Vehicles

The MOLIT should prepare legislation that requires that all trucks are equipped with digital tachographs and submit real-time data to KOTSA. The legislation should empower KOTSA to share aggregated tachograph data under strict privacy protection rules with a number of stakeholders for road safety research purposes. While equipping a digital tachograph (DTG) is mandatory for commercial vehicles, there is currently no obligation to submit real-time DTG data to KOTSA. Data is collected by administrative orders without strong legal support. The usage of real-time DTG is quite low; only around 5 000 trucks are equipped with real-time DTGs that automatically transfer real-time data to KOTSA. In addition, the data is not shared with the KEC and other motorway operators. KOTSA should work with partners including motorway operators to analyse de-identified DTG data to identify times and locations where compliance with driver fatigue is lowest. With this information, they should develop a range of countermeasures and monitor their effect. The Korean government should promote Advanced Driver Assistance Systems (ADAS), including Intelligent Speed Assistance (ISA), via channels like the New Car Assessment Program (NCAP) so that more vehicles are equipped with enhanced safety features. Unlike other NCAPs that are managed by private associations, Korea's NCAP is managed by KATRI (an institute under KOTSA) and the MOLIT approves the scoring system of the NCAP. Thus the government can guide NCAP in a certain direction by making changes in the scoring system.

The Korean government should schedule the mandatory equipment of all new vehicles with advanced safety features as close as possible to the EU schedule. Intelligent Speed Assistance (ISA) is a system that assists drivers in complying with speed limits. It will be mandated on all new EU motor vehicles from 2022. According to ETSC, "the European Union will have, by far, the most stringent vehicle safety standards in

the world with systems including Advanced Emergency Braking (AEB), Emergency Lane Keeping Assist (ELKS), drowsiness and distraction recognition and Intelligent Speed Assistance (ISA) all mandatory"³⁶.

The Korean government should stimulate the adoption of driver monitoring systems across the entire automotive industry. This is to prevent drowsy and distracted driving on conventional vehicles and to ensure the safe operation of partially automated vehicles. A driver monitoring system is a feature that measures the driver's vigilance level by tracking eye movement or other behavioural clues and vital signs. Such a system is required in Level 3 automated vehicles to know whether the driver is ready to take over the driving task when the automated system must give back control. A driver monitoring system on conventional vehicles could alert drivers when they are distracted or drowsy and could enhance the performance of autonomous emergency braking and other driver-assistance systems. The perception among customers that such systems are intrusive could be the main barrier to widespread adoption in the automotive industry. Considering the need for high-performance driver monitoring in Level 3 automated vehicles and the benefits of driver monitoring in conventional vehicles, the government should develop a strategy to stimulate the adoption of such systems. In the conventional vehicle sector, the government could envisage subsidies, retrofit programmes, reduced insurance premiums, and ultimately obligations.

The MOLIT should require that all vehicles involved in co-operative automated vehicle (CAV) trials on motorways are capable of handling unexpected situations such as C-ITS outage and the presence of pedestrians, animals, obstacles and debris on the roadway. Motorways are often perceived as the safest testbed for CAV technology on roads open to general traffic. This is due to the absence of curb activity, the exclusion of most vulnerable road user categories, high design and maintenance standards, and the growing provision of C-ITS services provided by roadside units. The situation should not lead to complacency towards the safety of automated driving systems. These should be able to cope with unexpected situations that occur, albeit rarely, on motorways and could coincide with C-ITS service outages. For instance, it would be wrong to consider a motorway as a road asset that is free of pedestrian traffic. Pedestrians represented 18% of victims on French motorways in 2019. Some came out of vehicles following a breakdown or a collision, while others came from outside the motorway premises. The ability to detect and avoid pedestrians, including at night, should therefore be a prerequisite to the testing of automated vehicles even on motorways.

Safe Roads and Operations

The MOLIT and the KEC should plan improvements of the motorway infrastructure that support the rapid deployment of automated vehicles, starting with automated trucks and truck platoons. Heavy goods vehicles currently represent a major safety challenge on the KEC network but could be largely automated sooner than private vehicles, with substantial safety, economic and environmental gains. The MOLIT and the KEC should examine where the physical and digital infrastructure risk is becoming a barrier to uptake.

The KEC should continue providing high-accuracy real-time information via all channels including C-ITS. This includes information on roadworks, congestion, incidents, variable speed limits, lane-use management, etc. One of the key success factors of C-ITS is how accurate the source information is. The KEC may need to improve its information-gathering procedure to provide more-accurate location and time information of roadworks and other lane blockages so that vehicles with Level 2 and above automated driving systems can use this information in actual driving tasks.

The MOLIT, together with telecommunication and road authorities, and with the vehicle and technology industries, should set guidance and standards for the rapid deployment of C-ITS services in Korea. They should consider road safety as the primary benefit of C-ITS services, which should be accessible to all vehicles by means of affordable retrofit programmes or smartphone integration. C-ITS services are particularly relevant to the safety of motorways. Examples include emergency electronic brake light (EBL), traffic jam ahead warning (TJW), in-vehicle signage (VSGN) and in-vehicle speed limits (VSPD). In addition, probe vehicle data (PVD) helps the motorway operator collect real-time traffic information on hazards such as slippery road surfaces, congestion and incidents. The pace of deployment of C-ITS by the automotive industry and by motorway operators depends on the regulatory visibility given by the MOLIT. The safety benefit of C-ITS services is such that the MOLIT should consider making these accessible to the widest possible public. To do so, it should favour C-ITS solutions that can be used with smartphones or with affordable retrofitted equipment.

The KEC should include 3D sensor data in its asset inspection protocol. Network-wide road safety assessments, road safety audits and asset maintenance tasks all require precise data that is often difficult to collect on motorways due to the presence of high-speed live traffic. Video and LIDAR surveys, resulting in a 3D point cloud representing the road asset, already help motorway operators in Japan collect precise data without having to conduct risky ad-hoc on-site surveys. The KEC should also include precise 3D maps in its asset inspection protocols, to better perform network-wide road safety assessments, road safety audits and asset maintenance tasks.

The KEC should assess the benefits and costs of further roadside barrier installation. The majority of the KEC network (54%) is equipped with roadside barriers. An analysis of historic crash data should, however, be conducted to estimate the life-saving potential of greater network coverage. The assessment should identify a cost-effective course of action.

The KEC should develop solutions that protect police and roadworks personnel during on-site operations. Solutions include roadside refuges, lane-use management systems and the use of robots to set up cones and barriers. The police rarely stop vehicles on motorways for enforcement operations, primarily for safety reasons. However, considering the need to deter unsafe practices in the road haulage industry, morefrequent police checks could be relevant. On-site police checks could stop trucks that are overloaded or carrying a load that is not safely secured. They could also stop drivers who fail to comply with the regulations on driver fatigue. According to Austroads, Lane Use Management Systems (LUMS) can facilitate safe enforcement and compliance operations. LUMS can indeed slow down approaching traffic and close a number of lanes to create a safe environment for the police to stop and inspect vehicles on a motorway. The same measures are applicable in the context of roadworks to protect workers from the risk of collision.

Notes

1 In grade-separated intersections, roads are constructed at different elevations, eliminating all crossing conflicts. Grade separation is typically achieved by the construction of a bridge.

2 In this report, all data reported as from the United Kingdom represents Great Britain alone, that is excluding Northern Ireland.

3 2017-19 average. Sources: DfT STATS19 / RAS30017, last updated Sept 2020. Reported Road Casualties Great Britain Annual Report 2019 (https://www.gov.uk/government/statistics/reported-road-casualties-in-great-britain-annual-report-2019) and DfT National Road Traffic Survey / TRA0104, last updated Sept 2020 (www.gov.uk/government/organisations/department-for-transport/series/road-traffic-statistics).

4 Conceived in 1994, the Vision Zero Initiative is a platform for the collected knowledge about and technology around traffic safety in Sweden. Founded by the Swedish Government and Swedish Industry, it summarises the Swedish approach to traffic safety. It can be summarized in one sentence: No loss of life is acceptable. See https://trimis.ec.europa.eu/project/vision-zero-initiative.

5 At the time of writing this report, no final decision was made on the exact baseline, but experts anticipate the baseline period to be 2021

6 The New Tomei and New Meishin Expressways will be extended to six lanes. The New Tokyo-Nagoya and New Meishin Expressways will be extended to six lanes to further improve the stability and efficiency of the double network connecting the three major metropolitan areas. This will further improve the stability and efficiency of the double network connecting the three major metropolitan areas.

7 See https://sustainablesafety.nl/

8 Select "Value of a statistical life, millions national currency current prices" and 2019 in OECD.Stat https://stats.oecd.org/Index.aspx?DataSetCode=EXP_MORSC.

9 See https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/915731/vehicle-speed-compliance-statistics-2019.pdf.

10 The inside lane is the one closest to on- and off-ramps; the outside lane is the one closest to the median barrier.

11 See Table SPE0114, "Time difference between vehicles and the vehicle in front in Great Britain", at https://www.gov.uk/government/statistical-data-sets/vehiclespeed-compliance-statistics-data-tables-spe.

12 See https://www.gov.uk/government/statistical-data-sets/quarterly-vehicle-speed-compliance-tables-spe25.

13 See https://www.politiet.no/en/services/driving-licence-and-passenger-carrying-vehicle-drivers-licence/fines-penalty-charges-and-other-sanctions/#undefined.

14 See https://www.racfoundation.org/motoring-faqs/enforcement#a30.

15 See https://www.transportxtra.com/publications/local-transport-today/news/65004/speeding-points-must-remain-under-a-decriminalised-regime-/.

16 See https://www.securite-routiere.gouv.fr/actualites/point-de-situation-sur-lexternalisation-de-la-conduite-des-voitures-radar.

17 Ibid.

18 See https://www.kent.gov.uk/roads-and-travel/road-safety/driver-education-courses/national-motorway-awareness-course-nmac and https://www.racfoundation.org/motoring-faqs/enforcement#a9.

19 The survey was undertaken by ASFA, which is a professional association comprising all actors involved in motorway exploitation and concession in France. Results are cited in SANEF (2019). See https://www.storage.sanef.com/DP/DP-observatoire-2019/index.html#page-9.

20 See https://austroads.com.au/publications/freight/ap-r591-19.

21 See https://www.justice.gc.ca/eng/cj-jp/sidl-rlcfa.

22 The North American Fatigue Management System comes with an associated website: https://nafmp.org/.

23 West Nippon Expressway Company (NEXCO West), Hanshin Expressway and Honshu-Shikoku Bridge Expressway Company.

24 Source: https://www.gov.uk/government/statistics/police-powers-and-procedures-england-and-wales-year-ending-31-march-2019.

25 See https://unece.org/sites/default/files/2021-03/R157e.pdf.

26 Level 3 refers to "conditional driving automation", where the driver must be ready to take over in a timely manner.

27 See https://www.globalncap.org.

28 See https://ec.europa.eu/transport/themes/its/road/application_areas/vehicle_safety_systems_en.

29 See https://etsc.eu/intelligent-speed-assistance-set-for-launch-on-all-new-eu-vehicle-types-from-2022.

30 See https://www.fmcsa.dot.gov/safety/research-and-analysis/ace-program-av-truck-maintenance-testing-and-storage-support.

31 See Table 7 for an explanation of "Day" 1, 1.5 and 2 in terms of C-ITS services.

32 Tunnels that allow lane changes must have a lane width greater than 3.6 metres, a shoulder width greater than 2.5 metres, a sectional speed limit, and a set level of bright illumination. See http://www.kgmaeil.net/news/articleView.html?idxno=265115.

33 ITS-G5 is a standard for vehicular communications elaborated by the European Telecommunications Standards Institute (ETSI).

34 See https://www.911.gov/about_national_911program.html.

35 See https://www.911.gov/issue_nextgeneration911.html

36 See https://etsc.eu/intelligent-speed-assistance-set-for-launch-on-all-new-eu-vehicle-types-from-2022.

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Annex A. Plotting two decades of motorway safety progress in ten countries



Figure A1. Canada: Motorway deaths per year



Figure A2. France: Motorway deaths per year

103











Figure A8. Sweden: Motorway deaths per year

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Nev

speed limit

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Figure A10. United States: Motorway deaths per year
Annex B. Organisations and experts who provided input for this report

With this report, the International Transport Forum (ITF) explores international best practice for motorway safety across 11 ITF countries: Australia, Canada, France, Germany, Italy, Japan, Korea, the Netherlands, Sweden, the United Kingdom and the United States. It provides examples of the precise actions found in these countries. It explores the opportunities for safer motorways resulting from the expected uptake of connected and automated vehicles.

The ITF engaged with over 40 experts and organisations in over ten countries to learn about best practices for motorway safety. The following is a list of those who provided verbal or written input.

Mohamed ABDEL-ATY, University of Central Florida, United States Ray BAKHOS, Operations, Greater Sydney, Transport for New South Wales, Australia Paul BOASE, Transport Canada, Canada Nicole DENTON, Road Safety Victoria, Australia Mark DOCTOR, FHWA, United States Laurie FLAHERTY, NHTSA, United States John FLETCHER, TRL, United Kingdom Daniel FLYNN, US DOT, Volpe, United States Gabriele GRIMM, Federal Ministry of Transport and Digital Infrastructure (BMVI), Germany Sangjin HAN, KOTI (Korean Transport Institute), Korea Benoit HIRON, Cerema, France Ducknyung KIM, KEC Research Institute, Korea Zamorano MARIA CRISTINA, Abertis, Spain Eleonora PAPADIMITRIOU, TU Delft, Netherlands Hyunjin PARK, KEC Research Institute, Korea Sujung PARK, KOTSA (Korea Transportation Safety Authority), Korea Iwan PARRY, TRL, United Kingdom Malo QUANCARD, Road Safety Observatory (ONISR), France Emanuelle RENZI, Ministry of Infrastructure and Transport, Italy Manuelle SALATHÉ, Road Safety Observatory (ONISR), France

Govert SCHERMERS, SWOV Institute for Road Safety Research, Netherlands Ibrahima SOW, Transport Canada, Canada Mick TIMMS, New South Wales Police Force, Australia King TSE, Ministry of Transport, Netherlands Anna VADEBY, VTI - Swedish National Road and Transport Research Institute, Sweden Pieter VAN VLIET, Ministry of Transport, Netherlands Peter VERMAAT, TRL, United Kingdom Esther WAGNER, NHTSA, United States John WALL, Transport for New South Wales, Australia Wendy WEIJERMARS, SWOV Institute for Road Safety Research, Netherlands Keith WILLIAMS, NHTSA, United States

In Japan, the following organisations have provided inputs to this report:

- Cabinet Office
- Ministry of Land, Infrastructure, Transport and Tourism (MLIT)
- National Police Agency (NPA)
- East Nippon Expressway Company Limited (NEXCO East)
- Central Nippon Expressway Company Limited (NEXCO Central)

This expert input, complemented by a literature review, helped the ITF develop an overview of best practices globally. When elaborating recommendations for Korea, the ITF consulted with the following organisations:

- Korea Expressway Corporation (KEC)
- Korea Transport Institute (KOTI)
- Korea Transportation Safety Authority (KOTSA)
- Korea Ministry of Land, Infrastructure and Transport (MOLIT)
- Korea Road Traffic Authority (KoROAD)
- Korean National Police Agency (KNPA)
- Korea Transportation Safety Authority (KOTSA).

Transport Forum

Motorway Safety in Korea Learning From International Best Practice for an Action Plan to 2030

Motorway crashes kill over 200 people in Korea each year. This report reviews international best practices in motorway safety across ten countries to inform ways to make Korea's motorways safer. Matching the average safety performance observed across Germany, Japan, the Netherlands and the United Kingdom would halve the number of motorway deaths. The report offers recommendations for an action plan to 2030, also taking into account the expected uptake of connected and automated vehicles.

International Transport Forum 2 rue André Pascal F-75775 Paris Cedex 16 +33 (0)1 73 31 25 00 contact@itf-oecd.org www.itf-oecd.org



