Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

CEDR TRANSNATIONAL ROAD RESEARCH PROGRAMME

SAFEPATH
SAFE caPAciTy Highways

SAFEPATH: SAFE caPAciTy Highways

WP3000: Empirical Research

Deliverable: D3.1, D3.2, & D3.3 Version 1.1

Date: 01/12/2022

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CEDR Call 2019(2)

SAFEPATH: SAFE caPAciTy Highways

WP3000 Empirical Research

D3.1 Interim Solutions Technical Report

D3.2 Final Solutions Report

D3.3 Database

Due date of deliverable:	01/11/2022
Actual submission date (version 1.0):	31/10/2022
Updated version submission date (version 1.1):	01/12/2022

Start date of project:	May 2021	End date of project:	April 2023

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Version: 1.1

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Executive summary

SAFEPATH

This Final Solutions Report is deliverable D3.2 from empirical research (WP3000) of SAFEPATH.

Objective

The objective of the Empirical Research Work Package (WP3000) is to build a database of projects and measures to increase highway capacity without diminishing road safety or building new physical infrastructure that have been implemented in various countries, including but not limited to CEDR member countries. The data will include information on the impact of measures on highway capacity and safety, along with various supplementary information such as user acceptance, challenges in implementation, and other relevant environmental, financial and societal factors.

Approach

Empirical research (WP3000) is based on work carried out in Problem and Systems analysis (WP2000), in which a systems analysis approach was adopted to define the research's scope and identify the ways to increase capacity. This formed the starting point for a literature review of deployed measures.

A stakeholder engagement plan was developed to identify key experts to engage via workshops, interviews, and questionnaires and collect more direct (and unpublished) information about these measures. This included effectiveness, any challenges faced in implementation, impacts on safety, and behavioural factors such as user acceptance.

Outcomes

An online interactive database has been created, complementing this report, which contains details of the measures with an overview of their impact on highway capacity, safety, and other factors.
The interviews, workshops, questionnaires, and literature review outputs are also stored in the database. The database can be accessed via the website: https://project-safepath.azurewebsites.net/

This report provides an overview of several measures which were found during the empirical research to have the most comprehensive evidence base. These included widely deployed traffic management measures such as hard shoulder running for which, because it is often under the direct control of a National Road Authority (NRA), data on acceptability, safety and effectiveness are readily available. Measures involving new technology, and others such as incident management, are also included, for the same reason.

New approaches to in-vehicle systems such as Intelligent Speed Adaptation (ISA) are included here although they are yet to be widely deployed, and practical evaluations yet to be carried out. Also, vehicle technologies along with driver behaviour and regulation measures are often out of the direct control of NRAs but they offer a great potential to reduce congestion if implemented properly.

For an NRA, the findings of this review suggest that there may be future tools to deploy to increase capacity, but they are yet to be proven and investigated to the same extent as direct traffic management measures using road infrastructure. Some will also require other actors such as vehicle makers and vehicle buyers to be involved. NRAs will need to keep up to date in this newly-emerging and dynamic field.

The findings of this report support Road Safety Analysis (WP4000) and Good Practice Guide (WP5000). The capacity measures outlined here will be further subject to a road safety analysis using a safety impact assessment methodology. The road safety analysis will also use the insights gathered here to compare the solutions and analyse their safety performance. The findings in empirical research along with road safety analysis will provide a base for the Good Practice Guide (WP5000) which will enable NRAs to make informed decisions when selecting which measures to deploy.

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List of Acronyms

ASEC	Average Speed Enforcement Cameras
ADAS	Advanced Driver Assistance Systems
AV	Automated Vehicle
AID	Automatic Incident Detection
ACC	Adaptive Cruise Control
AEB	Automated Emergency Braking
CAV	Connected and Automated Vehicles
CEDR	Conference of European Directors of Roads
C-ITS	Cooperative Intelligent Transport Systems
DoRN	Description of Research Needs
DSDS	Dynamic Speed Display Signs
DSL	Dynamic Speed Limits
ESC	Electronic Stability Control
GLOSA	Green Light Optimised Speed Advisory
HGV	Heavy Goods Vehicle
HOV	High Occupancy Vehicles
iVRI	Intelligent Traffic Control Systems (translated from Dutch)
I2V	Infrastructure to Vehicle
ISA	Intelligent Speed Adaptation
ITS	Intelligent Transport Systems
KPI	Key Performance Indicator
KPH/Kmph	Kilometres per Hour
KSI	Killed or seriously injured
LDW	Lane Departure Warning
LKA	Lane-Keeping Assistance
NRA	National Road Authority
OEM	Original Equipment Manufacturer
PESTEL	Political, Economic, Social, Technological, Legal and Environmental factors
PSP	Platooning Service Providers
PEB	Project Execution Board
RADAR	Radio Detection And Ranging
RPM	Rotations Per Minute
SQL	Structured Query Language
TIC	Traffic and travel Information services
VSL	Variable Speed Limits
VMS	Variable Message Signs
V2V	Vehicle to Vehicle
WP	Work Package

1 Introduction

In recent years, developments in transport and traffic technologies have led to many innovative solutions to improve traffic flow and efficiency. Using new methods, existing infrastructure can be utilised in a best and smarter way, thereby increasing highway capacity without having to construct new roads. The selection and implementation of innovative technologies depends upon factors such as desired outcomes, available resources, and technology and infrastructure maturity levels. These will vary due to differences in external factors such as climate, culture, and existing technology. These differences may result in the expected benefits not being realised.

In addition, lack of proper monitoring and assessment may result in innovative solutions being incorrectly or inappropriately implemented. They may reduce the efficiency of traffic flow rather than improve capacity, or decrease traffic safety. Thus, it is critical to properly assess and understand the requirements and implications of new implementations.

The Conference of European Directors of Roads (CEDR) has identified a gap in existing knowledge related to the safety performance of measures to increase highway capacity. This gap needs to be addressed within Call 2019(2) under the CEDR Transnational Road Research Program. The participating countries in the call include Austria, Belgium (Wallonia), Finland, Germany, Hungary, Ireland, the Netherlands, Sweden, and the United Kingdom.

The main objective of this project, as indicated in the Description of Research Needs (DoRN) call 2019(2), is to investigate different measures to increase highway capacity without compromising traffic safety.

There is a wide variety of innovative solutions and measures for increasing capacity without physical widening of the highway (i.e., additional road space). However, different measures have different influences on highway capacity and road safety. Thus, it is critical to assess the effectiveness of different measures on highway capacity and road safety, taking into consideration factors such as political, financial, environmental, social, technological, and legal matters.

Empirical research (WP3000) aims to gain a greater understanding of a wide variety of projects and measures, with an assessment of their impact on highway capacity, safety, and other relevant environmental, financial, and societal factors.

Report structure

This report contains the deliverable **D3.2: Final solutions report** within the empirical research (WP3000). It is structured as follows:

- Section **2** provides a recap of previous systems analysis.
- Section **3** describes the approach followed in this research and dives deeper into purpose, methodology, scope and various measure categories defined for further work.
- Section **4** gives an overview of questionnaires, interviews, and workshops to populate the database.
- Section **5** introduces an online database of measures that can be accessed via a website.
- Section **6** provides an overview of the measures in the database with the most comprehensive evidence base.
- Section **7** provides insight into the various measures discussed in section 6.
- Section **8** concludes this report with the next steps.

2 Previous work: Problem and systems analysis (WP2000)

A systems analysis approach was adopted to help understand the *highway system* and provide a systematic way to analyse the effect of different *means* and *measures* on highway capacity and road safety. The process of systems analysis involved 4 different steps:

1) Problem demarcation and determining the level of analysis. In this first step, problem analysis and demarcation were conducted to understand and demarcate the problem. The outcome was the *means-ends diagram* which provided a broad spectrum of the objectives and means from strategic to tactical and operational levels. From this, *increasing highway capacity* was identified as the focal objective of this research. The following means were identified as means for the core level of analysis:

- Increase infrastructure capacity;
- Improve driver behaviour;
- Improve vehicle technologies, data, and services; and
- Improve road safety.

Using the means-ends diagram, three *dilemmas* were identified in increasing highway capacity. These are a) Road safety; b) Investment costs; and c) Environmental effects. Road safety was considered the main dilemma and has been dealt with in the rest of the analysis.

2) Specifying objectives and criteria. The second step involved identifying more specific objectives and criteria. The main objective was narrowed down into three sub-objectives: a) Increase highway capacity; b) Improve user experience; and c) No diminishing of road safety. For these sub-objectives, a total of six criteria were identified which quantify and measure change in terms of highway capacity and road safety. These were: congestion severity, traffic flow, delays, travel time reliability, collision risk, and collision severity. They provided a set of reliable KPIs to measure the effect of different means and to continue with further steps of the systems analysis.

3) Identifying influencing factors and mapping out causal relations. The third step was to identify the factors that influence the criteria identified in step two and map the causal relations among these factors. The outcome of this step was the causal relation diagram, which provided insight into how different factors influence each other and the criteria.

4) Creating the systems diagram. In this last step, all the findings from the first three steps were combined along with findings on external factors to gain a full overview of the complete system. This step resulted in the systems diagram, which is a tool to analyse and understand (in this case) the *system* of highway capacity and road safety.

The systems diagram (*Appendix A*), the main product of systems analysis, forms the basis for further analysis within the empirical research. The diagram provides a basic conceptual model for the system, showing various aspects and fundamental building blocks affecting the system. In addition to expressing the description of research needs in a systematic model, the diagram also explains the influencing factors, means, and criteria.

As part of the systems analysis, an actor analysis was carried out to identify relevant stakeholders categorized based on their power to influence and their interest in the highway capacity and road safety system. These stakeholders were approached and engaged in gaining an overview of different traffic measures with the help of questionnaires, interviews, and workshops.

Readers are advised to review the systems analysis report for more details regarding the outputs of systems and actor analysis.

Note that this deliverable is a follow-up on Deliverable **D2.1:** Problem Definition, **D2.2:** Specified KPIs and research criteria, **D2.3:** Specified factors and variables and **D2.4:** Stakeholder engagement plan.

3 Purpose and methodology

The following subsections discuss the objective, scope and methodology used in empirical research (WP3000).

3.1 Purpose and research questions

The main purpose of empirical research (WP3000) is to collect evidence of measures which increase highway capacity and to build a database that contains a wide variety of projects and measures, with an assessment of their impact on highway capacity, safety, and other relevant environmental, financial and societal factors. However, the objective is scoped down to focus on those existing measures which increase road capacity without physical widening of the highway (i.e., additional road space) and without compromising traffic safety.

The main research question as defined within the Description of Research Needs (DoRN) is:

How can the highway capacity be increased without compromising traffic safety?

To answer this, it is important to gain an overview of the different measures that exist, their effectiveness in terms of improving capacity without diminishing safety, and various socio-technical factors that influence their performance.

To answer the main question, the following sub-questions were defined to conduct the analysis in this empirical research.

- *Which traffic measures have been implemented in given countries to improve highway capacity?*
- *How effective are these measures in improving highway capacity and traffic safety?*
- *What are the various challenges and factors in the implementation of these measures?*

3.2 Scope

Within this project, the focus was on collecting, consolidating, coordinating and analysing information from existing research targeting the defined scope of research to achieve the objective. However, conducting new research to gather information is out of scope of this project.

The scope was further geographically bounded to create an extensive database of traffic measures implemented across European countries (including but not limited to CEDR member countries).

A commentary into the safety aspects of various measures is out of the scope of this work package and shall be covered in Road Safety Analysis (WP4000). Empirical research (WP3000) also does not aim to provide any recommendations for choosing an effective measure. This aspect will be covered in the Good Practice Guide (WP5000).

Table 1 shows some DoRN requirements relevant to WP2000 and WP3000 and provides an overview of where different aspects are covered. The requirements which are not mentioned are covered in further work packages: Road Safety Analysis (WP4000), Good Practice Guide (WP5000) and final report (WP6000).

Table 1: Requirement assessment from DoRN

Requirement(s) from DoRN (page 4)	**Covered under**
Identify the various solutions to cater for increasing highway capacity without physical widening of the highway	WP3000 - D3.3 (Database) in combination with explanation in **D3.2 (This report)**
Consideration of locations within Europe and beyond, implementation dates etc.	WP3000 - D3.3 (Database) contains the locations where the measure was implemented
Solutions should be grouped into categories that allow for comparative analysis.	WP2000 – D2.1, D2.2, and D2.3 (Systems analysis) identified relevant categories. WP3000 – **D3.2 (This report)** explains the categories with some examples from the database D3.3 (Database) implements the category classification
Commentary on the transferability of different options to the EU Member States.	WP3000 – **D3.2 (This report)** provides a preliminary indication Detailed comments on transferability per measure are available under measure descriptions within the database **D3.3**
A detailed list of references and sources of information to allow Roads Authorities to facilitate further research.	WP3000 – D3.3 (Database) contains references within each measure description whenever a reference was available.

Key term: Highway capacity

Highway capacity is defined as the “maximum sustainable hourly flow rate at which vehicles reasonably can be expected to traverse a point or a uniform section of a lane or roadway during a given time period under prevailing roadway, environmental, traffic, and control conditions” (Highway capacity manual 5th Edition, TRB).

Since not all evaluations calculate the highway capacity, there are various other KPIs which indicate an increase in highway capacity. An increase in traffic flow, decrease in journey time, reduction in congestion duration, low frequency of traffic congestions, decrease in vehicle lost hours (delays), increase in average speed, and decrease in traffic restoration time are all indirect indicators to increase in highway capacity which are used in the study of traffic measures within this project.

3.3 Approach

As stated in previous sections, the purpose of this empirical research is to collect and collate a detailed list of good practices of measures and interventions which have been implemented across Europe, to create an accessible, user-friendly and complete database. This process includes gathering information regarding the measures such as implementation details, investment costs, environmental impact, user acceptance, challenges in implementation, etc. with focus mainly on the capacity and safety aspects of different measures.

The outcomes from problem and systems analysis (WP2000) were used as a starting point for the empirical research. Two main outcomes – means of increasing highway capacity and stakeholder engagement plan – were pursued in empirical research to define the further approach of gathering information. A four-pronged approach was chosen, in which information for the online database was collected using: Literature review, Questionnaires, Interviews and Workshops. This is illustrated in Figure 1.

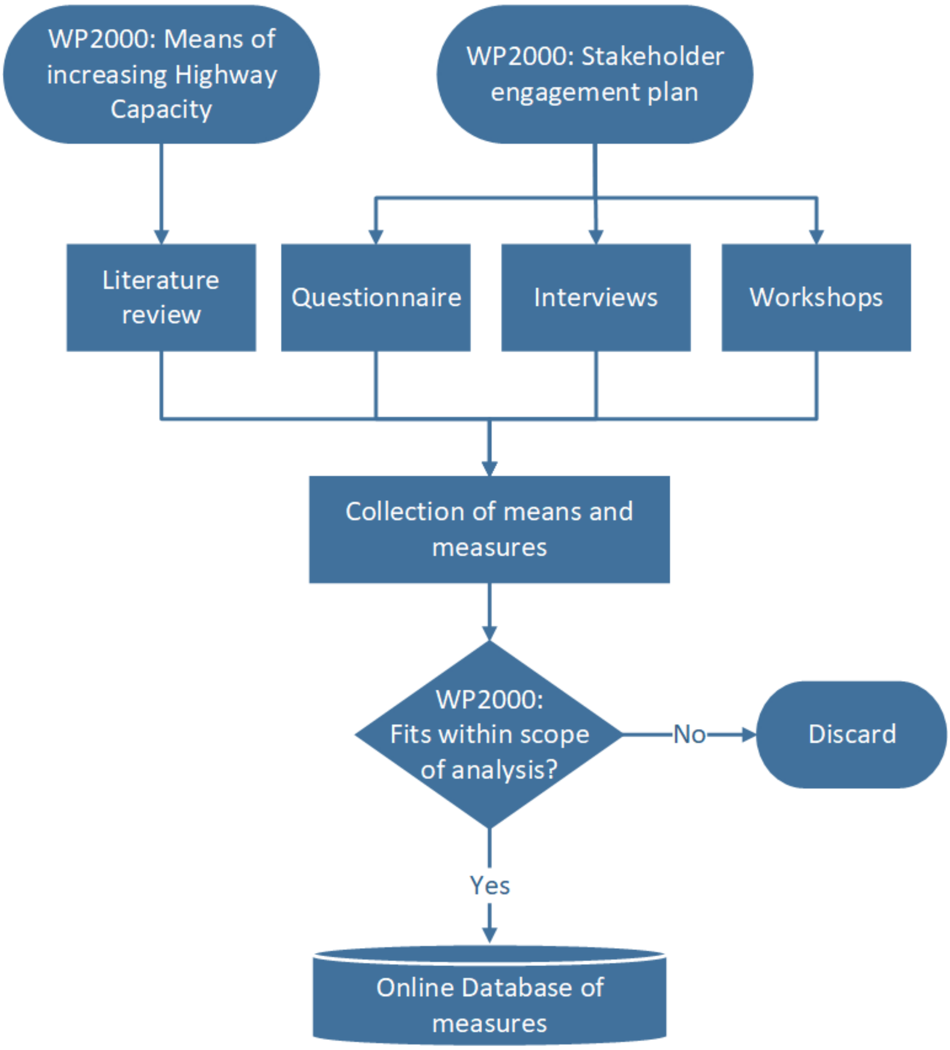


Figure 1: Methodology of collecting various empirical evidence related to traffic measures in WP3000

The identified means of increasing capacity from WP2000 were used as input to conduct the literature review. For example, measures to improve traffic management, such as hard shoulder running, were identified to increase capacity. The objective of the literature review is to collect the measures along with evidence regarding their effectiveness in terms of improving highway capacity and road safety. At the beginning of the process, a brainstorming session was conducted among the project consortium experts to capture and identify various measures and their references. Further, snowballing was carried out to identify related literature. The websites of NRAs, CEDR and EU were scanned thoroughly for any relevant information. The information found was structurally stored in the form of a database.

In WP2000, a stakeholder engagement plan was built, identifying relevant stakeholders and engaging them to collect more practical information regarding different measures and their implementation. This was used to identify and engage stakeholders through workshops, interviews, and questionnaires. The detailed procedure of stakeholder engagement is explained in *Appendix B*. The objective was to collect more direct (and often unpublished) information regarding various traffic measures and their effectiveness in increasing capacity and safety including practical details such as user acceptance and challenges faced during implementation or operation. The detailed process of conducting a literature review, questionnaires, interviews, and workshops is explained in *Appendix C*.

The outputs resulted in an extensive list of measures with information regarding their effectiveness and implementation. To organise a vast amount of information in a structured manner, identified solutions were organised into categories, subcategories and types. These are discussed in section 3.4. This also fulfilled the requirement from DoRN regarding grouping solutions allowing comparative analysis among them.

Finally, the information collected was again checked whether they fit within the scope defined in problem and systems analysis (WP2000). The information out of scope of the problem was discarded and the remaining relevant information was collated in an online database of measures. This database provides a quick accessible reference to detailed information on various types of measures, their implementation details, and how well they perform. The database is further discussed in section 5.

Phases of Empirical research

The work in empirical research (WP3000) was carried out in two phases. During **phase 1** of empirical research **(month 1 - 12)**, a database of various measures was created with the help of a literature review, interviews, workshops and questionnaires. At the end of phase 1, deliverable D3.1: Interim solutions technical report was produced, which provided an overview of the quick-win solutions for increasing highway capacity. **Phase 2 (month 12 - 18)** of empirical research aimed towards enriching the quality of the database by conducting more interviews, workshops and literature reviews.

This is a final report of empirical research (WP3000) (after phase 2) and is an update over the previous deliverable D3.1. Various discovered solutions/measures have been reviewed in this report to identify various quick wins. To help the reader distinguish between the two phases of reporting, all updates to the document have been highlighted by **a *bounding box*** like this paragraph.

During phase 2 of empirical research, the database of measures was further enriched with more information with the help of additional workshops, interviews, literature review and quality checks. The SAFEPATH team attended the ITS European congress 2022 (30th May to 1st June) in Toulouse, France, which provided more literature references to follow and new contacts who were invited to engage within the project via interviews and workshops.

3.4 *Measure categorisation*

As research resulted in an extensive list of measures, it became crucial to organise them in a structured manner. Thus, various measure categories, subcategories, and types were defined in accordance with the systems analysis carried out in the Problem and Systems Analysis work package (WP2000). The means identified in systems analysis provided a base for defining measure categories and subcategories. Further similar measures were grouped in a measure type category. The measure categorisation not only organises information but also provides an opportunity to perform a comparative analysis within groups of measures. This categorisation would enable NRAs to easily identify appropriate measures and find similar implementations. Table 2 briefly describes various measure categories, subcategories, and types.

Table 2: A list of various measure categories, subcategories and types with an explanation of the categories

Measures Category	**Measure subcategory**	**Measure type**
Infrastructure capacity *(Refers to the measures related to better utilisation of existing highway capacity)*	Traffic management *(Refers to the measures related to improvements in traffic management, enabling full utilisation of existing road capacity)*	Speed management *(Refers to measures influencing the speed of vehicles on highways, e.g., dynamic speed limits)*
		Extreme weather management *(Refers to measures which can be implemented during extreme weather events such as heavy fog, rain, snow etc.)*
		Road work management and safety *(Refers to traffic management and safety-related measures during road works such as lane closure, speed management etc.)*
		Hard shoulder and extra lane use *(Refers to measures related to the use of the hard shoulder or extra lanes for extra capacity e.g., hard shoulder running)*
		Ramp traffic management *(Refers to measures related to the management of traffic within on and off ramps e.g., ramp metering)*
		Lane use management *(Refers to measures repurposing lane use e.g., reversible lane, high occupancy vehicle lane, moving road barriers etc.)*
		Adaptive traffic management *(Refers to traffic management strategies that change based on the situation on the highway, e.g., time of day, traffic flow etc.)*
		ADAS management *(Refers to measures within infrastructure facilitating efficient functioning of the ADAS and communication systems in the vehicle)*
		Data-driven traffic management *(Refers to traffic management strategies based on insights from the data collected via different sources e.g., floating car data, loop detector data etc.)*
		Traffic and route information *(Refers to measures related to providing traffic and route information within the infrastructure to the road users)*
		Traffic signals *(Refers to traffic management via smart and effective traffic signalling strategies)*

Measures Category	**Measure subcategory**	**Measure type**
	Extend infrastructure *(Refers to the measures related to extending the infrastructure without physical widening of the highway, such as better utilisation of the existing space)*	Roadside assets *(Refers to measures related to improving/adding roadside assets to enable a more efficient flow of traffic)*
		Extend physical infrastructure *(Refers to measures related to the physical restructuring of the road to increase capacity)*
		Extend digital infrastructure *(Refers to measures enabling digital mapping of the infrastructure to facilitate new vehicle technologies)*
	Infrastructure design quality *(Refers to the measures incorporating improvements in design and quality of the infrastructure, leading to more efficient traffic flows)*	Lane design changes *(Refers to the measures involving changes in lane design to facilitate efficient traffic flows)*
		Clarity of environment *(Refers to measures improving the clarity and readability of the environment to avoid human and machine error)*
Driver behaviour *(Refers to the measures related to improving driver behaviour to minimise human error and improving traffic flow efficiency)*	Driver knowledge awareness *(Refers to the measures improving the driver knowledge and awareness with the means of training and education)*	Driver training and education *(Refers to measures involving driver training to achieve efficient traffic flows)*
	Human behaviour and infrastructure *(Refers to the measures intended to change human behaviour in the desired way leading to lesser human errors and reduction of congestion due to incidents)*	Engineering intervention (Nudging infrastructure) *(Refers to measures incorporating nudging techniques to influence human behaviour)*
		Enforcement intervention (Rule enforcement techniques) *(Refers to measures incorporating enforcement techniques to ensure rule compliance)*
		Human factors *(Refers to measures focusing on human factors perspectives to enable constructive behavioural changes)*
Vehicle technology *(Refers to the measures related to the development of in-vehicle technologies and how they can*	Communication and ITS *(Refers to measures involving vehicle-infrastructure communication and ITS services, which might have an impact on road capacity)*	C-ITS *(Refers to measures incorporating C-ITS technology to ensure reliable communication between human-vehicle-infrastructure)*
		Emergency communication devices *(Refers to measures regarding the safety systems in vehicles in case of an emergency)*

Measures Category	**Measure subcategory**	**Measure type**
contribute to realising higher highway capacity)		Vehicle platooning *(Refers to measures related to platooning of connected vehicles (or AVs))*
		Speed advisory *(Refers to measures in providing speed advisory to the road users)*
		Traffic and route information in vehicle *(Refers to measures that provide traffic and route information to road users via in-vehicle systems)*
	Driver assistance systems *(Refers to measures related to emerging technologies related to driver assistance systems and automated vehicles)*	Advanced driver-assistance systems *(Refers to measures incorporated for Advance driver assistance systems within vehicles)*
		Automated vehicles *(Refers to measures focusing on automated vehicles)*
Incident and impact management *(Refers to the measures to improve the incident and impact management, allowing avoiding capacity drop due to incident and faster recovery of capacity after the incident)*	Post-incident management *(Refers to the measures focussing on detection, recovery and clearance in the event of an incident)*	Access to emergency services *(Refers to measures that enable easy access to emergency services in case of an incident)*
		Institution's co-operation *(Refers to the cooperation strategies between different organisations for effective incident management)*
		Site clearance *(Refers to the measures enabling quick and efficient clearing of the incident site to enable restoration of the traffic flow)*
		Incident detection *(Refers to measures enabling quick detection of the incident for faster response by emergency services)*
	Incident avoidance *(Refers to the measures and strategies intended to avoid incidents)*	Strategy *(Refers to strategies related to incident avoidance)*
		Separation of slow and fast lanes *(Refers to measures related to the separation of lanes with different speeds to avoid incidents)*
		Tools and guidelines *(Refers to tools and guidelines enabling prediction and analysis of accidents)*
Regulations *(Refers to the measures laid out in the form of policies and*	Vehicle-related *(Refers to the regulations on vehicles)*	HGV policies *(Regulations and policies related to heavy goods vehicles)*
	Incident-related	Guidelines

Measures Category	**Measure subcategory**	**Measure type**
regulations to improve the highway capacity)	*(Refers to the regulations in the event of an incident)*	*(Guidelines to enable pro-active incident management)*
		Clearance *(Regulations imposed to facilitate clearance on incident site)*
	Infrastructure related *(Refers to the regulations with a focus on infrastructure)*	Traffic regulations *(Refers to various regulations imposed to control and manage traffic, e.g., rules, speed limits etc.)*
		Congestion pricing *(Refers to regulations imposing pricing schemes during congestion hours)*
	Driver behaviour related *(Refers to regulation on drivers or intended to change driver behaviour)*	Driver regulations *(Refers to regulations imposed on drivers to influence driver behaviour in the desired way)*

4 Stakeholder engagement via questionnaire, interviews, and workshops

In addition to the literature review, the engagement of stakeholders to obtain more direct (and often unpublished) information regarding measures is a crucial part of this project. To achieve this, the stakeholder engagement plan defined during problem and systems analysis (WP2000) was executed. The stakeholder engagement plan can be found in *Appendix B.*

At the beginning of stakeholder engagement, a short questionnaire was sent to identified and relevant stakeholders to capture who is interested, the level of involvement they wish to have, and how we can follow up. A short questionnaire captured whether the stakeholders were interested in getting involved via interviews and/or workshops. The respondents of the short questionnaire were invited for an interview and/or workshop based on their responses. If stakeholders were not available for an interview, they were sent a questionnaire, with the same questions as the interviews, which they can fill out at their convenience.

The stakeholder engagement was carried out both during P*hase 1 (up to month 12)* and *Phase 2 (month 12 - 18)* of empirical research (WP3000). Table 3 provides an overview of stakeholder engagement and highlights the number of stakeholders invited compared to those who engaged during phases 1 and 2. The table shows that very few stakeholders responded to the short or long questionnaires. One possible reason could be that the invitations were sent from a non-CEDR domain email, which might have lacked credibility.

Table 3: Overview of stakeholder engagement in phase 1 and phase 2

Phase	Engagement via	Number of stakeholders invited	Number of stakeholders who responded/attended	Number of sessions conducted
1	**Short questionnaire**	154	23	N/A
	Long questionnaire	12	2	N/A
	Interviews	18	15	15
	Workshops	23	8	1
2	**Long questionnaire**	*	0	N/A
	Interviews	4	2	2
	Workshops	31	12	1
Total	**Short questionnaire**	154	23	N/A
	Long questionnaire	12*	2	N/A
	Interviews	22	17	17
	Workshops	54	20	2

* Unknown number as questionnaire was distributed by PEB members

A list of participating organisations for phase 1 can be found in *Appendix I* whereas for phase 2 can be found in *Appendix J*.

During phase 2, the SAFEPATH team attended ITS European congress 2022 in Toulouse, France, which helped in establishing connections with various experts. The networking carried out at ITS European congress resulted in additional 2 interviews and 3 participants in the second workshop.

4.1 Questionnaires

Short questionnaires were intended to identify stakeholders interested in participating in interviews and workshops. Out of 23 stakeholders who responded to the short questionnaire, 11 were interested in attending an interview, and 16 were interested in attending the workshops. During phase 1, in addition, 12 participants who were not interested in attending the interview were instead sent a longer questionnaire to capture the same information as in the interviews. Two responses were received for the long questionnaire from Switzerland and Germany. The short questionnaire sent can be found in *Appendix D* and the content of the long questionnaire can be found in *Appendix E.*

*** Phase 2 questionnaires**

During phase 2, stakeholders were distributed a long questionnaire by PEB members, however, no response was received.

4.2 Interviews

To obtain a broader and more practical perspective of different traffic measures implemented across various countries; one-to-one interviews were conducted with interested stakeholders identified from the short questionnaire. In addition, several other stakeholders were also invited via personal networks, reaching 18 stakeholders. Of the invited stakeholders, 15 stakeholders participated in the interview during phase 1.

The interview participants came from The United Kingdom (8), The Netherlands (5) and Belgium (2).

The interviews covered various measures, including hard shoulder running, queue detection, incident management, carpool/High-Occupancy Vehicle (HOV) lanes, dynamic traffic signs, automated vehicles, and variable message signs (VMS). The measures covered were mainly within the infrastructure capacity. The process of conducting interviews is described in *Appendix C.* The questions asked during interviews followed the same structure as the content of long questionnaire, which can be found in *Appendix E.*

The interviews identified some critical practical highlights which are not found in the literature. The most common stated challenge for implementing new measures appeared to be changing policies and cooperation between different institutions. Another new issue was the difficulty in enforcement of HOV lanes. The interview explained that cameras installed in front and on the side of the road could not easily see into the car. Moreover, sometimes if there is no car in the HOV lane, the camera accidentally checks a car in the adjacent regular lane.

The insights from the interviews can be found on the database website which can be accessed here.

Phase 2 interviews

During this phase, two interviews were conducted, with experts from the UK and Austria. The interview with experts from the UK mainly covered the latest research on ramp metering uncovering various insights for the proper implementation of the ramp metering system. The interview with experts from Austria covered traffic measures such as traffic control systems, travel time estimation and broadcasting, HGV admission system, carpooling (HOV), incident management due to better cooperation between institutions, hard shoulder running, roadworks management, speed limit management.

4.3 Workshops

Workshops were set up to collect diverse viewpoints on the decision-making aspects involved in safely increasing capacity on highways. A workshop was conducted during phase 1 in which 8 stakeholders participated. The participating stakeholders belonged to the following countries: Belgium (3), Germany

(2), United Kingdom (2) and Sweden (1). The detailed methodology for conducting the workshop can be found in *Appendix C*.

Measures rated for capacity and safety

The participants rated a total of 10 measures for their effectiveness in increasing highway capacity and their effect on road safety. The average ratings are shown in Figure 2. *Hard shoulder running* and *variable speed limits* were, as expected, effective in increasing capacity whereas *driver training and education* were seen to have the lowest influence in increasing capacity. Among the list, *incident detection* was rated the safest measure whereas *moving road barriers* was rated the most unsafe.

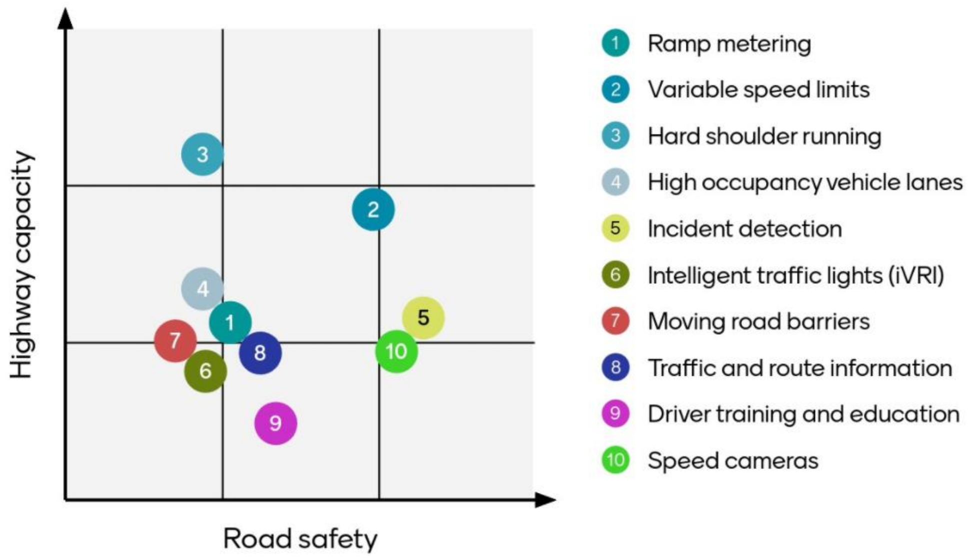


Figure 2: Average voted score representing the effectiveness of various measures in increasing highway capacity and road safety (Phase 1 workshop)

To obtain an overarching view of each traffic measure from different perspectives, a *PESTEL*[1] analysis exercise was carried out. Each participant of the workshop was asked to reflect on different aspects of PESTEL for a particular measure. The PESTEL analysis was conducted for three measures: Ramp metering, incident detection, and hard shoulder running. The outcome of the PESTEL analysis for these measures is provided in *Appendix G*.

Phase 2 workshop

During phase 2 of empirical research (WP3000), a workshop was conducted which was attended by 12 participants. The participants were from the following countries: United Kingdom (8), Netherlands (2), Austria (1) and Spain (1). Higher number of participants attended from UK due to their availability. Thus the information captured during this workshop could be more rich in viewpoints from UK's perspective. The second workshop followed the same structure as Workshop 1, except that different traffic measures (high occupancy vehicle lanes, speed enforcement cameras, and intelligent speed adaptation (ISA) systems) were discussed.

At the beginning of this workshop, the participants were presented with a similar set of traffic measures and were asked to rate them in their effectiveness in increasing highway capacity and improving traffic safety. The average results are shown in Figure 3.

[1] PESTEL refers to Political, Economic, Social, Technological, Environmental and Legal aspects

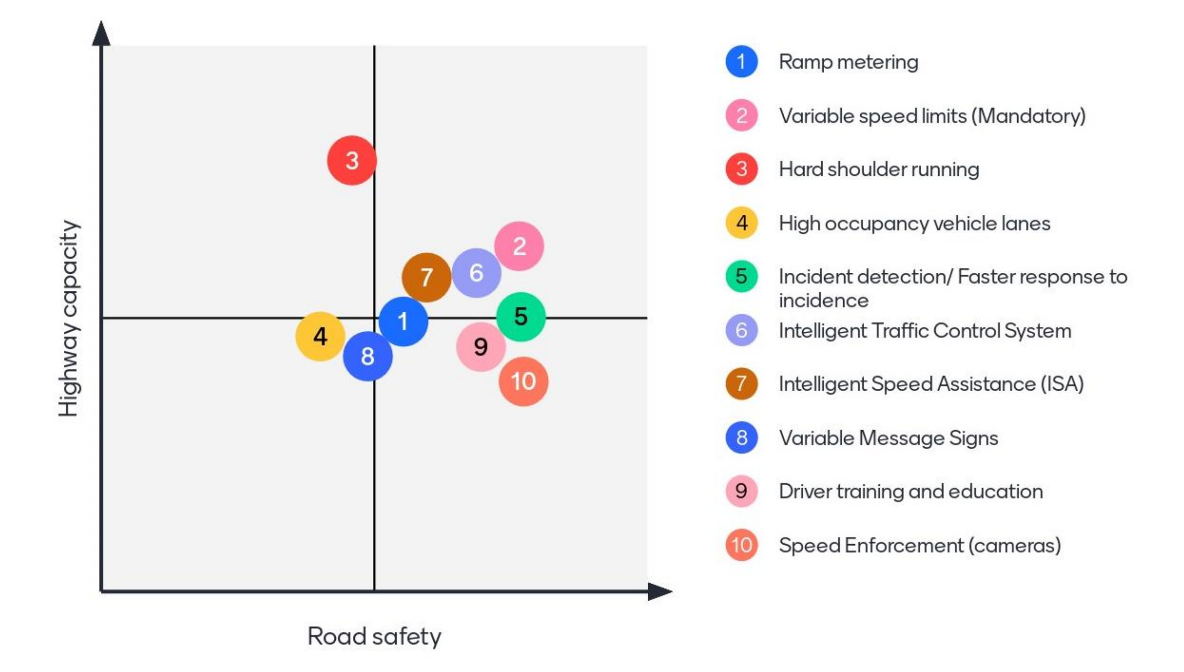


Figure 3: Average voted score representing the effectiveness of various measure in increasing highway capacity and improving traffic safety (Phase 2 workshop)

Comparing the results of the first and second workshops, some interesting insights were found. The relative effects of various measures assessed by two different groups of experts were quite similar thus validating the findings from workshop 1. It can be seen that hard shoulder running is still seen as a measure with high-capacity benefits but medium on a safety scale. Mandatory variable speed limits retained their position on the chart indicating both high capacity and safety benefits making it one of the most interesting measures to research upon. Speed enforcement cameras were still considered higher on the safety scale with little effect on capacity. High occupancy vehicle lanes were also consistent in their position indicating low road safety and medium effect on highway capacity. Variable speed limits, incident detection and speed enforcement were seen as the safest measures whereas hard shoulder running, variable speed limits and intelligent traffic control systems were seen as the most influential measures to increase highway capacity.

Furthermore, a PESTEL analysis was carried out for the following measures: high occupancy vehicle lanes, speed enforcement cameras, and intelligent speed adaptation (ISA) systems. The results of the PESTEL analysis can be found in *Appendix H*.

The later sections of the workshop contained questions related to road safety and Good Practice Guide whose results will be discussed in the deliverables of road safety analysis (WP4000) and Good Practice Guide (WP5000).

5 The online database of measures

The information collected from interviews, workshops, questionnaires, and the literature review is stored in an interactive online website database (https://project-safepath.azurewebsites.net/). The website database enables easy access to the information collected during empirical research and can be used to gain more insights about traffic measures. During the course of designing the website, multiple feedback and suggestions were received which helped in shaping the layout and user interface. This helped to make the website more user-friendly and intuitive, with a key focus on the user needs.

As the main purpose of the website is to provide easy access to a vast amount of information collected from empirical research, a suite of tools is provided to enable users to explore the content and extract the information they need. The website is equipped with filtering tools which enable users to find measures based on categories, subcategories, types, and locations. The website also features a search engine which enables users to look for a specific keyword. Users can also access statistics related to measures. A built-in manual (guide) helps new users to learn how to use the website and database of measures. These features make this website a powerful, easy-to-use and intuitive tool to access the database of measures, but one which can also be easily used by inexperienced users.

The homepage of the website provides details about the project. Users can navigate to the measures tab/page of the website (Figure 4) which is the main working space of the website. This contains the following elements:

A. An expandable table showing various traffic measures and country of implementation
B. An interactive map with the ability to filter database based on country
C. Filters to refine out measures as per different categories
D. A search tool to find specific measures
E. Links to navigate through different tabs of the website
F. Link to CEDR website
G. Summary statistics tab to shed an overview on the number of measures within different measure categories and subcategories
H. Link to the Homepage of the database website

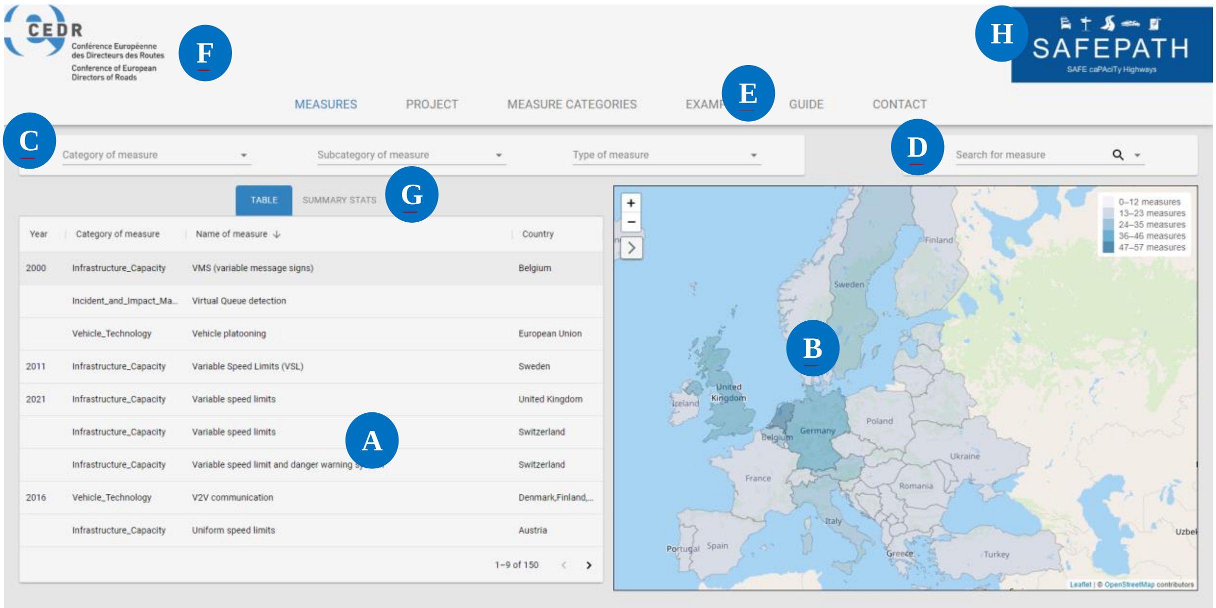


Figure 4: Homepage of the online database website

When the user selects a specific measure, details about the measure are displayed on a dedicated page (Figure 5 and Figure 6).

These include country, responsible NRAs, implementation details, implementation duration, the effect of the measure on capacity, safety & environment, investment costs, acceptance of the measure, challenges faced during implementation and publication details such as year, title, link to the publication, and publication type.

The website is expected to be live till April 2025 (hosted by Royal HaskoningDHV) and if needed, can also be moved to CEDR servers with the CEDR domain name. The website can be easily updated using an excel based database and a tailor-made updater tool (until close of project in April 2023) after which it will be in view only mode.

Using the updater tool, it will be possible for CEDR to update the database with new measures and information, if needed. The updater tool will be required to be slightly modified to allow CEDR to update the database, which will be taken care of during handover of database to CEDR servers.

The online database is currently stored in the form of Azure SQL database and can be accessed via the website: https://project-safepath.azurewebsites.net/

Updates to the database during phase 2

During phase 2 of WP3000, the database was updated with new measures emerging from different sources such as interviews, workshops, suggested reports and literature reviews. This resulted in the addition of 37 new entries in the database. In the whole database, a quality check was performed to ensure the correctness and completeness of the information. The subcategories of measures were appropriately redefined during this phase. The website was also updated with explanations of the different measure categories and an explanation of how to use the database.

Case Study within a publication - Reducing congestion with integrated network management (INM)

Country	Denmark
Publication year	2017
Responsible NRA	Danish Road Directorate
Category	Vehicle_Technology
Sub-category	V2X_Communication
Type of Measure	Traffic and route information

About the measure

Measure name
Traffic and route information

Authors
Christian Ebner

Implementation method
There were number of stakeholder involved: Danish Road Directorate(DRD), Osthyllands Polics, 10 municipalities and 2 public transport companies. The public transport companies only provide the input to webpage and don't participate in working or steering group.

Implementation duration
The Ostjylland traffic information app was launched in April 2014.

The winter app that cover whole of Denmark was launched in October 2013

Measure details
Webpage and App: With information about traffic conditions and current travel times for the road network in and around Aarhus, as well as road and traffic reports for the whole country, road user can be well informed before departure. Trafikken Østjylland gives access to live images from more than 300 webcams along the roads, as well as information about current road works that may have an impact on accessibility. Road user can also find the nearest available parking space in one of Aarhus' car parks, just as can easily see when the next ferry is sailing, or whether there are sold out or canceled departures.

Acceptance of the measure
The involved partners experince that road users get a better service, and that it become easier to coordinate different activities.

Downloads of Ostjylland app: 7,290 times

Downloads of winter app: 80,200 times

Challenges faced during implementation
The partners have different approaches, varying degree of traffic problems and various possibilities for financing of new initiative, lack of funding for normal data collection and implementation of ITS system with e.g. VMS

Figure 5: Measure details: About the measure

Effect of the measure

Method of Impact Assessment
Large Scale Evaluation

Overall effectiveness of the measure
Effective

Details - Effectiveness
The involved partners experince that road users get a better service, and that it become easier to coordinate different activities.

Impact on capacity
Increase

Details - Capacity
Reduce negative effects from congestion by better utilizing the infrastructure and transport system.

Impact on safety
Increase

Details - Safety
Helps in in better handling of the incidents by better communication about the incidents to road users.

Better communication between road authorities and polics about the events.

Impact on environment
-

Details - environment
Not specified

Investment costs
Low

Details - investment costs
The total annual cost for operation and minor adjustments of the webpage and app is approx 30-35000 euros. A framework agreement between different partners reduce the cost for development.

Coverage: Major roads in the area across RAs, pulic transport, bikes and ferries. Motorway and urban

Details of the publication

Publication title
Case Study within a publication - Reducing congestion with integrated network management (INM)

Report type
DoRN->Case Study

Publication/Project Reference

https://www.cedr.eu/download/Publications/2017/CEDR2017-01-Reducing-congestion-with-integrated-network-management-INM.pdf

Other References
Not specified

Other Information/Notes
Not specified

Figure 6: Measure details: Effect of the measure and Details of publication

5.1 Overview of the Database

As discussed in the previous sections, measure categories were defined to structurally organise information which allows for comparative analysis between them. Table 4 shows the number of entries in the database as per different measure categories, subcategories and types after phase 2 of empirical research (WP3000). It can be seen in Table 4 that some measures categories contain more empirical evidence than others which can be attributed to the wide implementation of measures, popularity of the topic, and greater focus on research. However, measures in other categories (with a low number of measures) lack empirical evidence about their impact and require more research.

It is to be noted that 41 new measures were added to the database during phase 2 of empirical research.

Table 4: Count of measures in the database as per different categories

Category of Measures	N	Subcategory of Measure	N	Type of Measure	N
Infrastructure Capacity	78	Traffic Management	68	Speed management	7
				Lane use management	8
				Extreme weather management	1
				Adaptive Traffic Management	11
				Road works management and safety	4
				Hard shoulder and extra lane use	18
				Ramp traffic management	5
				Data-driven traffic management	6
				Traffic signals	3
				Traffic and route information	4
				ADAS management	1
		Extend Infrastructure	6	Road side assets	2
				Extend digital infrastructure	3
				Extend physical infrastructure	1
		Infrastructure Design Quality	4	Lane design changes	3
				Clarity of environment	1
Driver Behaviour	11	Driver Knowledge Awareness	3	Driver training and education	3
		Human Behaviour and Infrastructure	8	Engineering Intervention (Nudging infrastructure)	3
				Human Factors	1
				Enforcement Intervention (Rule enforcement techniques)	4
Vehicle Technology	34	Communication and ITS	20	C-ITS	7
				Emergency communication devices	1
				Vehicle platooning	6
				Speed advisory	2
				Traffic and route information in vehicle	5
		Driver assistance systems	14	Advanced driver-assistance systems	10
				Automated vehicles	4

Incident and Impact Management	14	Post-incident management	11	Access for emergency services	2
				Site clearance	1
				Incident detection	5
				Institutions co-operation	3
		Incident avoidance	3	Separation of slow and fast lanes	1
				Tools and guidelines	1
				Strategy	1
Regulations	13	Vehicle-related	4	HGV policies	6
		Incident-related	3	Guidelines	2
				Clearance	1
		Infrastructure related	6	Traffic regulations	1
				Tax and pricing	6
		Driver behaviour related	0	Driver regulations	0
				Total	**154**

The research conducted involved the collection of empirical evidence of measures implemented across various countries. Table 5 shows the number of unique entries in the database per country which sheds a light on the geographical spread of measures.

Table 5: Count of measures per country

Country		**Count of Measures**
Participating Countries in this project	Austria (AT)	13
	Belgium (BE)	8
	Finland (FI)	1
	Germany (DE)	13
	Hungary (HU)	2
	Ireland (IE)	3
	Netherlands (NL)	36
	Sweden (SE)	6
	United Kingdom (UK)	17
Combination of EU countries	EU	33
Other EU countries	Czech Republic (CZ)	1
	Denmark (DK)	1
	France (FR)	1
	Italy (IT)	6
	Portugal (PT)	1
Non-EU European countries	Switzerland (CH)	7
Unspecified		5
	Total	**154**

It can be observed that countries such as the Netherlands, the United Kingdom, Austria and Germany has highest evidence base, potentially, due to higher number of implementation and research. It is also worth noting that many measures in the database are marked as "European Union" which includes EU projects as well as measures widely implemented in multiple EU countries.

While conducting the literature review, it was found that many evaluations are focussed on one aspect such as capacity, safety, environment etc., but did not include analysis regarding other aspects that we have been collecting. Thus, it was impossible to obtain information regarding all aspects of different measures. Figure 7 shows the amount of information captured and thus sheds light on the completeness of the information. It can be seen that not all the information was available for every entry in the database where very few details were found regarding the cost, overall effectiveness, acceptance and implementation challenges.

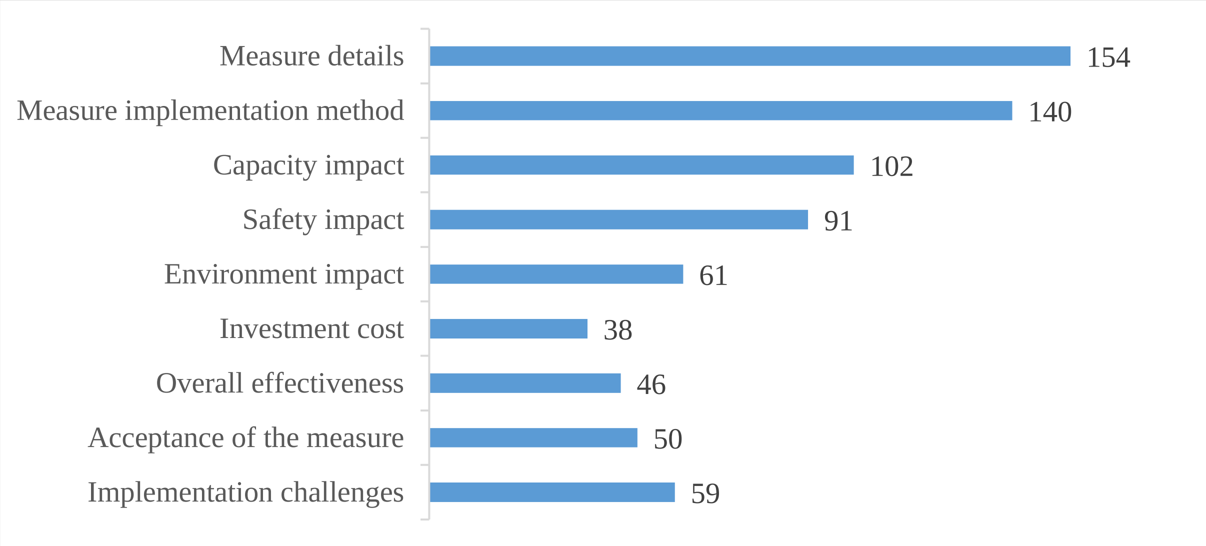


Figure 7: Amount of data for different measures (N=154) in the database

The results of measure evaluations are also dependent on the type of assessment. Since not all the measures are implemented on a large scale, some evaluations are also based on small-scale implementation or based on theoretical models and simulations. However, it is important to understand that the results of large-scale evaluations, small-scale evaluations or theoretical evaluations should not be compared with each other as the method of impact assessment is different. The results of simulations or small-scale implementations cannot be upscaled either to get a complete picture for large-scale implementation due to the complexity of external factors or research limitations.

Thus it is critical for the user to understand the method and setup of impact assessment and to make a judgement on the reliability, applicability, and usability of the information. To allow this understanding, various studies were also evaluated for their method of impact assessment. The studies were categorised into four categories:

- Large-scale evaluation, if measures were implemented on a large scale such as hard shoulder running, ramp metering, lane closure, congestion pricing etc. and for whom before-after studies were carried out.
- Small-scale evaluation, if the assessment was carried out using small implementations such as pilot tests for emerging measures like intelligent traffic signals, speed advisory systems, lane width changes etc.
- Predicted via models, if no implementation was carried out, but instead, simulations were used to assess the measure's impact. Models were mainly used for smart vehicle technologies such as V2X communication, ADAS systems etc., but also used to evaluate some traffic management measures such as reversible lane systems, adaptive traffic management etc.
- No study found, where no assessment of capacity or safety was carried out for a particular measure.

Table 6 shows the number of various entries in the database as per the impact assessment method. A majority of measures have been evaluated on a large-scale implementation. However, there are also many measures for which reports/information gathered don't include any safety or capacity assessment.

Table 6: Count of various measures in the database as per the method of impact assessment

Method of impact assessment	Number of Entries
Large Scale evaluation	72
Small scale evaluation	27
Predicted via models	26
No study found on evaluation	29
Total	**154**

During the empirical research phase of the SAFEPATH project, a lot of information regarding various measures has been collected. A long list of measures showcased the diversity of information which can be quite complex to comprehend and make use of. Thus categorisation of measures was performed to structure and organise information which makes it more useful and easier to understand. Figure 7 showcases the quality of information within the database and it can be observed that not all information was available within the evaluation reports. Table 4 also showcases that some of the measures are more widely implemented and evaluated than others leading to an imbalance in the information available per category.

However, it is important to understand that there is clearly a research gap in terms of evaluation of measure performance. Although, quite a lot of measures were widely implemented on a large scale (Table 6), very little to no evaluation was carried out to understand the impact of the measure in terms of capacity and safety. This can also be seen in Figure 7 where around 33% of measures are lacking in an assessment regarding the impact on capacity and around 41% of measures are lacking in an assessment regarding the impact on safety. Also, for 29 measures, no evaluation study was found (Table 6). Additionally, most of the measure assessments were seen to be found from NL, UK, DE, BE and AT (Table 5). Other EU countries had only a few evaluation reports available. This could be attributed to a lack of infrastructure, research, or resources needed to conduct such evaluations. Due to lack of evidence, the assessment of measures for those countries is rather incomplete and the results from limited evaluations cannot be reliably extrapolated. Thus, making a commentary on the effect of measures for those countries cannot be performed and more evaluation research is needed.

5.2 How to use the online database of measures

The online database of measures is a tool to gain more detailed knowledge about a traffic measure. It can be used by NRAs along with the Good Practice Guide to gain insights into different traffic measures and make an informed decision in choosing the best fitting traffic measure.

The measures within the database can be explored with the help of the following features:

1. *Filtering out the measures as per categories, sub-categories, and type of measure.*
2. *Searching for a measure using a keyword*
3. *Searching for a country-specific measure*

A detailed step-by-step guide on how to use the online database including the above-mentioned features is available on the website and users are advised to refer to the online guide for usage instructions. The online guide is updated every time there is a change in the contents of the website.

The online guide can be accessed via: https://project-safepath.azurewebsites.net in the "How to use" tab.

The Good Practice Guide will eventually contain the link to the database website. This website should be used in coordination with the Good Practice Guide for best results.

6 Overview of measures in the database

All the project's findings can be accessed online in the SAFEPATH database. The sections below provide examples of the measures found in the research to have the most comprehensive evidence of impact on capacity, in each of the categories. It was noticeable that in some cases findings from different evaluations/implementations are different from each other and sometimes contradicting. This may be explained by the dynamic nature of the subject and a multitude of external factors involved such as culture, driving behaviour, weather, method of evaluation, scale of implementation, road conditions, etc. The users are highly encouraged to refer to the online database for a complete overview of the measures and refer to the original publications for detailed review.

An overview of the impact on capacity and safety of all the measures in the database is provided in *Appendix K*.

6.1 Infrastructure capacity

Measures within this category include changes and implementations carried out on infrastructure to facilitate improvement in traffic flow. The measures do not include physical widening of the road, but include better management of the existing space. This measure category contains the highest number of measure types and entries in the database.

To improve the infrastructure capacity, *traffic management* is identified as one of the most common solutions, with 67 entries in the database. Hard shoulder running is one of the most often implemented measures and has the most thorough documentation within such traffic management measures. Multiple variants and implementations of hard shoulder running were found and recorded, details of which are provided in section 6.1.1.

Another significant measure type is 'adaptive traffic management', in which different measures come into place based on the state of the traffic and the time of the day. Dynamic traffic signs and reversible lane systems are examples of adaptive traffic control. Ramp metering, variable speed limits, high occupancy vehicle lanes, and road works management were also observed. Most of these measures improved capacity. Other measures included variable speed limits, using data to provide information to travellers, smart lane and intersection control, extreme weather warning systems, and moving road barriers. However, only a small number of studies were found for these measure types.

Extending infrastructure was also seen as one of the means to increase infrastructure capacity. The construction of safety barriers and extending digital infrastructure were effective measures in increasing highway capacity due to indirect benefits resulting from improvements in safety.

Other measures which increase the infrastructure capacity include improving the quality and design such as reconfiguring the roads and taper merging.

6.1.1 Hard shoulder running

Hard shoulder running is a measure that increases the capacity by providing road users access to the hard shoulder. Hard shoulder running is implemented across various European countries including the United Kingdom, The Netherlands, Germany, France, Belgium, Austria, Switzerland, and Italy.

Multiple variants are found in the literature and through interviews and workshops. Some of the variants are temporary hard shoulder use and speed harmonisation, rush hour lane, all lanes running, and dynamic hard shoulder running.

This assessment is based on the hard shoulder running measure type, which constitutes 18 entries in the database.

Impact on capacity:

Hard shoulder running is one of the most effective measures in increasing the capacity. During peak hours it can increase capacity by an average of 20-25% on a 3-lane highway and 27-33% on a 2-lane highway.

Hard shoulder running is also effective in easing congestion, and the morning rush hour congestion is reported to decrease by 79% and lost vehicle hours decreases by 73%.

Impact on safety:

The impact of hard shoulder running on safety is still under review. Multiple implementations of hard shoulder running have seen a diverse impact on road safety. While some of the implementations report an increase in road safety due to hard shoulder running, most of them are undecided on the effect on safety. Table 7 shows the count of publications with varying effects on traffic safety.

Table 7: Count of publications with various effects on road safety

Positive	Undecided	No effect
NL-1; UK-2; Belgium-1; Switzerland-2; Germany-3	UK-3; Belgium-1; Austria-1; France-1; EU-1	Italy-1; Germany-1

Overall effectiveness:

- Willingness to use is high among truck drivers but lower among passenger cars.
- The hard shoulder lane is used less than regular lanes.
- Highly effective in increasing the capacity of the highways and reducing journey times.

More effective in combination with ramp metering and speed harmonisation.

Challenges:

Various challenges have been identified as follows:

- Closing the lane in case of an emergency using variable message signs is challenging as road users might lack the credibility of information and not comply with the rules.
- The occupancy of the hard shoulder by road users makes emergency rescue operations difficult.
- In case of a vehicle breakdown, there is no space to park the vehicle.
- Legislation/approvals can be time-consuming.
- Driver training and education are required to teach how hard shoulder should be used and what should be done in case of an incident.
- High maintenance costs due to requirement of many cameras and technical installations. These systems need to keep functioning, and when in operation these need to be managed by the traffic management centre. Thus, it requires continuous effort in management, control and maintenance.

6.1.2 High occupancy vehicle lanes

High occupancy vehicles (HOV) with 3 or more occupants (3+) can be permitted to use, for example, an existing bus lane. The opportunity to save time should encourage commuters to share their cars and should result in more efficient car use. In 1999, a 2.8 km long HOV 3+ facility was opened in Linz, Austria. In Nieuwegein, Netherlands, a target group lane is applied for trucks and buses along the N408. This strip has its own traffic lights.

Impact on capacity:

In peak hours, the HOV lane is a significant advantage for occupants of HOVs and no disadvantage for passengers of buses. Driving time for the HOV group decreases significantly by a maximum of 14 minutes, sometimes at the expense of other traffic (+1 min) but sometimes also profit of up to 5 minutes (in the Netherlands).
Expert opinion from the workshop indicated that this measure has a negative effect on traffic flow, because of the few HOVs.

Impact on safety:

This was not evaluated. In terms of safety, there are some exit and entrance conflicts with new users that are merging in and out of the hard shoulder (when HOV lane was implemented in Hard shoulder).

Opinion from the workshop indicated that there is a potential to drive unsafe behaviours (additional street signage may be distracting) and fast changes of lane if drivers find themselves in the HOV lane by mistake.

Overall effectiveness:

As the primary outcome, implementing an HOV lane proves to be a practical approach for improving capacity. However, it must be seen only as one of many measures that would be necessary to create a real, sustainable solution for the whole metropolitan area. The HOV lanes are effective only in a certain set of conditions and enforcement.

It is to be noted that the assessment is based on studies that already had a separate bus lane and it was used as a carpool lane. The effectiveness of this measure on the highway might be different.

Challenges:

The main challenge is how to monitor the number of people in the car. Initially, a camera was installed in the front and one on the side, but it isn't easy to see into the car. Sometimes if there is no car in the HOV lane, the camera accidentally checks the car on the regular lane.

Some years ago, a study in the Netherlands found that the lane itself is not filled up with enough vehicles. Also, with HOV, the other lanes are may be congested with high occupancy lane being under-utilised. This brings annoyance to users struck in queues.

There may also be too many legal exceptions to make it enforceable, for example a single driver may use the HOV lane for safety reasons, on way to hospital emergency. There is also the question of whether an exception should be made for disabled drivers.

Acceptance:

There is a low public acceptance because the measure is seen as complicated and the benefit to road users is not clear. In some conditions users of the HOV lane can move slower than users in the regular lanes. Therefore, when speeds on the normal lanes exceed 50 km/h, drivers on the HOV lane would instead switch to the regular lanes to increase the speed. This can result in speed reductions due to lane switching. The stopping and changing of lanes also has a negative impact on capacity.

6.1.3 Variable speed limits

Variable Speed Limit (VSL) systems are an important motorway control strategy. They are used to make drivers adjust their speeds to better respond to changing traffic conditions downstream. VSL can be mandatory or advised. Mandatory VSL are enforced by the law and fines can be imposed on users who do not comply. Mandatory VSL are often combined with speed cameras to ensure enforcement.

Variable speed limits are achieved by using variable message signs (VMS) to provide the information above the lanes. Speed limits can be adapted remotely, either automatically by an algorithm or manually by an operator. This makes it possible to show different speed limits at different times and on different days.

The speeds that are displayed by the dynamic signs are based on data gathered by loop detectors and by automatic incident detection cameras. Data on speed and occupancy of the lane are used to set the speed limit. When the loops and cameras detect a high occupancy and a low speed, the speed limit is reduced.

Impact on capacity:

The implementation of mandatory variable speed limits in Belgium and the UK resulted in an increase in traffic throughput. Journey time reliability has improved in all time periods since the implementation of the schemes. Average journey times improved in some time periods, but when traffic volumes were high the impact was less noticeable.

In contrast to the UK and Belgium in Stockholm, Sweden, implementation showed no significant impact on traffic conditions, both immediately after its implementation and several months later. The VSL system in Stockholm is advisory, and this may be a relevant factor. Thus, VSL systems are most effective when mandatory and enforced by the law.

Impact on safety:

Through a large-scale evaluation in Belgium, the traffic safety effect is studied through an empirical Bayes (EB) before-and-after study that compares collisions after the implementation of the measure with the before situation

The meta-analysis shows a significant decrease of 18% of the collisions due to the implementation of VSL systems. Mainly the number of rear-end collisions (−20%) decreased, albeit just nearly significantly. The number of single-vehicle collisions showed a tendency to decrease, but this effect was not significant.

Investment costs:

In Belgium, the cost of installing the equipment is highly location-specific. However, 269 k EUR was reported as being representative of the material investment costs per km of highway covered (including maintenance costs in the first two years of operation). Over this material investment cost, there is an estimated salary cost of the supervising personnel of 47 k EUR per km.

These systems have high maintenance costs due to requirement of many cameras and technical installations. These systems need to keep functioning, and when in operation these need to be managed by the traffic management centre. Thus, it requires continuous effort in management, control and maintenance.

6.1.4 Ramp metering

Ramp metering is the control of a traffic stream from an on-ramp to the motorway. This is done using traffic lights which allow vehicles to enter the motorway one by one or in small platoons. The objective is to improve traffic conditions on the motorway, but conditions on the on-ramp and connecting roads in urban areas should be considered. An off-ramp metering controls the traffic entering the off-ramp from a motorway with an objective to improve traffic conditions in built up area/ up-stream of off-ramp.

On two cross-sections of the motorway (upstream and downstream of the on-ramp), traffic data is measured. The flow and average speed measured are compared with certain threshold values. If these thresholds are exceeded, the metering system is activated. During green time, only a few vehicles per lane are allowed to enter the motorway. The length of the red time varies, dependent on the actual situation on the motorway and taking the queuing on the on-ramp into account.

Impact on capacity:

- All the reports indicated an increase in highway capacity where ramp metering is implemented.

- A large-scale study in the Netherlands indicated a maximum 5% gain in highway capacity (average 2%), fewer (50%) and less severe shockwaves and 10% fewer lost vehicle-hours.

Impact on safety:

Attention should be paid to the safety of the highways related to the decrease in speed due to the off-ramp metering.

Investment costs:

In the Netherlands, the implementation costs are 150 k EUR for a one-lane controller and 175 k EUR for a two-lane controller, including outside equipment. Red-light cameras add another 45 k EUR. The maintenance costs are 10 k EUR per annum. All these figures are exclusive of central equipment and the costs for infrastructural additions like extra queuing capacity.

Overall effectiveness:

There are mixed results about ramp metering, with the best results where there are long on-ramps, and where sites can be sequenced in a corridor.

Challenges:

- There can be issues if the traffic signals at the top of the ramp queue back, as different road authorities can be responsible for the motorway and the roads leading to it.
- Being held up in a queue is annoying,
- It may improve capacity by only a small percentage, which may not be visible to politicians.
- In the US, usually, 12-15 ramps are in succession, whereas in the EU ramps are separated, so the implementation is more difficult.

6.1.5 Intelligent traffic control system

An intelligent traffic control system (known as iVRI in the Netherlands) is part of the national Talking Traffic programme. There are currently 2,294 traffic lights in Talking Traffic, about half of the Netherlands. They communicate with vehicles through apps and thus adjust the green times to minimise total vehicle stopping time. As a result, the traffic lights constantly contact the traffic that passes by and can respond to the current situation. This allows traffic to flow smoothly at busy times and a motorist no longer has to wait for a red light at an empty intersection late at night. Another advantage is that specific traffic flows can be given priority at iVRIs at the request of the road authority, including, for example emergency services, heavy freight traffic, cyclists, and public transport.

Although the traffic lights are not installed on highways, the congestion building in the connecting roads such as upstream in off-ramp may spill over to the highway leading to congestions on highway. Thus, improving the efficiency of intersections in connecting roads using intelligent traffic control system can lead to improvements in highway capacity.

Impact on capacity:

- Flow improves by an average of 5%.
- Average 2% increase in capacity.
- The preliminary conclusion of this evaluation is that iVRIs have a modest positive effect on the traffic flow for freight traffic and all traffic on the (regional) main routes. In urban areas, the effect on traffic flow is nil. This is partly because iVRIs have mainly been replaced at busy intersections with well-adjusted junction regulation, and also because the potential of Talking Traffic is not yet optimally utilised.
- The impact of iVRI on an NRA network is mainly to lower spillover in the main road due to improved traffic flow efficiency in the connecting roads leading to lower congestion.

Impact on safety:

On average there have been 19% fewer accidents, ranging from 15% to 45%. About 35% fewer secondary accidents.

Costs:

Research has shown that iVRIs at intersections can save around 90 million euros in social costs every year.

Challenges:

The penetration rate of vehicles that can communicate with the controllers is still low. That is anticipated to improve in the coming years, and it is expected that the improvements will be larger.

One of the main challenges is the maintenance of all the technologies and overall asset management. All the traffic management systems were installed beginning in the 1990s in the Netherlands. This must be improved before new technologies can be introduced. The road infrastructure is also ageing as most bridges and roads were built in the 1960s. The technology systems have a life cycle of 15-20 years, and they were implemented 20-25 years ago, so they need to be replaced and updated.

6.1.6 Tidal flow operation

On some highways, there can be more traffic in one direction during the morning and afternoon peak hours. This is known as tidal flows. There are a variety of measures which enables the management of traffic for tidal flows. Some examples are Reversible lanes and movable road barriers.

A reversible lane (also known as an interchangeable lane or alternating lane) is a lane that is opened for a certain direction of travel depending on how busy it is. A reversible lane is therefore an economical way to use the road infrastructure; only during peak hours, due to the amount of traffic, additional infrastructure is temporarily required, which can change direction depending on the evening or morning peak.

On the other hand, moving road barriers uses the Barrier Transfer Machine to lift barriers that can easily reconfigure travel lanes in real-time accommodating the peak hour traffic, all while maintaining a secure barrier between lanes.

Impact on capacity:

Moveable barriers and reversible lanes give more lanes to the peak traffic direction for daily and weekend commuters. Thus due to an extra lane, the capacity in one direction increases whereas the capacity in the other direction reduces. Thus these systems are useful only in the case of high tidal flows. No scientific assessment was found showcasing the impact of these measures on capacity.

Impact on safety:

Reversible lanes are more unsafe as there is a potential for confusion among road users. On the other hand, movable road barriers are deemed to be safer as they reduce the possibility of a head-on collision and possible crossovers.

Overall effectiveness:

Regarding the efficiency of the reversible lane system the results of the simulations allowed to verify that the scenario of operation of the reversible lane was, in general, always more favourable than when considering a scenario with a central lane of fixed direction, although for some variables the differences\ were not significant.

It was estimated that the Road Zipper System cuts total construction time by 12-18 months and saved approximately €10 million in Germany. However, it is to be noted that the road zipper was used temporarily in a construction project.

Challenges:

Because the switching on the reversible lane is controlled via a dynamic system that is connected to the national traffic control centre, malfunctions cannot always be avoided. To guarantee the safety of road users, this may mean that the reversible lane is not always open during rush hour.

Moving road barriers pose potential problems in case of difficulties with the equipment/technology. Also, it cannot be used in road sections where there is already a physical separation between lanes for example islands. An implementation of Road Zippers in Austria didn't work well as reported by ASFiNAG.

These systems have high maintenance costs due to requirement of many cameras and technical installations. These systems need to keep functioning, and when in operation these need to be managed by the traffic management centre. Thus, it requires continuous effort in management, control and maintenance.

6.1.7 Lane redesign and adjustments

Changes in the design of lanes can be made which has the potential to optimise the traffic flows and realise higher capacity. The measures mainly concern with readjustments of lane markings to realise a new design that can be applied to main links, exit/entry ramps, and interchanges. Some of the lane design implementations found are optimisation of lane width and adjustments of lane division (Belgium), 2+1 roads (Sweden), and tapering in merges (Netherlands).

Belgium: ANWB (Royal Dutch Tourist Association) in Belgium identified road segments where lane lines or divisions of lanes could be adjusted to increase capacity, for instance at on-ramps, off-ramps or interchanges between two motorways. There were differences in the lane lines of freeway off-ramps where there is more demand and lane line adaptations made at the off-ramp could yield more capacity.

Sweden: The Swedish Road Administration started a development program in 1998 that denoted alternative 13-metre roads since 2002 denoted ”collision-free roads”. The program objectives were to increase traffic safety on existing 13 m-roads and semi-motorways (two-lane expressways) cost-effectively with significantly lower investment costs and smaller intrusion compared to traditional measures. To achieve this, lanes were redesigned to achieve a 2+1 lane with the help of separation by a cable barrier in the median.

Netherlands: The Netherlands implemented tapering in lane merges, especially in a 2+2 configuration (2 lanes on the main lane and 2 lanes on the merging lane), which had a varying effect on capacity.

Impact on capacity:

Belgium: With the modification of lane widths in Belgium, there was a gain in the capacity on the Ghent side.

Sweden: Due to 2+1 roads in Sweden, travel speeds for passenger cars at 90 km/h speed limit have increased by 2 km/h with median barrier and 4 km/h with painted design.

Netherlands: Due to tapering, a decrease in capacity was observed. One study found that a higher percentage of trucks led to lower capacity. The exit capacity of the examined taper fusions is lower than the free capacity. The capacity drop for the taper assemblies of the Grijsoord and Waterberg interchanges are 8 and 3% respectively.

Impact on safety:

Lane modifications provided a safety measure to reduce ambiguity for road users.

In Belgium, no safety assessment for modification of lane width was found.

In Sweden, due to 2+1 roads, the total number of fatalities were reduced by 76% from 228 to 54 people killed.

With tapering in the Netherlands, no significant difference in safety was observed.

Overall effectiveness:

In Sweden, among the discussed measures, 2+1 roads were seen as highly effective. Due to its success, around 1000 kms of roads in Sweden are implemented with 2+1 roads.

In Belgium and the Netherlands, no commentary regarding the overall effectiveness of these measures was found.

Challenges:

In the Netherlands tapering of the merges, the presence of solid lines on other lanes led to a reduction in capacity as road users were not able to perform lane changes to accommodate merging traffic. Thus lane designs for other lanes should also be examined carefully when tapering is implemented.

No challenges were described in the found references for Belgium and Sweden.

6.1.8 Traffic and route information

There are various measures which help in providing information about upcoming traffic conditions and provide road users with information about faster routes, congestions etc. The measures found within the research range from warning road users about queuing traffic to the dynamic re-routing of traffic.

A measure implemented in Germany provides dynamic rerouting to road users and is composed of displays that show a possible alternative route in case of accidents. Magnetic loops provide information about the lane's occupation in this system. Another system in Germany uses Variable Message Signs (VMS) installed for traffic control in case of traffic blocks (due to accidents or congestion).

Austria: system tested in Austria determines the dynamic travel time especially due to roadworks and broadcasts it to the road users via variable message signs on roads, mobile phone applications and a website.

Impact on capacity:

Mostly with traffic and route information, an increase in capacity was observed, mainly due reduction in incidents with prior warnings and alternate routes chosen by road users.

In Germany, with dynamic rerouting and information broadcasting with the help of variable message signs (VMS), 10% – 15% of rerouted users are expected. In case of a critical event, more than 40% of users can be expected to reroute. With network control using VMS, travel time gain is between 1.5 to 8 minutes whereas vehicle lost hours reduces to 2.5% in a junction.

The impact is low but it depends on the country. It is possible to sustain high flows when you have vehicle to vehicle communication.

Impact on safety:

Traffic and route information has indirect impacts on safety due to the reduction of rear-end collisions. No comment on safety was found in references for the above measures.

Challenges:

In the Netherlands one main challenge is to provide information directly inside the vehicles by the road operators and integrate the information within ADAS systems. It would demand a lot of cooperation between OEMs and NRAs.

No other challenges were mentioned.

6.1.9 Fog warning system

The main purpose of the fog detection and warning system is to provide information about the severity of fog and provide road users with a warning. The system can also implement variable speed limits to reduce the risks due to low visibility.

The fog detection and warning system implemented in the Netherlands consists of fog detection instruments, a central system, facilities for operation, and communication facilities. The system uses 20 sensors along the 12 km stretch to measure visibility. Based on the visibility distance calculated, an appropriate speed limit is shown on overhead message signs. For a visibility distance greater than 140 m, no speed limit is shown. For those from 70 to 140 m, the 80 kph speed limit was posted, and for those less than 70 m, the 60 kph speed limit was displayed.

Impact on capacity:

On the A16 Motorway in the Netherlands, an automatic fog warning system prompted drivers to slow down by 8 to 10 kph and drive at more uniform speeds; however, during extremely foggy conditions the system increased the average vehicle speed by 31 kph, matching the recommended speed.

Impact on safety:

Fog warning systems have a greater impact in improving safety on roads as with a reduction of speed by 5kmph, the number of accidents reduces approximately by 15%.

Overall effectiveness:

The system has a positive effect on speed choice in fog: it was found to result in an additional decrease of speed of about 8 to 10 kph and a slight reduction in the standard deviation of the speed. In extremely low visibility (< 35 m), the system had an adverse effect. The average speed with the system in this situation was 60 kph, whereas without the system was 29 kmph.

6.2 Driver behaviour

Driver behaviour can play a major role in traffic efficiency. Measures to improve it can be classified into two subcategories: *Human behaviour and infrastructure* and *Driver knowledge and awareness*.

Human behaviour and infrastructure includes enforcement interventions such as speed cameras and engineering nudging interventions such as chevron signs and dynamic speed display signs.

Driver knowledge and awareness measures include providing driver training and education such as training for automated vehicles and rules of eco-driving. The impact on highway capacity for these interventions has not been studied yet.

6.2.1 Speed enforcement using spot speed measurement

Speed enforcement using speed cameras is an effective way of improving driver behaviour. There are two types of speed camera enforcement techniques: spot cameras and average speed enforcement cameras (6.2.2).

Spot speed cameras help enforce speed limits at an individual location by monitoring the speed of vehicles in view of the camera. They can either be fixed or mobile and should be used as part of a combination of route treatment measures. When the camera has detected a vehicle travelling above the posted speed limit, a photograph is taken, which is then reviewed by a law enforcement officer. Finally, an infringement notice is issued to the registered owner of the vehicle.

This assessment comprises 26 evaluation studies conducted in Europe (UK, Sweden and France), Australia and Canada.

Impact on capacity:

The publications did not perform an in-depth analysis of the effects on highway capacity. However, most of the evaluation studies have reported an increase in traffic flow after the implementation of this measure. The primary cause of improvements in traffic flow is a reduction in the number of incidents which in turn leads to lower congestion. However, as per the opinions captured via workshop, there is a negative impact on traffic flow and safety due to instant braking and accelerations.

Impact on safety:

The twenty-six studies were evaluated for a pre/post reduction in the proportion of speeding vehicles. In the vicinity of camera sites, these pre/post reductions ranged from 14% to 72% for all collisions, 8% to 46% for injury collisions, and 40% to 45% for collisions resulting in fatalities or serious injuries. However, in the workshops it was mentioned that speed cameras may cause driver distractions as drivers are constantly using speedometers to keep track of their speeds.

Overall effectiveness:

The benefits associated with spot speed cameras include a reduction in the instances of vehicles travelling over the speed limit in the vicinity of the cameras, and potentially an increased awareness to drivers that they are travelling in an area with a road safety issue.

Challenges:

Police enforcement (such as camera vans) produces only temporarily change driver behaviour. Reductions in speed are mainly limited to times of deployment, and when drivers have passed the enforced area, they speed up again.

While road engineering and enforcement can reduce driving speeds, their measurable effects are limited to those locations on the road network where they operate.

Unforeseen behaviour changes such as camera surfing or making up for time off-network may present a challenge.

Differences in driving style between European countries may determine compliance or acceptability.

6.2.2 Speed enforcement using average speed measurement

Average Speed Enforcement Cameras (ASECs) are a route-based road safety measure used to enforce speed limits along a route by monitoring a vehicle's average speed between two locations. An ASEC scheme consists of cameras at the entry and exit points of a section of the road with a time-stamped photo taken of each vehicle as it enters the area.

ASECs are clearly distinguishable from spot speed cameras and are usually mounted on gantries or cantilever poles high up to enable the automatic number plate recognition (ANPR) cameras to work effectively. The most visible use of the systems (although not one that falls within the scope of this analysis) is at roadwork schemes with temporary lower speed limits, where they have become a common sight over the last decade. It is reported that the use of these systems, rather than spot speed cameras, achieves a greater level of compliance and improved traffic flow.

All ASEC systems make use of ANPR technology to identify and record vehicles at the start and end of the enforced section with their entry and exit times which, together with the known distance travelled, are used to calculate an average speed. When a vehicle’s average speed exceeds a set threshold, the offence is recorded by the system and may ultimately, following a review by police staff, result in a Notice of Intended Prosecution (NIP) being sent to the registered keeper of the vehicle. All ASEC systems are digital and do not require a film to be loaded, unlike older spot speed cameras. The early ASEC systems required the installation of roadside cabinets with write-once, read-many (WORM) drives to record offence data digitally for transfer to a police office for processing. New devices obviate the need even for a site visit, as they use wireless communications, such as 3G, to transmit offence information in real-time.

Impact on capacity:

Opinions from the workshops were that there is less negative effect of ASEC on traffic flow in comparison to spot speed cameras. One large-scale study indicated an improvement in traffic flow upon using ASEC, but overall evidence is still lacking.

Impact on safety:

A before-after analysis approach with pre- and post-implementation periods ranging from two to eight years in the UK found a decreasing trend in Killed or Seriously Injured (KSI) crashes after the installation of average speed enforcement, ranging from 33% to 85%. Reductions in minor injury crashes were also noted across several evaluations. ASECs are considered safer than spot speed cameras as they do not encourage instant braking and acceleration, rather they help in harmonising the speeds along the enforced route.

Challenges:

Differences in driving style between European countries may determine compliance or acceptability.

Over-instrumentation of roads leads to frustration and non-compliance. There is a limit to the amount of driver behaviour technology that can be deployed on a road.

It is a perception that Police/Local Authorities are making money from cameras.

It is a perception that motorists from other nations will not be subject to enforcement.

Another challenge is how to determine how many tickets to issue. It is undesirable for the police if lots of drivers break the limit.

It should be considered how long speed cameras will exist until it is superseded by in-vehicle tech like mandatory ISA.

6.2.3 Driver training and education

Several measures have been implemented to train, educate and spread awareness about different measures among road users. In Switzerland, a traffic information and safety campaign on variable message signs (VMS) was launched to inform road users about safer practices. During the campaign, messages were written in 3 different languages and distributed throughout the country.

A campaign in the Netherlands was intended to spread awareness about the dangers of ignoring “red crosses”. Ignoring red crosses has long been a serious problem in the Netherlands. The slogan #nietvoorniX is displayed, among other things, on the dynamic signs above the road and used via social media. A car belonging to road inspector which was hit by another car who ignored a red cross, in a hit-and-run incident, is displayed on the side of motorway during campaign to spread awareness.

In a large-scale European project named ECOWILL (ECOdriving – Widespread Implementation for Learner Drivers and Licensed Drivers), a European eco-driving standard was compiled to educate drivers. This standard involved both eco-driving lessons directed at learner drivers (“level 1”) and short-duration training for licensed drivers (“level 2”). It includes content as well as didactics. The standards were integrated into handbooks for train-the-trainer seminars, again both for educating learner drivers and conducting short-duration training for licensed drivers.

ECOWILL updated ‘The Golden Rules of eco-driving’, including the five most important eco-driving tips and some detailed information aimed at experts such as driving instructors. The five tips are:

1. Greater Anticipation: Anticipate situations and other road users as far ahead as possible; Maintain a greater distance between vehicles in order to avoid unnecessary acceleration and braking and make maximum use of the vehicle's momentum.
2. Maintain a steady speed at low RPM: Drive smoothly, using the highest possible gear at low RPM.

3. Shift up early: Shift to a higher gear by approximately 2,000 RPM.
4. Check tyre pressures frequently, at least once a month and before driving at high speed
5. Remember all ancillary loads add to fuel consumption. Electrical equipment and in particular, air conditioning adds significantly to fuel consumption, so use it sparingly; Avoid carrying dead weight and adding unnecessarily to aerodynamic drag e.g.by opening windows at high speed or carrying roof boxes when not in use.

Impact on capacity:

A positive impact in capacity was seen due to campaigns regarding traffic information via VMS. Education provided through the safety campaign ensures that user's incorrect behaviour does not lead to negative impacts on the traffic flow. However, those publications do not look into the capacity impacts of the measure.

Impact on safety:

All the measures related to driver training and education had a very positive impact on safety. The safety campaigns inform road users about dangerous behaviour like driving too close to each other or drinking alcohol. This has resulted in higher compliance with rules.

Impact in environment:

Positive impacts on traffic flow can reduce air pollution and traffic noise. For the ECOWILL short-duration training, the average reduction in fuel consumption seen on the day of training varied from 9.2% to 18.0% among partners, resulting in a weighted mean effect of 14.0% in all 13 ECOWILL countries. This figure refers to the fuel reduction recorded for the second lap compared to the first lap. The long-term effect of the training for daily driving is estimated, based on experiences of other initiatives, to be around 7.5%.

Acceptance of users:

With the campaign regarding VMS, the use of pre-trip information increased from 25% in 2002 to 57% in 2017 with satisfaction with pre-trip info rising from 82% in 2004 to 95% in 2017. The use of on-trip information also increased from 50% in 2002 to 77% in 2017. Satisfaction with VMS has increased from 50% in 2002 to 90% in 2017. 91% of users deem the messages to be appropriate, good or very good.

There are sometimes situations where road users think that ignoring a red cross is allowed. For example, if the motorist has passed an accident or the accident is out of sight. But even if there seems to be no obvious reason for a red cross above the road, they are there for a reason and ignoring them can be life-threatening.

Overall, 10,624 ECOWILL short-duration training courses were conducted in the thirteen countries, which slightly exceeds the project’s target numbers. The participating drivers were very satisfied with the training courses: 98% found that the training was useful for them, 92% expected to be able to drive more energy-efficient in the future and 95% said that they will recommend the training to their friends and colleagues.

Challenges:

In the ECOWILL project, the demand for training was lower than expected and some partners found that unsubsidised training was hard to sell. Ten of the thirteen partners think there is no significant market for selling unsubsidised short-duration training to private drivers in their country.

6.2.4 Dynamic speed display signs (nudging technique)

Dynamic Speed Display Signs (DSDS) are intended to help motorists self-enforce their speed. DSDS should not be confused with dynamic speed limits (DSLs) which can impose different speed limits depending on traffic or weather circumstances. The essence of DSDS is individual feedback on driven speeds.

Dynamic speed display signs (DSDS) measure the speed of approaching vehicles and communicate the vehicle's actual speed to drivers on a digital display along the road, possibly also including pictures or verbal messages such as “Slow down” or “Thank you”.

Although, dynamic speed display signs are more commonly used on low-speed roads, it is important to know their impact on capacity and safety. Their benefits can potentially be harnessed by NRAs to improve the connecting roads and thus avoiding spillback on highway.

Impact on capacity:

No specific impact on capacity was seen due to DSDS. In an implementation in Germany, 51.2% of drivers with average speeds below the posted speed upstream of the DSDS increased their speeds adjacent to the DSDS. The authors explain this by the fact that DSDSs might act as a reminder to some to raise their speed to meet the posted speed. Indirect improvements in traffic flow can be expected due to the harmonisation of speeds in traffic.

Impact on safety:

An overall reduction in the number of crashes of 5% was observed due to DSDS. Results consistently show that DSDS have favourable effects on speeds.

The results of the analyses indicate that the DSDS are effective in reducing free-flow passenger car operating speeds while in place and activated. However, the speed reductions observed while the DSDS were in place disappeared within a few weeks after the devices were removed from the study sites.

6.3 Vehicle technology

Improvements in vehicle technology may in the future have an influence on highway capacity. Additionally, vehicle technology may play a vital role in avoiding accidents, which will reduce congestion and a higher overall capacity may be realised. Vehicle technology can be divided into V2X communication and Deployment of Automated driving. As the technology is not yet in wide use, many of the studies assess the effect of the measure based on models.

V2X communication includes C-ITS applications such as vehicle-vehicle and vehicle-infrastructure communication. Vehicle-to-vehicle communication may enable vehicles to run in a platoon and share information regarding the surroundings of the vehicle. There have been various studies regarding platooning where capacity is expected to increase due to shorter gaps between vehicles. Vehicle-to-infrastructure communication aims to provide extra information to the drivers to enable more efficient and informed driving. Examples include traffic and route information, roadworks warning, digitised road geometric design, smart and connected traffic lights, incident and congestion detection, green light optimised speed advisory, etc.

Advanced driver assistance systems (ADAS) assist in the driving task and help in avoiding critical situations. Simulation studies suggest vehicle technologies such as Adaptive Cruise Control (ACC), Lane Departure Warning (LDW), Intelligent Speed Adaptation (ISA), Electronic stability control (ESC), and connected and automated vehicles (CAVs) are expected to help enable safer and more efficient driving resulting in an overall increase in highway capacity. However, some research also suggest that great compliance to traffic rules and defensive driving by CAVs may lead to reduction in capacity.

6.3.1 Intelligent speed assistance (ISA) mandate

To make driving safer, EU legislation made ISA mandatory for all new vehicles starting in 2022, and mandatory for all cars that will be sold from July 2024. The legislation applies to all European cars, vans, trucks and buses sold in EU.

This helps drivers to comply with the speed limit. A variety of ISA systems have been developed which can provide information on safe speeds to the driver (Advisory/Informative ISA), warn the driver when he/she is exceeding the speed limit (Supportive ISA), or control the brakes or throttle to prevent speeding (Mandatory/Limiting ISA).

ISA systems require four basic elements:

1. Speed limit detection via maps or in-vehicle cameras. A speed limit map provides detailed information on the speed limit in force at each section of the road. Since local or national authorities are responsible for determining speed limits, it follows that they should also play a major role in the development of such map databases.
2. The means to determine the position and direction of travel of a vehicle, usually achieved using GPS technology. However, more advanced so-called ‘dynamic’ ISA systems can also use information from vehicle sensors or roadside information systems.
3. Actual speed is measured by the vehicle’s own speed measurement system.
4. Determination of the relationship between the appropriate speed and the actual speed. This dictates how, when and in what way the ISA system is activated.

This assessment is based on multiple large scale and small-scale evaluations carried out in Sweden, the Netherlands, Finland, Denmark, Belgium, France, and the United Kingdom.

Impact on capacity:

One large-scale UK study included in this review showed that ISA resulted in an increase of approximately 4.4% in travel time across the day on national, regional and local roads but no increase on motorways. However, other studies showed that ISA helped to improve traffic flow, which should reduce average travelling times and traffic congestion. Thus, the impact on capacity is unclear.

Impact on safety:

None of the studies on ISA was sufficiently large to provide evidence demonstrating safety improvement. Indeed, it is likely that the true effects of ISA will only emerge when a larger percentage of vehicles equipped with ISA is being used.

Some negative aspects of ISA were reported in many studies. These include direct effects such as driver distraction and indirect effects such as behavioural adaptation. Any activity that distracts the driver, or competes for his/her attention while driving, can potentially degrade driving performance and thus have serious consequences for road safety. Thus, careful consideration is needed when deciding on the nature and positioning of in-vehicle warnings and displays.

Environmental impact:

Several studies indicated that ISA would significantly reduce the CO_2 emissions of private and commercial motoring activities. Overall, the evidence reviewed suggests that the introduction of ISA would result in reductions in fuel consumption and emissions.

Investment costs:

A recent cost assessment for the European Commission found that a camera-based system, shared between several systems such as Automated Emergency Braking (AEB), Lane Keeping Assistance (LKA) and Intelligent Speed Assistance (ISA), would cost in the range of €47-62 per vehicle. The total cost for components (camera, ECU, brackets, trim, wiring) and OEM design and development, tooling costs, etc., was estimated at €186-249, based on individual costs extracted from NHTSA, 2012.

Challenges:

Research outcomes also suggested that those who would most benefit from ISA (e. g., young, male and/or inexperienced drivers) are least willing to use it. This highlights the risk of self-selection bias if activating ISA is optional.

6.3.2 HGV platooning

Heavy Goods Vehicle (HGV) platooning is the use of technology to allow HGVs to travel safely in close proximity at speed, with the driver of the lead vehicle controlling the speed, acceleration and braking of the whole 'platoon'.

Platooning is not driverless technology; all HGVs in a platoon have a driver who is responsible for steering as normal and is ready at all times to take over manual control or leave or dissolve the platoon if necessary. The platooning vehicles are connected using V2V communication and the following vehicles adapt their acceleration and braking to the movements of the lead vehicle.

Truck platooning represents a promising means to enhance the efficiency of freight transport. By decreasing distances between trucks, fuel consumption, as well as pollutant emissions, can be reduced. Typically, distances between trucks are controlled using the latest state of the art of automated driving technology.

Various studies and trials have been conducted to evaluate the impact of platooning on capacity, safety and the environment. Most of the studies, for example Concorda, ENSEMBLE are theoretical, but projects such as HelmUK, EDDI and truck platooning challenge have tested it on public roads.

Impact on capacity:

Austrian road operator ASFiNAG conducted an analysis on the benefits of truck platooning by simulation. The analysis found platooning is expected to improve the traffic flow efficiency as the density of traffic can be increased without any compromises with the speeds. Project ENSEMBLE also points out the potential benefits of platooning in improving the traffic flow which can further be improved with the help of a strategic traffic controller that can communicate between trucks from different manufacturers.

In contrast, a trial conducted by the HelmUK project did not identify any difference in traffic flows on the days of their trial. This could be expected as there was only a 3-vehicle platoon leading to a very low penetration rate.

Impact on safety:

Most research has found that truck platooning brings improvements in traffic safety. As deployed in the HelmUK trials, platooning is as least as safe as ACC despite travelling at half the headway and is unlikely to introduce new collision types. The systems required for platooning operations, such as LKA, offer additional safety improvements regardless of whether platooning is operational or not. The ENSEMBLE project highlights that platooning enables a faster reaction to potentially dangerous braking situations because of V2V communication.

However, platooning may lead to extra risks in certain situations such as highway on-off ramps.

Impact on environment:

Platooning is expected to bring benefits in terms of reduction in fuel consumption and emissions. The HelmUK road trials found that fuel savings of 0.5% could be realised by a three-vehicle platoon. With uninterrupted platooning, 4.1% of fuel savings can be achieved. ENSEMBLE project identifies a 4-10% fuel reduction for the following vehicle (with a distance of 1.5s, speed 80 km/h).

Challenges:

The key risk for HGV platooning is the conflict between vehicles joining and leaving the carriageway at junctions and the platoon. This conflict could increase the chances of a collision or mean that vehicles have to join the main carriageway at a dangerously low speed. One potential solution to this issue is the use of ramp metering to manage the traffic joining the mainline carriageway.

Another challenge identified in HelmUK was that junctions which are too close to each other cause the platoon to split very often and thus platooning fails. This means that network with junctions very close to each other leads the platooning to fail.

Relevance for NRAs:

As per the HelmUK report, the NRAs and road operators may become Platooning Service Providers (PSPs) as forming a platoon with multiple operators might be required. PSPs will have knowledge and understanding of proposed journeys from multiple operators so that potential platoon participants can be coordinated. Additionally, acting as a PSP will provide a road operator with additional real-time data which can be used to improve traffic management and incident response effectiveness.

6.3.3 Green light optimised speed advisory (GLOSA)

This system uses timely and accurate information about traffic signal timings and locations to guide drivers (through infrastructure-to-vehicle (I2V) communication) with speed advice for a more uniform commute with less stopping time through traffic signals. The GLOSA algorithm affects only those vehicles that, if continuing to travel at their current speed, would arrive at an intersection during the red signal phase. The system advises those vehicles to change their speed (within a permitted range) in such a way that they pass without stopping through an intersection during the green light.

GLOSA systems can be implemented both as a infrastructure or in-car measure. In the Netherlands, GLOSA systems are implemented as a infrastructure measure where speed is advised on road for the users to catch the green wave. While the GLOSA systems aren't implemented on highways as they are specific to the traffic lights, they can significantly reduce the spill back from queue emerging in connecting roads to the highways.

There are two ways to get the GLOSA service into the vehicles:

- via ETSI G5 directly into the on-board computer of the vehicle

- via mobile network into a smartphone app

GLOSA was implemented in Germany via the C-Roads ITS Project. The two main applications are the Green-Wave- and the Deceleration Assistant:

1. Green-Wave-Assistant: The assistant shows information which enables it to reach the green phase at the next signal-controlled junction. Thus, unnecessary stopping and acceleration procedures can be prevented.

2. Deceleration Assistant: The driver will be informed that he cannot reach the green phase at the next signal-controlled junction. He can roll out the vehicle to prevent unnecessary brake and acceleration procedures.

To determine if a vehicle will have to stop at the intersection, the current length of the queue at the relevant intersection approach is considered. The queue on each intersection approach is estimated by considering the position of an arriving vehicle and its speed. Since the vehicle's position is communicated to the 'controller' each second it is easy to know whether a vehicle is on a particular link in front of the signal's stop line.

In the UK, Highways England (now National Highways) and Amey Consulting ran a trial with Transport for Greater Manchester at two slip roads off motorways in Oldham and Bury. One was on the A627(M) and the other was on the M66.

Impact on capacity:

GLOSA systems are expected to bring benefits to traffic in terms of improving journey times. In a trial on a 6km stretch of the A45 Coventry Road in Birmingham, GLOSA reduced journey times through the test stretch of road by 7%.

GLOSA is more effective in fixed signal control with a higher penetration rate. In the case of actuated signal control, the GLOSA effect goes from reducing vehicle stopped delay by approximately 3% to increasing total delay by around 13%.

Impact on safety:

Studies show that the introduction of the GLOSA system eliminated the need for sudden rapid deceleration in the vicinity of the intersection. Therefore, it can be stated with confidence that the use of the GLOSA system would result in safer intersection traffic flows in signalised intersections. On the other hand, drivers without GLOSA systems may find other vehicles moving slower than expected leading to confusions and unsafe situations.

Impact on environment:

Analysis of results shows CO_2 emissions were reduced by up to 27% during the trial with NOx emissions down by up to 17%. The most impressive results were for larger vehicles. It is estimated that freight vehicles save on average 12.5% in fuel, at current diesel prices, in not stopping on a slip road, suggesting significant financial, as well as environmental benefits.

Relevance for NRAs:

NRAs can invest in making their traffic signal controllers smarter to reap the benefits of GLOSA systems. Additionally, public campaigns to encourage the use of GLOSA information may help in increasing the penetration rate of GLOSA-activated road users.

6.4 Incident and impact management

Incidents are a major cause of congestion, and measures to avoid incidents or reduce their impact can lead to higher overall capacity. Incident and impact management has two subcategories: Incident avoidance and post-incident management. These are interconnected and require cooperation between institutions (e.g., NRAs, emergency services, maintenance contractor, towing companies, cities, and municipalities) for efficient operations.

Measures related to incident avoidance include the separation of slow and fast lanes to help in improving the speed homogeneity in traffic and thus reduce potential incidents. Additionally, providing information regarding incidents can warn drivers about potential road blockages.

Post-incident management refers to the measures which enable incident detection, access to emergency services, and restoration of traffic after incidents. Incident detection plays a vital role in the timely detection of incidents and sending emergency services to mitigate the impact. Measures such as queue detection and incident detection via vehicle data help in the early identification of incidents on the highway. Strategically placing towing vehicles on incident hotspots may reduce the time taken to clear the incident sites. Access to emergency services can be provided by cut-through or movable guard rails that can make space for the emergency vehicle in case of all lane running. The safety of the incident recovery zone is important, and safety vehicles can barricade the incident zone for the safe operation of emergency services.

6.4.1 Faster response to incidents

Measures that enable early detection and faster response to incidents are effective in quick recovery and lead to faster resolution of congestion and restoration of capacity. Measures that can enable faster response to incidents include placing towing vehicles near incident hotspots, establishing a cooperation framework between various institutions such as NRA, emergency services, maintenance contractors, towing companies, cities, municipalities, etc., motorway incident detection systems to detect early warning signs of incidents, emergency cut through barriers for easy access to emergency vehicles, notification of incidents to road users, and securing the incident site by barricading the scene to avoid further accidents by fast-moving traffic.

Impact on capacity:

The effect of a faster response is to reduce the congestion duration.

Impact on safety:

The effect on road safety is significant. For example, several places do not have direct automatic matrix boards that can automatically close a lane. Thus, arriving at the incident scene earlier and securing the scene can significantly affect road safety. In addition, drivers can be distracted by seeing the incident and may drive erratically, which negatively affects road safety.

6.4.2 Access to emergency services

In the event of an incident, it is important to enable quick access to emergency services at the incident site. Disassembling a segment of a guard rail to use the parallel road network or use the opposite carriageway to reach the incident site can be time-consuming and can lead to unsafe situations. An emergency cut-through barrier enables faster access to the incident site in case of a serious disruption to the traffic flow. A "CADO" is a cut-through (a movable or movable guide rail) for emergency motor vehicles between two separate lanes, to be used exclusively for the timely prevention of calamities and incidents reach, remove any victims and unlock trapped traffic. A CADO is a segment of a guide rail, which can be opened in case of an emergency. The CADO can be controlled both locally and remotely. When opened, a passage is created which is a minimum of 6 and a maximum of 9 meters wide.

Moreover, before the process of recovery can start, the scene must be safe to work in. This is done by barricading the scene with a safety vehicle. This is usually done by the Road Inspector, who uses their safety vehicle to barricade the scene before any of the recovery/towing works can start. Due to the shortage of road inspectors, they may not always arrive quickly on the scene, which delays the work. In the Recovery-Safe Recovery project (in the Netherlands), VBM (trade union for defence personnel in the Netherlands) came up with the idea that its members can ride with not only one or more vehicles for the recovery works, but also immediately a safety vehicle to barricade the incident scene so recovery works could start immediately, especially when there is no Road Inspector available.

Impact on capacity:

Cut-through guard rail (CADO) also provides indirect benefits to traffic flow due to the fast recovery of the incident as emergency vehicles can reach the incident site quicker by cutting the barrier and using the other side of the hard shoulder.

In the case of the recovery-safe-recovery initiative, traffic was restored up to 20 minutes faster due to there being no need to wait for the Road Inspectors to arrive with their safety vehicles.

Impact on safety:

This measure has a large positive effect on road safety. Many places lack direct automatic matrix boards that can automatically close a lane. Arriving at the incident scene earlier and securing the scene can therefore have a major effect on road safety. At every incident people driving by may be distracted by the scene, and this has a negative effect on road safety. The earlier the scene can be cleared, the less distraction results, and this has a positive effect on road safety.

6.4.3 Incident detection

Motorway Incident Detection systems keep highway managers aware of traffic flow with constant monitoring across vital routes. They spot early warning signs of traffic build-up and intervene to reduce the risk of serious congestion. The monitoring and tools in the control centres reduce detection and intervention times in case of an emergency.

An existing system by INRIX can provide advance notifications of crashes, unplanned road closures and other traffic-causing delays enabling agencies to keep drivers informed and safe on their roadways. The system monitors queues using real-time GPS readings. The back of the queue can be a dangerous place, especially when the speed of traffic decreases from 70 KPH to 20 KPH within a short distance.

An Automatic Incident Detection (AID) system in the Netherlands uses data from loop detectors (with a loop every 500 metres on each traffic lane) to determine vehicle speeds and, on that basis, the location of traffic jams. The system automatically warns road users about congestion and queuing traffic ahead. The aim is to prevent secondary accidents at the tail of queueing traffic by reducing the maximum speed for approaching vehicles, improving reaction time and thus avoiding further congestion due to accidents.

A Swedish study found that incident detection is also relevant for the safe operation of Automated Vehicles (AVs) where they can receive SOS alarms from the traffic control centre and can be forced to drive manually in case of an approaching emergency vehicle.

An incident detection system is installed in Italy on the tunnels in the A24-A25 motorway.

Impact on capacity:

Incident detection generally has an indirect effect in increasing capacity due to reduced critical event management time. Due to faster incident detection a faster response of incident services is possible and both aspects together will lead to a quicker clearing and a faster restored traffic flow.

Impact on safety:

Most of the studies and implementations report an increase in safety due to incident detection systems. In an emergency, every second counts. The reduction of emergency management time leads to an increase in safety.

Challenges:

The main problem is a high number of False Positive alarms. It is thus required to improve the setting of the camera and software but also to have multiple sources of data.

There are multiple sources of data, such as e-call, loops, RADAR systems. Cameras can also give automatic information if there is a queue or stopped vehicle or animal on the roads. When RADAR is used for detection, more failure rates were predicted. Thus it is necessary to ensure that equipment fits the purpose. RADAR-based stopped-vehicle detection appears to come from a very small supply chain, which has cost and pace of deployment issues.

6.4.4 Institution cooperation

There are several examples of cooperation between different institutions to enable fast detection and recovery of incidents.

An institution cooperation model is set up in Finland which includes coordination between various stakeholders such as NRA, emergency services, Maintenance Contractor, Towing companies, Cities and Municipalities. This model solves the problem of uncoordinated and inefficient incident management.

The TIC (Traffic and travel information services) system offered by GEWI in Germany offers road incident management features which guide operators through high-stress incidents, sharing relevant information needed to take quick decisions and actions needed to reduce response times. All data related to an incident, based on type or location, is available to the operator to reduce the time it takes to move through all steps of the incident from detection to incident clearance. Information on the position and status of a vehicle or crash barrier truck is distributed to commercial service providers directly and goes into the incident management system and control centre. The information can be distributed by variable message signs (VMS) in the vicinity of incident. The system also provides the information in a format that can be used by TomTom and HERE or can be broadcast via radio and connected vehicles. The information can also be distributed via NAPs (National Access Points) which can also used by various service provides.

The Austrian road operator ASFiNAG has an institution cooperation scheme which takes up the responsibility to deploy traffic managers on the road and collaborates with police to help control the situation. The traffic management centre responds to the detected incident and informs the traffic managers to reach the site of the incident and help in traffic management.

Impact on capacity:

A cooperation between the involved institutions in incident cleaning will lead to synchronised activities leading to faster and more effective cleaning. Faster clearing of incident site restores the traffic much quicker and increases the efficiency of the road network.

Impact on safety:

Faster handling of incident management, faster information chain and better situational awareness led to improvements in traffic safety.

Challenges:

Rigid Institutional Boundaries and lack of cooperation may hamper the implementation.

6.5 Regulations

Regulations and guidelines play a vital role in the efficient governance and management of the systems. However, traffic measures laid out in the form of regulation do not often appear in tangible implementation but instead refer to rules, guidelines, and frameworks for the safe and efficient operation of traffic and related management services. Regulations can be laid out in four categories: Infrastructure, driver, vehicle, and incident related.

Regulations on the infrastructure side may include congestion pricing schemes, speed limit enforcement, and rules for automated vehicles. Vehicle regulations include bans on overtaking by heavy goods vehicles, entry time restrictions, and similar measures. Mandatory insurance for cars and trucks helps in incident and impact management.

Regulations generally lie within one of the four categories mentioned above, and thus there are fewer findings for regulations-related measures in the database.

6.5.1 Congestion pricing scheme

Various tax and pricing schemes can be implemented to improve the traffic flow and increase capacity. The congestion pricing scheme is a measure implemented both in Stockholm, Sweden and London, UK. The congestion pricing scheme charges road users to use the road during peak hours. This policy is implemented by a system which uses automatic number plate recognition in the regulated area. Vehicles are registered automatically by cameras that photograph the number plates. The system consists of overhead gantries, cameras at all entrance points, pavement markings, and street signage.

Impact on capacity:

In Sweden, traffic to and from the inner-city cordon was reduced by 20%, and traffic delays decreased by 30-50%. Vehicle miles travelled decreased by 14% in the cordon and decreased by 1% outside the cordon. After the variable pricing system was introduced in 2016, traffic congestion dropped an additional 5% during that period.

In the UK, Transport for London reported a 30% reduction in traffic congestion, an increase in average speed by 30%, and significant increases in travel time reliability in 2004, the year after the scheme was implemented. Traffic volume reductions have been sustained over time as a result of congestion pricing, with 9.9% less volume in 2015 compared with 2000, despite nearly 20% population growth in London.

Impact on safety:

In the UK, the accident rate fell by 22% after the implementation of policy. The probability of having an accident in Central London fell because of reduction in traffic congestion. Thus, by reducing congestion, the pricing both saved lives by moving people out of automobiles but also by making the commute safer for those that continued to drive automobiles.

Impact on environment:

In Stockholm, the reduction in traffic in the inner city meant the Parliament's environmental goals were met, with post-pricing reductions of 14% in carbon dioxide (CO_2), 7% in nitrogen oxide (NOx) and 9% in particulate matter (PM_{10}). Outside of the cordon, greenhouse gases were reduced by roughly 2.5%.

London has also experienced environmental and public health benefits as a result of the reduction in traffic in the inner city. From 2002-2003, carbon dioxide (CO_2) emissions declined by 16%, nitrogen oxide (NOx) emissions declined by 13.5%, and particulate matter (PM_{10}) declined by 15.5%.

Costs:

In Sweden the initial investment in the system, including the trial and first-year operations, was 2 billion kronor (USD 236 million).

The annual operating costs have decreased over ten years of operation from around 250 million krona/year (USD 29.7 million) to 100 million krona/year (USD 11.8 million), and the net revenues have increased since the variable fare updates in 2016.

In the UK, the initial investment in infrastructure and operations for congestion pricing was £161.7 million (USD 214 million). The annual operating costs are roughly £130 million (USD 172 million), and the annual net revenue is roughly £137 million (USD 182.1 million). Since the launch of the program, the fee has increased over time from £5 in 2003 to £8 in 2005, £10 in 2011 and £11.50 in 2014. The annual operating costs in London soak up almost half of the annual gross revenue, which is not the case in Stockholm.

6.5.2 Overtaking ban on HGVs

HGVs can cause delays and traffic jams by overtaking manoeuvres. HGVs travel at lower speeds due to speed limitations or uphill gradients. An overtaking by HGV can take a significant amount of time as the speed difference is usually very low. This causes HGVs to hold up traffic for prolonged periods. An HGV Overtaking ban channels the heavy goods vehicles onto a single lane (slow lane) and not allow them to overtake each other.

The ban can be applied using:

1. Restrictions on vehicles depending on weight
2. Dynamic time duration (during peak periods)
3. Signage
4. Use of hard shoulder
5. Use of climbing lane

The overtaking ban can be static, periodic, or dynamic. Static control is permanent (it is controlled by traditional traffic signs and it is concerned with the weight threshold indicated by additional traffic signs). Periodic control is controlled by traditional traffic signs and it is concerning to the time period that is indicated by additional traffic signs, e.g. control is in force between 06-22. Dynamic control implements the ban dependent on the current traffic and weather conditions and other real-time data. Variable message signs can be used for information dissemination.

An overtaking ban has been implemented in many countries in Europe including the Netherlands, UK, Hungary, Austria, Germany, Belgium, Denmark, Italy, and France.

Impact on capacity:

Overtaking ban on HGVs has a slight positive effect on capacity. In the Netherlands, the effects on traffic flow are very location specific. The capacity effect is diffused from -4% to +4%, +1% on average.

In Hungary, it causes an increase in motorway capacity and allows better traffic flow, especially during rush hours and between cities on high-traffic load sections.

Other studies reported –2 to –13 seconds for cars and –8 to +8 seconds for HGVs in travel time.

Impact on safety:

No study found any significant change in the number of incidents. There were, however, reported changes in traffic behaviour that could affect accident risk. For example, less frustration for car drivers and a more homogenous traffic flow could result in a lower accident risk. According to a study of a sample of accidents involving HGVs (European Commission, 2007), accidents after an overtaking or lane-changing manœuvre accounted for 11.3% of all HGV accidents.

Challenges:

HGV overtaking bans result in platoons of HGVs in the nearside lane. This has consequences for traffic entering and exiting the main carriageway. For traffic in other lanes, traffic signs could be obscured by platoons of HGVs.

6.6. References

All the information above is taken from the database of measures which also contains references to the relevant reports and publications. The users are requested to refer to the online database for references. The online database can be accessed via: https://project-safepath.azurewebsites.net.

7 Insight into measures in the database

The measures discussed in the previous section are those which were found to have the most comprehensive evidence of impact on capacity and safety in each of the categories. However, the list of measures mentioned above is not complete and all the other pieces of evidence can be found and accessed via the online website database (D3.3).

From the above, the category 'infrastructure capacity' contains the largest amount of evidence as these measures are widely implemented. Measures such as hard shoulder running and ramp metering are deployed on roads on a large scale in many countries and thus more evaluations have been carried out over time. Adaptive traffic management is also a common and effective choice which is implemented in the form of various measures and technologies. Several other measures such as high occupancy vehicle lanes and reversible lanes have been tried out in many countries, but failed due to technological challenges. The wide variety, diversity, availability of information, practical aspects, and pre-established technological framework make the measures from this category interesting possibilities for consideration by the NRAs.

The measures within the 'driver behaviour' category are the lowest in number. This is due to the fact that these measures are often out of the direct control of NRAs and require collaborations with other stakeholders such as enforcement agencies, driver training schools etc. These measures are in general highly effective in improving safety on roads by influencing driver behaviour, and this has the indirect effect of improving capacity. However, it might take a while to realise the real benefits as the driver's behaviour may adapt over time.

The measures within the category 'vehicle technology' are also often out of the influence of the NRAs and are mainly driven by OEMs. However, the NRAs can influence more on the C-ITS side of vehicle technology in terms of improving the roadside facilities for vehicle communication, optimisation of traffic signals based on vehicle data, providing traffic and route information inside the vehicle, and mandating standards/policies to control the emerging ADAS technologies. NRAs need to have close collaboration with vehicle manufacturers to mitigate the challenges behind emerging technology from both the infrastructure and vehicle side. This would lead to improvements in vehicle technologies leading to the realisation of higher capacity on highways.

The measures within the category 'incident and impact management' mainly revolve around early detection of incidents, providing quick access to emergency services, and faster recovery of the incident site. This indirectly benefits the capacity as congestion is resolved faster and traffic flow restored. NRAs can implement several changes which can not only prevent incidents but also enable fast recovery of the incident site. Most of the evidence found focuses on the safety aspects but very little evaluation has been conducted to assess the impact of these measures in improving capacity.

Most of the evidence within the category 'regulations' were found to be related to pricing schemes to change road usage, or bans on HGVs. Very few evaluation reports were found in research regarding these measures and impact assessment has for the most part been carried out based on small-scale study or theoretical models. While most policy measures are within the scope of ministries, NRAs can impose certain measures such as overtaking bans to improve traffic conditions.

From the above insights, it can be said that *traditional* traffic management measures such as the different types of hard shoulder running, are under the direct control of NRAs. Measures that reduce incidents and their impact can help retain the average capacity of the road when seen across a longer time period. There are many proven ways to reduce incidents and their impacts, such as speed enforcement and rapid recovery of vehicles in a collision. In contrast, new approaches to in-vehicle systems such as ISA are yet to be widely deployed, and evaluations mainly rely on simulations and small studies. Thus more practical research is needed to understand the real-world effect. Driver behaviour and regulation measures are for the most part out of the direct control of NRAs, but they offer the potential to reduce congestion if correctly implemented. Other emerging technologies such as automated vehicles are also beyond the direct control of NRAs. However, the NRAs can contribute to the development of such technologies by collaboration with OEMs and helping in providing digital maps/infrastructure.

Hence for an NRA, the findings of this research suggest that there may be future tools and technology that can be deployed to increase capacity, but they are yet to be proven and investigated to the same degree as direct traffic management measures using road infrastructure, and may require other actors, such as vehicle manufacturers and vehicle buyers, to be involved. Additionally, NRAs need to remain aware of the developments in the field of emerging technologies.

A good first step in identifying the capacity impact of a new technology would be to conduct proof of concepts or pilot trials in real-world traffic.

7.1 Transferability of measures within the EU

As most of the measures that have been found in empirical research (WP3000) are based within the European Union, the results are expected to be transferable as there are similarities in various factors within EU countries such as road rules and policies, vehicle types, infrastructure design, speed limits and other regulations. However, some of the publications have also made a statement on the transferability of the results to other countries, as shown in Figure 8.

There are many situation-specific external factors which govern the transferability of results. For example, some emerging measures such as platooning depend on network topography, for example junction spacing, which changes between networks and within networks. Thus the transferability of results is not a given. The good practice guide aims to provide users with support regarding the transferability of results where users can check highway characteristics and decide whether a measure would be suitable to their situation.

Other References
Not specified

Other Information/Notes
Transferability of results

The results from the Nordic countries may best be transferred to regions with good cellular network coverage and whose inhabitants mostly have experience using different applications. The road network in the Nordic countries is mostly sparse (few alternative routes) with little traffic (except in Denmark) and, therefore, incidents are more often related to adverse weather conditions or accidents than congestion caused by over-demand. Thus, exceptional situations are of interest to road users, even though none of the information content was considered unimportant on any network.

Other References
Not specified

Other Information/Notes
European dimension: likely transferability of the result

Arc Atlantique has chosen the EW DG services as basis to report on deployment. These services are well specified and known by the ITS world. This is clear advantage. Nevertheless some problems were met. E.g. implementing peak hour lane also includes that gantries are implemented with speed advice and lane control. By consequence 3 EW DG services are concerned. Arc Atlantique has also used an integrated service. It allows presenting on one map the progress. The LOS of this integrated service is defined independently of the different operating environments as defined on the Easyway map. This is maybe a disadvantage, at the other hand by using the operating environments one need again several maps in order to present progress. This topic needs further discussion in the framework of EIP.

Arc Atlantique has chosen Vehicle Hour Lost as KPI for the impact evaluation. Main advantage of this KPI is the possibility to monetize it. By monitizing the results the benefit can be compared with the investment cost. It can be expressed in Pay Back Period. It is done for several projects of Arc Atlantique. It certainly contributes to input for ex-ante evaluation. The results can be used as well to promote ITS on an European level.

Figure 8: Information regarding transferability captured within a C-ITS measure in the online database

8 Conclusion and next steps

This report concludes the work which has been carried out in empirical research. The key output of empirical research (WP3000) is a database of traffic measures found via literature review, questionnaires, interviews, and workshops. The database is online and equipped with tools enabling searches for relevant information. This solutions report also provides an overarching view of the measures included in the database in each category along with recommendations for NRAs. It should be referenced in conjugation with the database.

As possible future work, CEDR could adopt and append more data to the database of measures. The database can also be used as a resource for future projects.

The next steps within the SAFEPATH project include a road safety analysis of the measures (WP4000) and the creation of a Good Practice Guide (WP5000). The safety impacts of the identified capacity measures from empirical research will be analysed in the road safety analysis. Road safety analysis will also use the insights gathered in the previous work packages to analyse various solutions' safety performance.

Ultimately, the KPIs identified in problem and systems analysis (WP2000), the highway capacity measures identified in empirical research (WP3000), together with the road safety analysis (WP4000) will provide a firm base for creating the Good Practice Guide (WP5000), as shown in Figure 9. The results of the empirical research along with results from the road safety analysis and the Good Practice Guide will also be taken along in the final report, which will be worked on in WP6000.

The project team started dissemination activities at the ITS Toulouse conference in June 2022. A one-to-one session with National Highways (UK) was also conducted for discussion regarding the Good Practice Guide. The team will publish and present a paper at Transport Research Arena (TRA) conference (Portugal) and the National Road Safety Conference (UK) in November 2022. The results of this project along with an online/web-based database of measures will be further taken in the dissemination process (WP7000) to spread the word across various interested stakeholders. This would provide long-term access to the identified measures for CEDR, NRAs, and other relevant stakeholders. The project team plans to use several other means of dissemination such as online one-to-one sessions, workshops, webinars, social media posts, conferences and university lectures to ensure a wider reach of the project results to potential users.

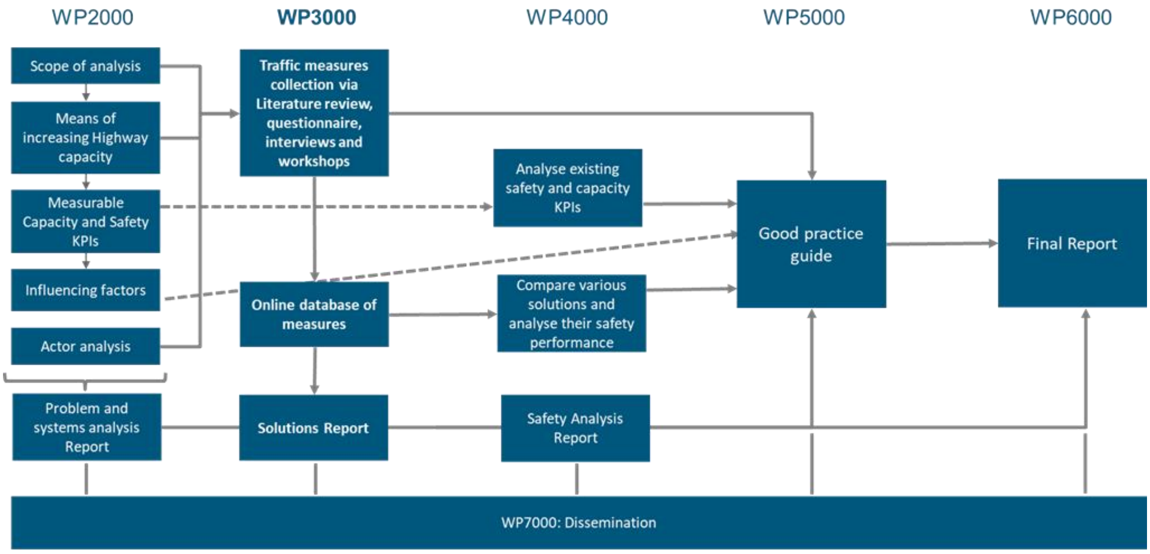
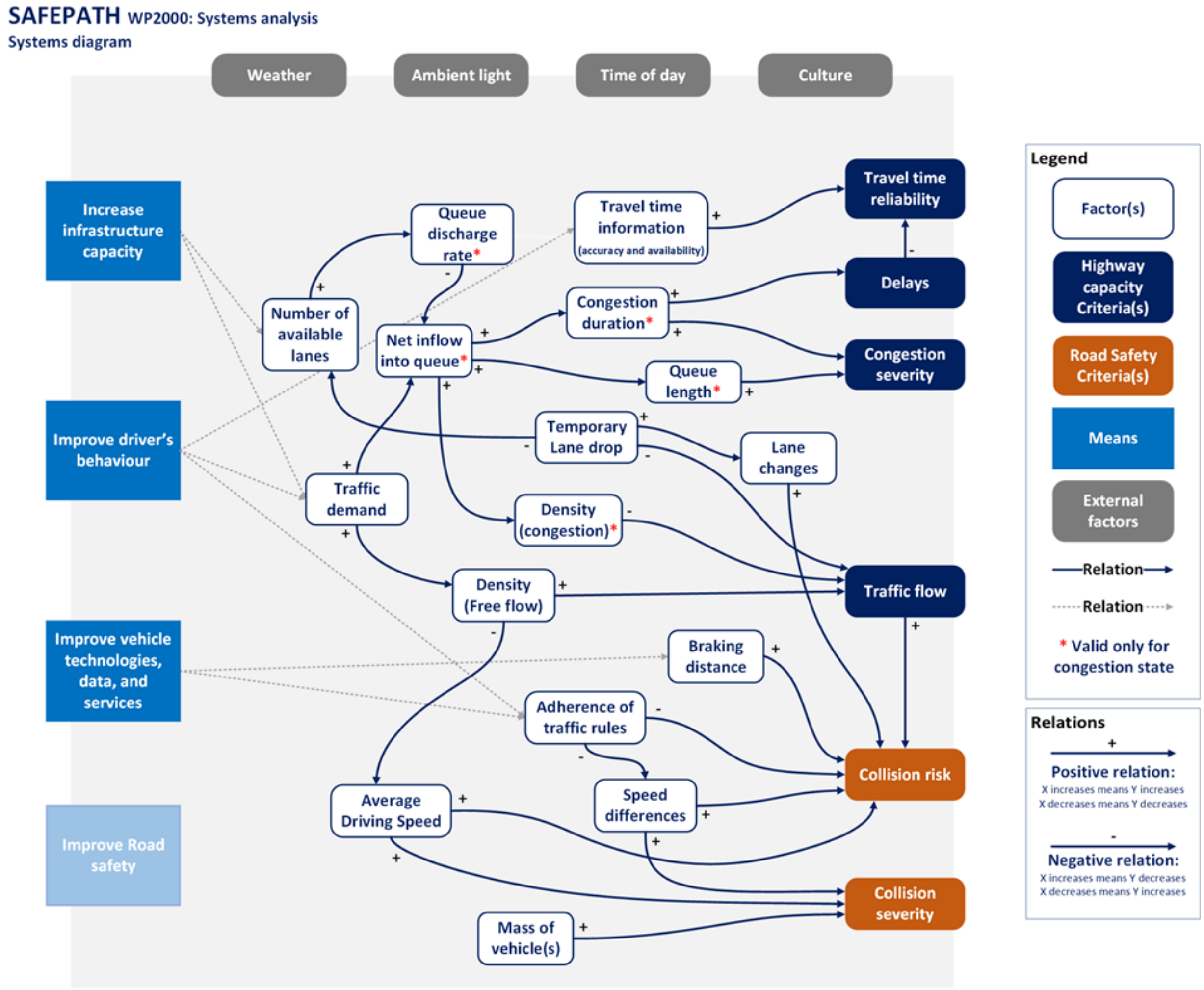


Figure 9: Process and relations between different work-packages

Appendix A WP2000 outcome – Systems diagram



Appendix B Stakeholder engagement procedure

The engagement of stakeholders was carried out in a multiple-step process. Figure 10 shows the process of stakeholder engagement. The process started with first identifying and listing relevant stakeholders with the help of actor analysis and a stakeholder engagement plan. The identified stakeholders were sent an email with a description of the project, expected outcomes, benefits, request for their involvement and a short questionnaire where they could indicate their interest to get involved in the SAFEPATH project via means of interviews and workshops. The stakeholders who showed their interest in attending an interview were sent an invitation to the interview. The stakeholders who did not show an interest in attending the interview were sent a link to fill in the long questionnaire, whose contents were the same as that of the interview. The stakeholders who showed an interest in attending the workshop were invited for attending a workshop. However, the stakeholders who did not show interest to attend the workshop were informed about the date, time, and contents of the workshop to check if they could attend.

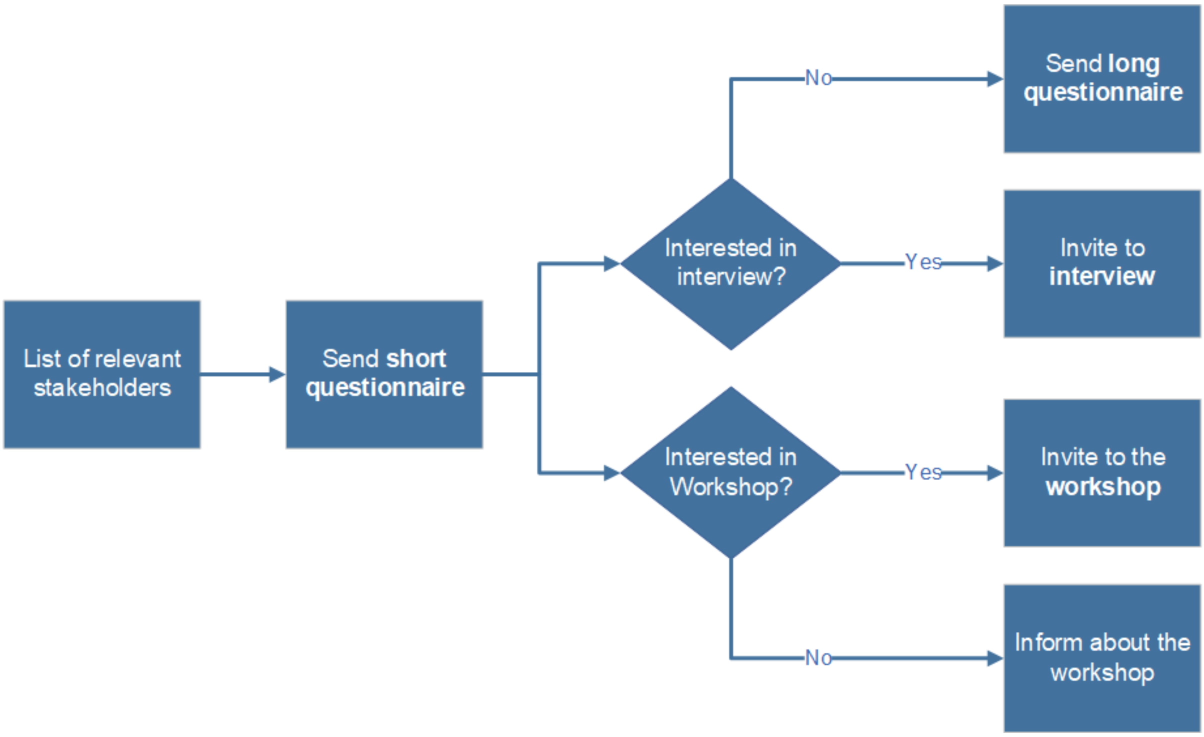


Figure 10: Stakeholder engagement procedure

Appendix C Methodology of literature review, questionnaire, interviews, and workshops

Literature research methodology

To conduct the literature review, means of increasing highway capacity as identified in WP2000 were used as a starting point. However, to drive the process systematically, various sub-research questions were framed, which served as a guide while conducting the literature review. These research questions helped to follow a systematic approach while analysing publications and also to find new publications. The sub-research questions used are the following:

- What different measures to increase the road infrastructure capacity exist that can directly/indirectly increase the highway capacity?
- What are the different measures (existing practices) to increase the highway capacity by influencing driver behaviour? e.g. driver training, infrastructure vs driver distraction, cameras to enforce the speed limit, Driver Knowledge and Awareness etc.
- Which in-vehicle technologies and C-ITS services are currently available and impact the highway capacity (e.g. ADAS systems, V2X communication, C-ITS services etc.)?
- What is the impact on highway capacity due to future developments of connected and autonomous vehicles (CAV)?
- Which traffic measures exist to facilitate incident and impact management?
- Which regulations have been implemented to improve the highway capacity from infrastructure, vehicle technology, driver behaviour, and incident management side?

Following the sub-research questions, the literature review was conducted in a three-stage process, as shown in Figure 11.

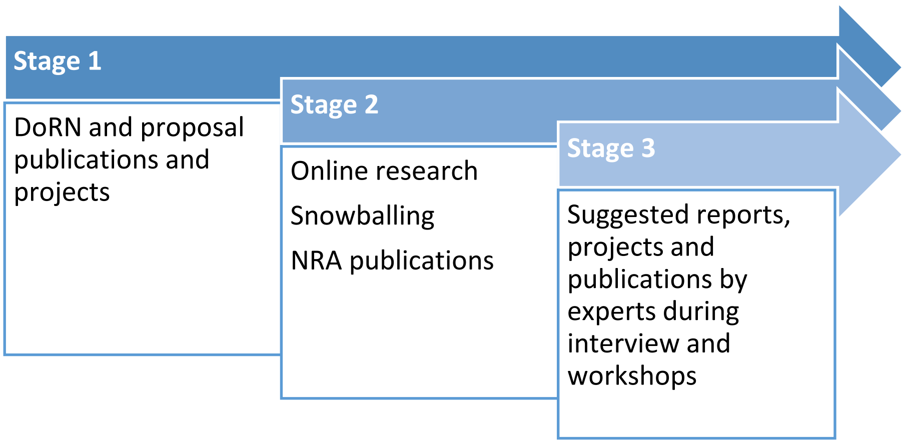


Figure 11: Literature review process

In the first stage of the literature review, relevant publications and projects listed in the DoRN and proposal were carefully analysed to collect information regarding different measures and their effectiveness. Based on the findings of this first stage, a basic structure of the online database was defined to keep a record of the findings from the literature review. This stage of the literature review formed a firm foundation for the second stage of the literature review.

In the second stage, an online search was carried out to find relevant projects and publications regarding different traffic measures and their effectiveness. First, websites of various NRAs were scanned to search for relevant studies and implemented traffic measures. Second, from the identified relevant publications, snowballing was carried out to find more relevant research in that field and to complete the missing information in the database.

In the third stage of the literature review, various projects, reports, documents, and studies suggested by stakeholders via interviews, workshops, and questionnaires were studied, to complete the database. A second iteration of snowballing was carried out on newly identified sources to gain an overview of existing and planned traffic measures.

In order to ensure that the information collected is relevant, the research was focussed on finding resources published after year 2010.

Questionnaires

WP2000 provided useful insights to understand the highway capacity and road safety system. These insights were used to formulate several research questions. These research questions helped to decide what questions were required to capture the right and complete information from the stakeholders. Besides the research questions, the first stage of the literature research also formed a basis for developing the questionnaire.

Since the required information was extensive, it would have been difficult to get a high response from stakeholders on a long questionnaire. It was thus decided to follow a two-step approach to solve this problem.

Step 1: Short Questionnaire

This questionnaire was kept very short such that the respondent would be able to fill the questionnaire in less than 5 minutes.

First, a short general questionnaire was formed which constituted of basic questions to engage with the stakeholders. The main purpose of the short questionnaire was to inform the stakeholders about the project and to get a first overview of the measure types that have been implemented in their respective countries to increase highway capacity.

This questionnaire also captured how the stakeholders would like to be involved in the project, i.e. via interviews or through a more elaborate questionnaire. The questionnaire also captured if the respondent were available to participate in a workshop. The format of the short questionnaire is attached in Appendix D.

Step 2: Long Questionnaire

The long questionnaire was meant to capture practical information about the different measures implemented in European countries to increase highway capacity along with details of the effectiveness of these measures in increasing highway capacity and road safety. The long questionnaire was designed to be sent to those stakeholders who were not available to participate in the interviews. Thus, the content was the same as the content of the interviews. The long questionnaire also forms a basis for conducting interviews and workshops. The data collected from the long questionnaire was used in completing the information to be presented in the online database. The format of the long questionnaire is attached in Appendix E.

Interviews

To obtain a broader and more practical perspective of different traffic measures implemented across various countries; one-to-one interviews were conducted with stakeholders who showed interest via the short questionnaire and provided their availability. Interviews helped in obtaining new insights and providing more information for completing the database of traffic measures. During the interview, the interviewees were asked about which traffic measures have been implemented in their country that aim towards improving the capacity of highways and other relevant environmental, financial, and societal factors. The interviewees were asked about various details regarding the measures, such as:

- Implementation details of the measure

- Responsible Road authority/organisation
- Duration of implementation
- Challenged faced during implementation
- Effect of the measure on Highway capacity
- Effect of the measure on Road safety
- Method of capacity and safety assessment
- Effect of the measure on the environment
- Implementation costs of the measure
- Any report showcasing detailed information

The information obtained from the interviews was carefully studied and was used in completing the online database.

Workshops

Stakeholders who showed their interest and provided their availability were invited to attend workshops intended to collect different viewpoints on decision-making aspects to safely increase capacity on highways. The workshop session involved multiple sections.

At the start of the workshop, the participants were asked to list various measures implemented in their country to increase highway capacity. Among the entered measures, ten (10) measures were selected, and participants were asked to rate these measures based on their effectiveness in increasing highway capacity and road safety. The outcome of the workshop is provided in section 4.3.

A PESTEL based approach was adopted to conduct the next section of the workshop. PESTEL analysis is a strategic framework to assess various Political, Economic, Social, Technological, Environmental, and Legal factors affecting the implementation of a measure. Among the ten (10) measures rated for highway capacity and road safety, three measures were selected and analysed utilising the PESTEL-method. The participants were asked to participate in a brainstorming session to enlist various PESTEL aspects in the implementation of the corresponding selected measures.

The next section of the workshop aimed toward *Road safety measures* and initiated discussion regarding the safety aspects critical for highways. This section aims towards identifying attributes relevant for the comparison of safety measures between countries and is meant to fulfil the requirements of WP4000.

The last section of the workshop intended to collect relevant information regarding the applications of the Good Practice Guide to fulfil the requirements of WP5000.

The workshops were conducted keeping in mind missing aspects from the database and intended to complete the database based on their findings. The discussions from the workshop resulted in obtaining unreported facts regarding different traffic measures.

Appendix D Short questionnaire

Welcome to this short questionnaire about capacity on highways!

National Road Authorities (NRAs) are facing many challenges, from balancing the urgency of reducing the environmental impact of the road network to meeting traffic capacity demands and forecasts; whilst improving road safety and delivering better real-time driver information.

Commissioned by CEDR, the SAFEPATH (SAFE caPAciTy Highways) consortium is currently conducting a study to identify effective measures to increase highway road capacity without compromising road safety. We are conducting this survey to gain an overview and greater understanding of existing measures to increase capacity on highways. The results of this survey and the next steps will be presented in the form of a Good Practice Guide that can be used by all NRAs.

We would like to hear from you about which measures have been implemented in your country. Based on the responses to this survey, we will approach respondents at various stages. This survey allows you to select if and at which stage you would like to be involved and how we can approach you.

By filling in this survey and participating in one or more of the next steps, you can gain practical and technical experience from other countries. You can learn about and contribute to best practices for increasing capacity on highways without compromising traffic safety. In other words, you will contribute to shaping the future of efficient traffic management and have a chance to validate those best practices with a wider European audience. In addition, by responding to this survey, you will get early access to the project results.

This short questionnaire will not take more than 5 minutes to fill. Please feel free to share this survey with any colleagues and connections you think can also contribute and benefit from being part of the engagement and feedback process.

All data is processed anonymously. It is used and saved only for the purpose and duration of this study.

Thank you in advance for your contribution!

Best regards,
On behalf of the SAFEPATH team

At first, we would like to hear about the priorities regarding capacity on the highways in your country.

1. What are the main priorities regarding the highway network and its functionality in your country? *(More than one answer is possible)*
    a. Traffic safety
    b. Road user experience
    c. Maintenance and improvement of road infrastructure
    d. Efficient traffic flow
    e. Low environmental impact (e.g. low emissions)
    f. Other (go to 1a)

    1a. Please explain (open question)

2. Are you aware of any measures that have been taken in your country to increase capacity on highways in the last five years?
    - Yes (go to question 3)
    - No (go to the end of the survey)

3. What are the top three measures that have been implemented in your country to increase highway capacity? Please select the three most favoured measures from the list:
    a. Expansion of current infrastructure (e.g. extra lanes)
    b. Better use of current infrastructure (e.g. use of hard shoulder, peak lanes, ramp metering)
    c. Improvement of current infrastructure (e.g. improved design quality)
    d. Traffic Management (e.g. automatic incident detection, variable speed limits, Variable Message Signs, carpool lanes)
    e. Incident Management (e.g. improve collaboration between emergency services and Road Authority)
    f. Improvement of road user behaviour (e.g. driver training, campaigns)
    g. Intelligent Transportation Systems (ITS) (e.g. advice on maximum speed based on the traffic situation)
    h. Other (go to 3a)

    3a. Please explain (open question)

4. To which extent have the highway capacity measures affected traffic safety on the highways? *Please choose from 0 to 10 (0=highway capacity measures had a very negative effect on traffic safety, 10= highway capacity measures had a very positive effect on traffic safety)*
    - 0 – Very negative effect on traffic safety
    - 1
    - 2
    - 3
    - 4
    - 5- Neutral (no effect on traffic safety)
    - 6
    - 7

- 8
- 9
- 10- Very Positive effect on traffic safety
- I do not know

5. Do you have access to any studies about the implemented measures and their effectiveness? Please upload your document(s) below. (optional)
   <upload>

Finally, we would like to hear if you are interested to participate in the next steps of the SAFEPATH project.

6. As a follow-up to this survey, we plan to organise expert interviews and virtual workshops to get more insight into the measures and challenges of different countries. Please indicate if and how would you like to participate in the SAFEPATH project.
   a. Yes, I would like to participate in the interview round. (go to question 7)
   b. Yes, I would like to participate in a virtual workshop with other NRAs and stakeholders. (go to question 7)
   c. No, I am not interested in participating further in this study. (go to question 8)

7. Please provide the following details so that we can contact you to participate in the way you have indicated.
   a. Name:
   b. E-mail ID:
   c. Organisation Name:
   d. Country:
   e. Your role in the organisation:

8. Do you have any other remarks or suggestions? (Open question)

Appendix E Long questionnaire

Welcome to this questionnaire on traffic capacity on highways!

We are very happy that you have shown interest in the SAFEPATH project and would like to further participate in it. Your participation is significant since your input contributes to the work of the SAFEPATH consortium to identify efficient and effective solutions to increase capacity on highways.

Through this survey we want to know what measures and actions have been implemented and are being considered in your country to increase capacity on highways. This information will be used to develop a Good Practice Guide, which will include best practices for increasing highway capacity.

We are thankful to you for sharing your knowledge and contributing towards shaping the future of efficient traffic management. Since you are contributing to the development of a Good Practice Guide which will be made available to a wide European audience, your organisation will get attention at EU level. The National Road Authorities (NRAs) will have the opportunity to learn from your organisation and from NRAs of other countries through this Good Practice Guide. The guide will inform on the different measures that can be taken, how effective they are, and what challenges they potentially bring.

Thank you in advance for your contribution!

Best regards,

On behalf of the SAFEPATH consortium

Your organisation's role in increasing capacity on highways

How does your organisation contribute directly or indirectly to increasing traffic capacity on highways?

- By making and/or implementing policies/regulations
- We have an operational role (e.g. traffic management and road maintenance)
- By training drivers to behave responsibly and safely
- By providing drivers with the best equipment for live traffic information and/or driver assistance systems
- By providing technical (e.g. design), operational (system implementation) and policy advice to the local/national road authorities
- By carrying out research on and assessment of current/future measures to increase highway capacity
- By providing analytic services (e.g. collection and analysis of data)
- Our organisation does not influence the highway capacity neither directly nor indirectly
- Other, please specify below what contribution your organisation provides: <free text>

Recent measures to improve capacity on highways

In this section, we want to know the key interventions/measures that have been taken by your organisation to increase the highway capacity.

Note: Feel free also to mention the ways in which your organisation had an indirect contribution. For example, incidents are one of the major causes of congestions and thus, measures to improve incident and impact management can help increase highway capacity.

Examples of measures (direct)

- Policies & regulations
- Improve Traffic management
- Road infrastructure design

Examples of measures (indirect)

- Driver training and education
- Rule enforcement techniques
- Improve Incident and Impact Management

Measure # 1

Please answer the next set of questions about one measure your organisation implemented that contributed to increasing the capacity on the highways.

1.1 Name (type) of the first measure: (please specify) <free text>

1.2 Duration of implementation: <from year> to <end year/current>

1.3 Responsible Road Authority: (please specify) <free text>

1.4 Please describe the measure shortly: (please specify) <free text>

1.5 Was there any evaluation of the measure's impact on highway capacity?

- No (go to 1.8)
- Yes (go to 1.6)

1.6 Please describe shortly how effective the measure was in increasing highway capacity.: <text>

1.7 How was the impact on road capacity been evaluated? <text>

1.8 Was there any evaluation of the measure's impact on traffic safety?

- No (go to 1.11)
- Yes (go to 1.9)

1.9 Please summarise how this measure impacted traffic safety: <free text>

1.10 Please describe how the safety was measured: <free text>

1.11 What were the challenges that your organisation faced in the development and or/ implementation of the measure (if any)? <text>

1.12 Was the evolution of connected or automated vehicle considered while designing and implementing the measure?

- No
- Yes

1.13 Please upload any document that you think can help us understand the measure and its impact in a more detailed manner (optional).

1.14 Are there any other measures with which your organisation has contributed to increasing capacity on highways?

- Yes (go to second measure)
- No (go to 4)

Measure # 2

Please answer the next set of questions about one measure your organisation implemented that contributed to increasing the capacity on the highways.

2.1 Name (type) of the first measure: (please specify) <free text>

2.2 Duration of implementation: <from year> to <end year/current>

2.3 Responsible Road Authority: (please specify) <free text>

2.4 Please describe the measure shortly: (please specify) <free text>

2.5 Was there any evaluation of the measure's impact on highway capacity?
- No (go to 2.8)
- Yes (go to 2.6)

2.6 Please describe shortly how effective the measure was in increasing highway capacity.: <text>

2.7 How was the impact on road capacity been evaluated? <text>

2.8 Was there any evaluation of the measure's impact on traffic safety?
- No (go to 2.11)
- Yes (go to 2.9)

2.9 Please summarise how this measure impacted traffic safety: <free text>

2.10 Please describe how the safety was measured: <free text>

2.11 What were the challenges that your organisation faced in the development and or/ implementation of the measure (if any)? <text>

2.12 Was the evolution of connected or automated vehicle considered while designing and implementing the measure?
- No
- Yes

2.13 Please upload any document that you think can help us understand the measure and its impact in a more detailed manner (optional).

2.14 Are there any other measures with which your organisation has contributed to increasing capacity on highways?
- Yes (go to third measure)
- No (go to 4)

Measure # 3

Please answer the next set of questions about one measure your organisation implemented that contributed to increasing the capacity on the highways.

3.1 Name (type) of the first measure: (please specify) <free text>

3.2 Duration of implementation: <from year> to <end year/current>

3.3 Responsible Road Authority: (please specify) <free text>

3.4 Please describe the measure shortly: (please specify) <free text>

3.5 Was there any evaluation of the measure's impact on highway capacity?
- No (go to 3.8)
- Yes (go to 3.6)

3.6 Please describe shortly how effective the measure was in increasing highway capacity.: <text>

3.7 How was the impact on road capacity been evaluated? <text>

3.8 Was there any evaluation of the measure's impact on traffic safety?
- No (go to 3.11)
- Yes (go to 3.9)

3.9 Please summarise how this measure impacted traffic safety: <free text>

3.10 Please describe how the safety was measured: <free text>

3.11 What were the challenges that your organisation faced in the development and or/ implementation of the measure (if any)? <text>

3.12 Was the evolution of connected or automated vehicle considered while designing and implementing the measure?
- No
- Yes

3.13 Please upload any document that you think can help us understand the measure and its impact in a more detailed manner (optional).

Support Needed and Upcoming Measures

4. What support is needed, in your opinion, to overcome the current challenges in implementing measures to increase highway capacity? Please tick all the options that apply. (more than one answer possible)

- More expertise on national level
- More (exchange of) knowledge with other countries
- A comprehensive list of measures with information on effectiveness and implementation
- Funding
- Support from European organisations, like CEDR
- Other, please specify <free text>

5. What other measures are being considered/ or planned to implement in your country in the future to increase capacity on highways? (free text)

6.1 Are you aware of good practices or measures that have been implemented by the other countries?

- Yes
- No

6.2 Would you find a Good Practice Guide (containing the different measures implemented across the countries) useful?

- No (skip to next section)
- Yes (go to 6.3)

6.3 What kind of information would your organisation find most useful in such a Good Practice Guide?

- Cost of the implementation
- Challenges faced in implementation
- Impact of the measure on highway capacity
- Impact of the measure on road safety
- Impact of the measure on the environment
- User acceptance
- Case studies or real-world examples
- How and where to share knowledge

Smart Solutions to increase highway capacity

The digitalisation of infrastructure is making space for new innovative smart solutions that can be implemented to improve highway capacity. Such a solution is Cooperative Intelligent Transport Systems (C-ITS). C-ITS describe technologies and standards to connect vehicles with other vehicles (V2V) and infrastructure (V2X).

In this section, we would like to know if your country is already implementing or considering smart solutions and how do you see the ongoing development in this field.

7. Have smart solutions/measures been implemented in your country to increase capacity on highways?

- No, we are not aware of smart solutions that can increase highway capacity
- No, smart solutions/measures are not yet implemented but will be in the future
- Yes, some smart solutions/measures have been implemented and I provided relevant information in the previous section
- Yes, some smart solutions/measures have been implemented and I would like to give more information about them <go to 8>

Smart Solutions/Measures

Please answer the next set of questions about the smart solution(s)/measure(s) implemented in your country to increase the capacity on the highways.

8.1 Name (type) of the smart solution/ measure: (please specify) <free text>

8.2 Duration of implementation: <from year> to <end year/current>

8.3 Responsible Road Authority: (please specify) <free text>

8.4 Please describe the measure shortly: (please specify) <free text>

8.5 Was there any evaluation of the measure's impact on highway capacity?

- No (go to 8.8)
- Yes (go to 8.6)

8.6 Please describe shortly how effective the measure was in increasing highway capacity.: <text>

8.7 How was the impact on road capacity been evaluated? <text>

8.8 Was there any evaluation of the measure's impact on traffic safety?

- No (go to 8.11)
- Yes (go to 8.9)

8.9 Please summarise how this measure impacted traffic safety: <free text>

8.10 Please describe how the safety was measured: <free text>

8.11 What were the challenges that your organisation faced in the development and or/ implementation of the measure (if any)? <text>

8.12 Was the evolution of connected or automated vehicle considered while designing and implementing the measure?

- No
- Yes

8.13 Please upload any document that you think can help us understand the measure and its impact in a more detailed manner (optional).

8.14 Are there any other smart solutions/measures that have been implemented in your country?

- Yes (repeat set of questions)
- No (go to 9)

9. What other smart solutions/measures are being considered/ or planned to implement in your country in the future to increase capacity on highways? (free text)

11. Do you have anything else to add? Feel free to write here any other thoughts and suggestions. (open question)

Appendix F Contributing project team members and experts

The various project team members and experts who have been involved in the process are mentioned in Table below.

Name	Organisation	Role
Anastasia Tsapi	Royal HaskoningDHV	Project team
Evert Klem	Royal HaskoningDHV	Expert
Jan van Liere	Royal HaskoningDHV	Expert
Marson Jesus	Royal HaskoningDHV	Project team
Peter Vlugt	Royal HaskoningDHV	Expert
Sacco Barendrecht	Royal HaskoningDHV	Project team
Shubham Bhusari	Royal HaskoningDHV	Project team
Shubham Soni	Royal HaskoningDHV	Project team
Ravi Chaudhary	Royal HaskoningDHV	Project team
Dave Cowell	AECOM	Project team
Edward Bingham	AECOM	Expert
Keith Gilmour	AECOM	Expert
Lee Street	AECOM	Expert
Scott Stephenson	AECOM	Project team
Stephen Heathcote	AECOM	Expert
Andy Graham	White Willow Consulting Ltd	Project team
Priyanka Karkhanis	Eindhoven University of Technology	Project team
Yanja Dajsuren	Eindhoven University of Technology	Project team
Gökhan Kahraman	Eindhoven University of Technology	Project team

Appendix G
Outcome of PESTEL analysis carried out in the Workshop 1

Aspects measure ->	Ramp metering	Incident detection	Hard shoulder running
Political	UK: the introduction of any traffic control, including traffic lights, can be politically sensitive BE: Who gets priority? UK: Can cause issues if the traffic signals at the top of the ramp queue back as different road authorities can be responsible for the mainline motorway and the roads leading to it UK: being held up by a queue is annoying, being held up by a politician or engineer installing a traffic light is infuriating, because it is taking away a freedom.	UK: There is huge political pressure to ensure stopped-vehicle detection is deployed on all stretches of All-Lane Running motorway. BE: Mandatory in tunnel with a certain length	UK: Very important not to underestimate quite what a big change going to all-lane running is for a driving population who have been trained that a motorway will always have a hard shoulder, and so need help to understand what to do in the event of a breakdown. BE: Dynamic hard shoulder is the best for safety. BE: Underutilisation of open hard shoulder BE: Highway is more efficient, can be understood by politicians
Economic	BE: high cost of the equipments UK: Cheaper than many other control measures, but not offering a great cost:benefit ratio	UK: There's no point in having incident detection unless it goes hand-in-hand with the resources to respond.	BE: High cost but visible effect
Social	BE: Compliance is a issue NL: Need a camera otherwise people will not adhere to the rules BE: More traffic on local roads avoiding ramp metering	BE: false alarm rates (workload at traffic centre)	BE: Understandable...even in foreign countries UK: Any move to open the hard shoulder requires a substantial communications program for drivers. UK: Compliance with the closure of a blocked lane (by use of a Red X signal in England) must be backed up by strict enforcement by the police.

			BE: More dangerous on exists and entrances
Technological	BE: Hard to maintain	UK: Technology needs to be fit for purpose, there were comments that the technology for stopped vehicle detection and radar on the motorways was not effective UK: Radar-based stopped-vehicle detection appears to come from a very small supply chain, which has cost and pace of deployment issues SE: We use several of detection systems, mostly radars and cameras. Budget wise it is a bit expensive and the radar system is not as stable alarm wise as expected	UK: Communication is really important, drivers need to know what they should be doing and what to do if they have an incident BE: No standardization at the moment BE: Can only be done with Electrical equipment
Environmental	BE: Pollution at the entrance, often in a city UK: Our access ramps aren't long and queues soon back up onto local roads.	NL: Faster incident detection - > Faster clearing of congestion - > Lower emissions UK: SVD and any incident detection should improve road safety	BE: Usually good to decrease pollution because speed limit is decreased
Legal	-	UK: We are encouraging drivers to use the e-call system to call in alerts if they spot serious incidents, particularly stopped vehicles on stretches of motorway all-lane running	BE: Bypassing your own regulations BE: the same for all, trucks, cars, motorbike, etc.

Appendix H Outcome of PESTEL analysis carried out in the Workshop 2

Aspects measure ->	High occupancy vehicle lanes	Speed enforcement cameras	Intelligent speed adaptation (ISA)
Political	Can cause driver frustration and impact on connected routes. Local residents who do not use the route but can be affected may lobby and complain to local elected officials. Can reduce access to certain locations including residential areas creating more traffic or longer routes	Hypothecation = who gets the money from fine? Perception that Police/Local Authorities are making money from cameras	Has received negative coverage in some UK media and from some politicians.
Economic	Does this optimise the capacity across all lanes?	Resourcing for enforcement	Is this only available to people with new vehicles? Encourages retaining older vehicles for those who like to drive fast
Social	Pandemic led people to prefer more single-occupancy Potential to drive unsafe behaviours (additional street signage = distraction) and fast changes of direction if drivers find themselves in HO lane by mistake Can this be implemented in locations where large employers have similar policies, such as shared vehicle parking priorities? Will people follow the concept, will they see the benefit well enough to support the scheme?	Accordion effect on traffic flow from speeding up and slowing down. Less of a problem on average speed camera routes. Differences in driving style between European countries may determine compliance or acceptability Unforeseen behaviour changes such as camera surfing or making up for time off-network. Perception that motorists from other nations will not be subject to enforcement. Over instrumentation of roads leads to frustration and non-compliance	Only new cars, so will this extend life of older cars for drivers who don't want ISA (currently average age of cars in UK is 8 years) Younger drivers accept it. Effect on older/less capable drivers – is it usable for all types of drivers? Point of sale training required?

		There is a limit to the amount of driver behaviour tech that can be deployed on a road Motorists expect there to be a moral justification for the location of a speed camera e.g. crash hotspot or sensitive location e.g., near a school	
Technological	This measure is difficult to enforce (how to check how many people are in the car) Will commercial players find a way to exploit this measure?	How long until it is superseded by in-vehicle tech (mandatory ISA)? Average age of cars in Europe >10 years, so ISA will take a long time to impact (if mandatory) Mature technology	How will the data be used in a claims process? Road sign positioning/maintenance should take account of ISA cameras Field of View Accuracy/reliability of the system in all conditions (e.g. bad weather, poor GPS position) Technology is already available in premium vehicles, and will be standard as part of General safety Regulations. (note: GSR2 includes other useful ADAS features.)
Environmental	Does this cause additional congestion at merge points.	Better understanding of impact on environment by speed (e.g. emissions at 50mph are half than at 10 and 70mph)	Does this result in improved traffic smoothing, and therefore better emissions?
Legal	Too many legal exceptions to be enforceable? E.g., single driver used lane for valid reasons (e.g. for safety reasons, on way to hospital emergency) Does it disadvantage road users who have no choice but to travel by personal vehicle (e.g. disabled drivers)	How to determine how many tickets to issue? Undesirable for police if lots of drivers break the limit?	Liability if accident relating to ISA What happens if I get a speeding ticket as google got the speed limit wrong

Appendix I List of participating organisations during phase 1

Organisation name	Country	Engagement level
Trafikverket	Sweden	Workshop
Polis	Belgium	Workshop
Road Safety Foundation	UK	Interview, Workshop
AWV (Flemish Road Authority) Traffic Centre	Belgium	Interview, Workshop
SPW	Belgium	Interview, Workshop
ANWB	Netherlands	Interview
Rijkswaterstaat	Netherlands	Interview
VBM (Association Recovery)	Netherlands	Interview
German Federal Highway Research Institute (BASt)	Germany	Workshop, Questionnaire
AECOM	UK	Interview
RAC Foundation	UK	Interview, Workshop
TU Delft	Netherlands	Interview
SysElek	UK	Interview
INRIX	UK	Interview
GEWI	UK	Interview
Centras Associates Ltd.	UK	Interview
Highways England	UK	Interview
Federal Roads Office FEDRO	Switzerland	Questionnaire

Appendix J List of participating organisations during phase 2

Organisation name	Country	Engagement level
ASFiNAG	Austria	Interview
Atkins	UK	Interview
National Highways	UK	Workshop
Bergnet	Netherlands	Workshop
Syselek	UK	Workshop
Centras	UK	Workshop
Joanneum research	Austria	Workshop
AECOM	UK	Workshop
Rijkswaterstaat	Netherlands	Workshop
AXA insurance	UK	Workshop
ENIDE	Spain	Workshop

Appendix K Overview of impact in capacity and safety for measures in the Database

↑ - Increase
↓ - Decrease
↔ - No effect
~ - Indirect effects

#	Measure	Country	Impact on capacity	Impact on safety
1	2+1 Lanes	Ireland	~	↑
2	2+1 Lanes	Sweden	↑	↑
3	Accident prediction and analysis	Italy, United Kingdom, Germany	~	
4	Active Traffic Management (ATM)	United Kingdom	↑	
5	Adaptive Cruise Control (ACC)	France, Germany, Italy, Sweden	↑	↑
6	Adaptive Cruise Control	Hungary	~	↓
7	Adaptive Cruise Control	Netherlands	↑	
8	Adaptive Cruise Control	Sweden	~	
9	Adaptive Traffic Management	Austria	~	
10	Advanced Cruise Control (ACC)	Netherlands	↑	↑
11	All Lane Running	United Kingdom	↑	
12	All lanes running	United Kingdom	↑	
13	Appropriate Speed saves All People	Belgium, Germany, Sweden, United Kingdom	~	
14	Automated Driving	European Union	~	↑
15	Autonomous driving	Sweden	~	↑
16	Average Speed Cameras	United Kingdom	~	↑
17	Avoiding rush hour	Netherlands	↑	
18	Carpool lane	Belgium	~	
19	Chevron signs	Netherlands	↑	↑
20	Cloud data management	European Union		
21	Combining Ramp Metering and Hard Shoulder	France	↑	
22	Congestion Pricing Cordon Scheme	Sweden	↑	
23	Congestion Pricing Cordon Scheme	United Kingdom	↑	

24	Connected and Automated Vehicles	Belgium	↓	
25	Data for Traffic Management	Germany, United Kingdom, Austria	~	
26	Driver motivation	United Kingdom, Netherlands, Finland, Belgium		↑
27	Dynamic Hard shoulder running	United Kingdom	↑	↑
28	Dynamic hard shoulder runnning	United Kingdom	↑	↑
29	Dynamic rerouting	Germany	↑	
30	Dynamic Speed Display Signs	Germany	~	
31	Dynamic speed limits (DSLs)	Belgium	~	↑
32	Dynamic Traffic Signs	Netherlands	~	
33	Dynamic travel time estimation and broadcasting	Austria	~	
34	Eco-driving	Austria, United Kingdom, Netherlands, Finland, Greece, Poland, Czech Republic, Lithuania, Croatia, Italy	~	↑
35	Electronic stability control (ESC)	European Union	~	↑
36	Emergency Call (eCall)	European Union	~	↑
37	Emergency cut through barrier	Netherlands	~	↑
38	Emergency services warning	Netherlands	~	
39	Enhancing Motorway Operation Services (eMOS) - Intelligent transportation systems (ITS) technology	Ireland	~	
40	Enhancing Motorway Operation Services (eMOS) - Network Intelligence and Management System (NIMS)	Ireland	~	
41	Extension of motorway exits and entrances	Switzerland	↑	↔
42	Floating car data	Germany		
43	Fog warning systems	Netherlands	~	↑
44	Framework for Incident and Impact Management	European Union	↑	↑
45	Green Light Optimised Speed Advisory (GLOSA)	Germany	↑	↑
46	Green Light Optimised Speed Advisory (GLOSA)	United Kingdom	↑	↑
47	Guidelines on Roadworks safety	Belgium, Germany, Ireland, Norway,		

		Slovenia, United Kingdom		
48	Hard shoulder running	Austria	↑	
49	Hard shoulder running	Switzerland	↑	↑
50	Hard Shoulder Running	Belgium	↑	
51		European Union		
52	Hard Shoulder Running	Germany	↑	↔
53	Hard shoulder running	Germany	↑	↑
54	Hard Shoulder Running	Germany	↑	↑
55	Hard Shoulder Running	Italy	↑	↔
56	Hard shoulder running	Switzerland	↑	↑
57	Hard Shoulder Running	United Kingdom	↑	↑
58	Hard Shoulder Running	United Kingdom	↑	
59	Heavy goods vehicle (HGV) platooning	United Kingdom	↔	↔
60	High occupancy vehicles lanes	Austria	~	
61	High occupancy vehicles lanes	European Union	↓	
62	I2V communication	Austria	~	
63	Incident detection	European Union	~	
64	Incident detection for autonomous vehicles	Sweden	~	↑
65	Incident management	Austria	↑	
66	Incident management	Netherlands	~	
67	Incident Reporter	United Kingdom	↑	↑
68	Increase speed limit	Netherlands	~	↓
69	Information for travellers	Netherlands	~	
70	INRIX AV Road Rules	United Kingdom		↑
71	Institutions co-operation model	Finland	↑	↑
72	Integrated network management (INM)	European Union	~	
73	Intelligent Speed Adaptation (ISA)	European Union	~	↑
74	Intelligent Speed Adaptation (ISA)	European Union	~	
75	Intelligent Speed Adaptation (ISA)	Sweden, Netherlands, Finland, Denmark, Belgium, France, United Kingdom	↑	↑
76	Interchange Lane Control	Netherlands	↑	
77	Interchangeable lane	Netherlands	~	
78	ITS (ArcAtlantique)	United Kingdom, Ireland, French		

		Republic, Spain, Portugal, Beligum, Netherlands		
79	ITS (NEXT-ITS 2)	Sweden, Denmark, Finland, Germany, Norway		
80	ITS (Nordic Way 2)	Denmark, Finland, Norway, Sweden		↑
81	ITS Control	Czech Republic	↑	↑
82	iVRI	Netherlands	↑	↑
83	Lane Departure Warning (LDW)	Sweden,Germany,Italy	↔	↑
84	Lane line/lane division adjustments	Belgium	↑	
85	Lane Rental	United Kingdom	↑	
86	Level 3 (L3) autonomous Vehicles		↓	
87	Line Control	Germany	↑	↑
88	Line Control Systems	Germany	↑	↑
89	Mid- and long term planning of availability and traffic densities	Austria	~	
90	Model Predictive Control (MPC)	Netherlands	↑	
91	National Traffic Management Plans (TMP)	Switzerland	↑	↑
92	Network control	Germany	↑	↑
93	On-Ramp and Off-Ramp metering	Netherlands	↑	
94	Optasense road monitoring system	Netherlands	~	
95	Overtaking ban for freight traffic on rush hour lane	Netherlands	↔	↔
96	Overtaking ban on freight traffic	Netherlands	↑	↑
97	Overtaking ban on freight traffic	Netherlands	↔	↔
98	Overtaking trucks ban	Hungary	↑	↑
99	Overtaking trucks ban	United Kingdom, Netherlands, Germany, France, Denmark, Belgium, Austria, Italy		↔
100	Park&Drive for carpooling	Austria		
101	Pro-Active Incident Management	Netherlands, United Kingdom, Sweden	~	
102	Queue tail warnings	Netherlands	↑	
103	Ramp metering	Netherlands	↑	
104		European Union	↑	

105	Ramp metering	United Kingdom	↑	↑
106	Recovery-Safe-Recovery	Netherlands	↑	↑
107	Red crosses	Netherlands	~	↑
108	Regiodesk: Improve accessibility with traffic management scenarios	Netherlands	↑	↑
109	Regulations for Incident and Impact Management	Netherlands	↑	↑
110	Reversible lane	Netherlands	~	↓
111	Reversible lane system	Portugal	~	
112	Road Reconfiguration	Belgium	↑	
113	Road use tax	United Kingdom	↑	
114	Road work: Speed management	European Union	~	↑
115	Road zippers: Movable road barriers	Germany	↑	↑
116	Road/traffic monitoring	Italy	↑	↑
117	Roadworks traffic management	Austria	↑	
118	Roadworks warning—closure of a lane (C-ITS)	Italy	↑	
119	Rush hour lane	Belgium	↑	↑
120	Rush hour lane and additional lane running	Netherlands	↑	↑
121	Smart and connected traffic lights	Netherlands	~	
122	Smart Intersection	Netherlands	↔	
123	Smart Roads Geometric Design Criteria	Italy	↑	
124	Speed Cameras	European Union	↓	↓
125	Speed Cameras	United Kingdom, Sweden, France, Australia, Canada	~	↑
126	Speed limit enforcement	Netherlands	↔	
127	Speeding Intervention Matrix		~	
128	Standby Locations	Netherlands	↑	↑
129	Tapers	Netherlands		
130	Target group lane	Netherlands	~	↔
131	TCC and data exchange (DATEXII) upgrading	Italy	↑	↑
132	Temporary Hard Shoulder Use and Speed Harmonisation	Germany	↑	↑
133	TIC for Road Incident Management			↑
134	Traffic and route information	Denmark	↑	↑

135	Traffic information	Belgium, Netherlands, Denmark, Germany	↔	
136	Traffic information	Netherlands	~	
137	Traffic information and safety campaign on variable message signs (VMS)	Switzerland	↑	↑
138	Traffic management control system (VMIS2)	Austria	~	
139	Traffic monitoring and control	Italy	↑	↑
140	Traffic signalling	Netherlands	↑	↑
141	Truck admission system	Austria	↑	
142	Truck platooning	European Union	↑	↑
143	Truck platooning	Netherlands, Belgium, France, Germany, Spain	~	
144	Truck Platooning	Germany	↑	↑
145	Truck platooning	Austria	↑	
146	Uniform speed limits	Austria	↑	↑
147	V2V communication	Denmark, Finland, Norway, Sweden	↑	↑
148	Variable speed limit and danger warning system	Switzerland	↑	↔
149	Variable speed limits	Switzerland	↑	
150	Variable speed limits	United Kingdom	↑	
151	Variable Speed Limits (VSL)	Sweden	↔	
152	Vehicle platooning	European Union	↑	↑
153	Virtual Queue detection		↑	↑
154	VMS (variable message signs)	Belgium	↑	↑

Measures with negative influence on capacity and safety

The following measures were found with negative influence on either capacity or safety or both during the empirical research. The readers are requested to refer to the measure details directly in the online measures database.

#	Measure	Country	Impact on capacity	Impact on safety
122	Speed cameras	European Union	↓	↓
106	Reversible lane	Netherlands	~	↓
85	Level 3 (L3) autonomous Vehicles		↓	
67	Increase speed limit	Netherlands	~	↓
60	High occupancy vehicles lanes	European Union	↓	
24	Connected and Automated Vehicles	Belgium	↓	
8	Adaptive Cruise Control	Hungary	~	↓