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METHOD: Managing European Traffic using Human-Oriented Designs

Human factors reflection on existing traffic management measures

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Transnational Road Research Programme
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Executive summary

Traffic management (re)directs traffic flows over the road network with the aim to optimise movements of people and goods in terms of reliability, safety and environmental sustainability. Measures of traffic management become increasingly important because road mobility continues to increase while the mobility demand increases faster than the increase in road capacity. This leads to increasing road network density and an aggravating congestion problem. However, if designed and applied without accounting for human strengths and limitations, the traffic management measures will not have optimal results in terms of throughput and traffic safety. Hence, to achieve high compliance rates for traffic management measures, human factors must be addressed.

This study identifies current best practices as well as knowledge gaps in the area of human factors considerations in traffic management. A literature review on road user needs and behaviours in relation to traffic management points out five key human factors which influence traffic behaviour and related choices:

1. Perception
2. Comprehensibility
3. Skills
4. Willingness
5. Behavioural adaptation

Four of these aspects are conditional for achieving the desired road user behaviour: *perception, comprehensibility, skills* and *willingness*. The fifth human factor aspect concerns *behavioural adaptation*: the collection of behaviours that occur following changes in the road traffic system which were not intended and negatively impact road safety.

The questionnaire survey amongst 11 traffic management and human factors experts across Belgium-Flanders, Denmark, Finland, the Netherlands, Norway and the United Kingdom gains insight into the deployment and effectiveness of current traffic management measures in practice, current use of human factors thinking as standard practice when designing traffic management and potential cultural differences in this respect

The inventory shows that many practices and experiences of traffic management measures are applied in these 6 countries. Dynamic speed management measures such as dynamic speed limits and variable message signs are most often implemented. Most types of traffic management measures are found in the Netherlands and the fewest in Finland. In the Netherlands traffic management measures are also most frequently applied.

Traffic management measures are assessed to be fairly effective. However, some relevant differences in effectiveness parameters (e.g. improving traffic flow, reducing accidents and cost effectiveness) between clusters of traffic management measures and between countries exist. Local traffic flow management measures are assessed as the most effective cluster of traffic management measures closely followed by dynamic speed management. Further, some between-country differences in the effectiveness assessment were found with Finland assessing their traffic management as most effective and the Netherlands as less effective.

Country experts indicate that the five key human factors are used as standard practice when designing traffic management in Belgium, Denmark and Finland. The Netherlands and the United Kingdom show differences between the use of these human factor aspects as standard practice. Across the countries in this study traffic management operators most

frequently use perception and comprehensibility as standard practice when measures of traffic management are designed.

Although most countries indicated (to a different degree) use of human factor aspects as standard practice when designing traffic management measures, the Netherlands is the only country that actually provides documentation on the specific framework used. The 10 Golden Rules (Dutch Ministry of Infrastructure and the Environment, 2008) and the Human factor in Traffic Management framework (Harms, 2012) used in the Netherlands are the best practices found across the six European countries. Both documents can be used as relevant input for Work Package 2 of the METHOD project.

The lack of relevant evaluation studies as a source for the effectiveness assessment of traffic management measures currently applied in the 6 countries and the lack of official documentation and frameworks on the use of human factors as standard practice for designing traffic management are shortcomings of this study. The effectiveness assessments can be dependent on the relatively small sample of experts that were interviewed. Carrying out more interviews with different experts is recommended in further research. This will also contribute to collect more relevant human factors documentation used for designing traffic management measures.

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CEDR profile

The Conférence Européenne des Directeurs des Routes/ Conference of European Directors of Roads (CEDR) transnational road research programme promotes co-operation between European national road administrations to contribute to the development of safe, effective, sustainable and efficient practices in road engineering.

1 Introduction

1.1 Background: traffic management and the role of human factors

Traffic management can be defined as the management of traffic flows (people, vehicles and goods) by demand management measures, traffic information, traffic control, and other means to keep the transport system available, uncongested, safe and environmentally sustainable (NRA, 2008)[1]. The primary purpose of traffic management is to optimize the movement of people and goods in such a way that a reliable, safe and sustainable traffic system is possible.

Traffic management becomes increasingly important because road mobility continues to increase while the mobility demand increases faster than the increase in road capacity. This leads to increasing road network density and an aggravating congestion problem (European Commission, 2011; Hoogendoorn et al., 2012). The average mobility per person in the EU, measured in passenger-kilometres per inhabitant increased by 7% between 2000 and 2008, mainly due to higher motorisation levels (European Commission, 2011).

Traffic management consists of a variety of measures applied for multiple purposes. Four main clusters of traffic management measures can be distinguished:

- Dynamic speed management (e.g. dynamic speed limits, variable message signs);
- Local dynamic warning or informative systems (e.g. incident warning, local queue warning, weather warnings);
- Local traffic flow management (e.g. lane closures; peak hour lanes, overtaking prohibition for trucks);
- Network-wide traffic flow management (e.g. dynamic route information, multi-modal information).

Experiences show that theoretically effective traffic management measures are not always effective in practice. For example, in the Netherlands in the past few years more and more road users have been ignoring red crosses on overhead matrix signs that denote closing of a traffic lane (Godthelp et al., 2012). If designed and applied without accounting for human strengths and limitations (both physical and mental), the traffic management measures will not have optimal results in terms of throughput and traffic safety. Hence, to achieve high compliance rates for traffic management measures, human factors must be addressed.

[1] Nordic Road Association, ITS Terminology (ver. 2008.06.04) http://www.nvfnorden.org/lisalib/getfile.aspx?itemid=5582

1.2 METHOD project

Management of European Traffic using Human-Oriented Designs (METHOD) is a project funded by CEDR. The project officially began on July 14th 2014 and will continue to 31st May 2016. Three technical Work Packages of METHOD work together to meet the following objective:
"*Develop a human factor perspective on traffic management measures in order to get more out of the existing measures and future measures taken by the national road administrations in terms of higher throughput and traffic safety."*

The three Work Packages are:
WP1: Human factors reflection on existing traffic management measures
WP2: Human factors framework for traffic management operations
WP3: Human factors in 'in-car' management: simulator studies

1.3 This report

This report is the first deliverable of the METHOD project. The report describes the results of the activities conducted in WP1. WP1 aimed to identify current best practices as well as knowledge gaps in the area of human factors considerations in traffic management.

Three tasks were conducted in this work package:
(1) analysing road user needs and behaviours in relation to traffic management measures;
(2) conducting an inventory of current practices and experiences in a number of European countries;
(3) assessing the effectiveness of traffic management measures from a human factors perspective.

These tasks were accomplished by studying the literature and conducting a questionnaire survey among traffic management experts.

1.4 Outline

Chapter 2 describes the methods of the literature study and the questionnaire survey. Chapter 3 presents the results of the literature survey and Chapter 4 the results of the questionnaire survey. The final chapter (Chapter 5) summarizes the main results, provides the conclusions and formulates some preliminary recommendations awaiting the results of the remaining work in the METHOD project.

2 Method

The current study used two main sources of information: a review of the literature and a questionnaire survey amongst human factors and traffic management experts. The two subsequent sections describe the methods we applied. First we describe how the literature review was carried out and what sorts of literature were processed. Second this chapter presents the participants, the framework and the approach of the questionnaire survey.

2.1 The literature review

The aim of the literature review was to:
(1) identify road user needs and behaviours in relation to traffic management measures
(2) determine assessment parameters useful for effectiveness assessment of traffic management measures

2.1.1 Identifying road user needs and behaviours

To start with, relevant international projects and databases were used, such as International ITS databases: the 2Decide ITS Toolkit[2] and Easyway ITS[3]. In addition, national projects in the four countries of the consortium were utilized. We searched specifically for available human factor frameworks, documents, practices and guidelines for traffic management measures.

Furthermore, a search of relevant literature, published up to November 2014, was conducted using the following scientific databases: Web of Science, the Transportation Research Information Database (TRID), the Transportation Research Records (TRR) and the library catalogue at SWOV Institute for Road Safety Research. Search terms used to find literature into road user needs and behaviours were: “human factors”, “perception”, “comprehensibility”, “skills”, “willingness”, “framework”, “guideline”, “road user behaviour” and “compliance” combined with “traffic management”.

Finally, wider knowledge and theories of engineering psychology and human performance were used, specifically Wickens et al. (2004) and Theeuwes, Van der Horst & Kuiken (2012).

2.1.2 Determining assessment parameters

The same international and national projects and scientific databases which were used to identify road user needs and behaviours (see above) were also used to determine assessment parameters. As a result, a number of potentially relevant assessment parameters were identified, which were then used as search terms for searching through the above mentioned scientific databases. The following search terms were used: “evaluation”, “traffic flow”, “congestion”, “accidents”, “safety” and “environmental benefits” combined with “traffic management” or “ITS”.

[2] http://www.its-toolkit.eu
[3] http://www.easyway-its.eu/

2.2 The questionnaire survey

The second source of information comes from a questionnaire survey providing an inventory of the current practices and experiences in European countries regarding human factors and traffic management. The aim of this survey was to gain insight into the deployment of current traffic management measures in practice in order to understand their perceived effectiveness, current integration of human factors thinking in their application and potential cultural differences in this respect. To achieve this, a targeted and structured questionnaire was developed and presented to experts in a sample of European countries.

2.2.1 Participants

Given the time and budget available in this project, experts from six countries known to have experience with human factors or traffic management measures participated in the survey. The four consortium members (Flanders (Belgium), Finland, the Netherlands and the United Kingdom) were complemented with Denmark and Norway to form a good representation in terms of motorization rate, motorway density and safety record.

Each consortium partner provided a list of experts both at national road authorities and at research institutes. For each country, besides Denmark and Norway, both experts at national road authorities and experts at research institutes were invited to participate in the survey. For Denmark and Norway we only received names of experts from road authorities. Therefore, in these two countries only road authority experts were invited to participate.

In total 21 experts were invited by email to participate in the survey. To ensure a sufficient response and to gain insights from both traffic management operators and from researchers, efforts had been made to interview at least two but preferably three experts in each country: one expert at a national road authority and one expert at a research institute.

The overall response rate was 52%. Eleven national experts were willing to participate in the survey. Unfortunately, in Denmark and in Norway only one expert was found willing to participate. Table 1 shows the participating experts and their affiliations per country. More information about the experts can be found in Annex A.

Table 1: Participating experts by affiliation per country

Country	Expert	Affiliation
Belgium-Flanders	Jean-Pierre Vijverman	Flemish Traffic Centre
Belgium-Flanders	Sven Vlassenroot	Flemish Institute for Mobility
Denmark	Anders Bak Sørensen	Danish Road Directorate
Finland	Merja Penttinen	VTT
Finland	Mika Jaatinen	Finnish Transport Agency
Norway	Terje Solheim	Norwegian Road Authority
The Netherlands	Marieke Martens	University Twente / TNO
The Netherlands	Isabel Wilmink	TNO / TrafficQuest
The Netherlands	Ilse Harms	Rijkswaterstaat (Connecting Mobility)
The United Kingdom	Max Brown	UK Highways Agency
The United Kingdom	Samanta Jamson	Leeds University

2.2.2 Questionnaire

The questionnaire was based on the insights from the literature review (see also the results of the literature review in chapter 3) and consisted of three main parts covering:
(1) the current deployment of traffic management measures;
(2) an effectiveness assessment of these traffic management measures deployed; and
(3) the current use of human-oriented frameworks i.e. human factors knowledge in designing traffic management measures.

In the first two parts of the questionnaire four clusters of traffic management measures were distinguished:

- Dynamic speed management
- Local dynamic warning systems
- Local traffic flow management
- Network-wide traffic flow management

In the first part, the respondents were asked to specify different types of traffic management measures within each cluster that had been implemented in their country. Next they were asked about what road type (rural roads, urban roads or motorways) to which these sorts of traffic management measures were applied. For each sort of traffic management measure the experts were also asked to provide an example of the current practice.

In the second part of the questionnaire, the respondents were asked to assign an effectiveness score for each cluster of traffic management measures. This effectiveness score varied from ‘1’ (‘not effective at all’) to ‘5’ (‘very effective) and had to be assigned to five assessment parameters. These parameters were:

- Improving traffic flow
- Reducing accidents
- Saving costs
- Optimizing road user behaviour
- Improving environmental sustainability.

In addition, this part contained one question about the role of behavioural adaptation: “Do the traffic management measures lead to behaviours which are not intended by the measure (both positive and negative), for example decreased attention, greater risk taking or increased navigational efficiency?”

The third and last part of the questionnaire survey was about the use of human oriented frameworks and human factors knowledge when designing traffic management measures. Those factors had been determined on the basis of the literature review. Respondents were asked whether each of five different human factor aspects were taken into account as a standard practice when designing traffic management measures:

- Perception
- Comprehensibility
- Skills
- Willingness
- Behavioural adaptation

The complete questionnaire can be found in Annex B.

2.2.3 Procedure and data collection

Each consortium member carried out the interviews with experts from their own country, except for the United Kingdom: SWOV (NL) interviewed the experts from the United Kingdom. Potential respondents were invited by email to participate in the telephone interview. The questionnaire survey was attached to this e-mail to allow the expert to prepare for the telephone interview and if needed to ask input from colleagues for some parts of the survey.

A telephone meeting was arranged with seven Experts (see Table 2). The telephone interview took approximately 45 to 60 minutes. The interview was semi-structured: the interviewer completed the questionnaire based on the responses from the interviewee. This approach, rather than asking the experts to complete the questionnaire themselves, offered the opportunity to ask further information if the answers were not clear or too general.

Two experts (see Table 2) were interviewed in person and two experts provided input by just returning the questionnaire.

Table 2: Respondents and type of survey

Country	**Expert**	**Type of survey**
Belgium-Flanders	Jean-Pierre Vijverman	Interview
Belgium-Flanders	Sven Vlassenroot	Interview
Denmark	Anders Bak Sørensen	Questionnaire
Finland	Merja Penttinen	Interview in person
Finland	Mika Jaatinen	Interview in person
Norway	Terje Solheim	Interview
The Netherlands	Marieke Martens	Interview
The Netherlands	Isabel Wilmink	Interview
The Netherlands	Ilse Harms	Interview
The United Kingdom	Max Brown	Interview
The United Kingdom	Samanta Jamson	Questionnaire

3 Results from the literature review

This chapter describes the results from the two types of literature reviews as described before. First (3.1) theories and principles regarding human factors in traffic are described. Subsequently (3.2) we describe current practices and guidelines of human factors in road design as well as traffic management. The third section (3.3) presents the results of the review on the assessment parameters related to measures of traffic management. Finally (3.4) this chapter summarizes what this literature review has gained in the light of working towards a preliminary human oriented framework in traffic management.

3.1 Human factors in traffic: theories and principles

Road user behaviour is often studied with general models on traffic behaviour but one must realise that there is no thing such thing as an average road user. Travelling by road takes place in a wide variety of contexts and fulfils different needs for different types of road users. All sorts of road users (e.g. car drivers, motorcyclists and truck drivers) vary in skills, experience, age, sex, travel type, travel length and so on. Road users also differ in behaviour due to for example, motivation, capability, and state-of-mind.

In practice, this translates into many, easily recognisable, differences. One car driver may be in a hurry, whilst another may be ‘taking it easy’. One truck driver may have many years’ experience and feel at ease with each situation encountered, whilst another may be working his first day on the job and have difficulties simply keeping up with traffic.

Furthermore, not every road user sees and understands the information and messages of the traffic management measures the same way. Moreover, not every road user is able to perform the same driving task. This underlines the variety in the road user’s behaviour and the importance of taking into account the scope of behavioural differences. Despite these individual differences, general models do provide for a good understanding of traffic behaviour and form a good starting point for the current analysis.

3.1.1 The three-level model of the driving task

Traffic behaviour can be understood by looking at the driving tasks of the road user when participating in traffic. Michon (1985) created a model which divides the driving task into three levels. This model contributes to the understanding of the driving task and the road user behaviour.

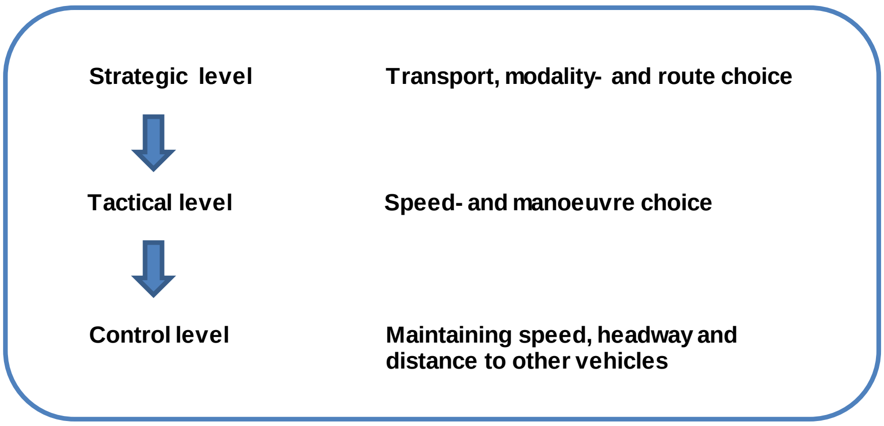


Figure 1: Driving task model (Michon, 1985)

At the strategic level the road user makes decisions on whether or not to travel, where and when to go and which mode of transport to choose. Once the road user is on his/her way, route choices and possible modality choices are also made. Traffic jams or diversions can for instance lead to a change in modality or route. The decisions made all have impact on exposure of the road user to the traffic system, which is highly relevant for traffic management, traffic volume, and hence, fluency of traffic. Exposure is also critical for traffic safety. At the tactical level decisions are made dealing with concrete traffic situations. This decision making is based on perceptions, estimation of distances and velocities, and anticipation of traffic situations in a matter of seconds. For example, determining the speed at which to drive, or making a decision to switch lanes, merge or overtake. In this stage the driver divides his attention, scans possibilities and processes in-car and roadside information (Michon, 1985). The third level is the operational or control level of the driving task. The control level consists of tasks to stay on course (positioning in traffic lane), following distance and maintaining the desired speed.

Traffic management measures are intended to optimize the movement of road users in a reliable and safe way usually by influencing one or more of these behavioural levels. To achieve this, traffic management measures can inform, guide and control (Godthelp et al., 2012). This will be discussed more extensively in paragraph 3.3.2.

3.1.2 The five main types of human factors

By human factors we mean the set of behavioural factors that contribute to the traffic behaviour of road users and thus are a part of the current course of the traffic system (Harms, Lambers & Westerman, 2011).

This study distinguishes five human factor aspects (figure 2) that are particularly important and relevant for traffic management measures. The first four aspects must be taken into account for bringing about the desired behaviour of road users and must be considered when understanding why measures do or do not lead to the desired behaviour. The fifth human factor aspect – behavioural adaptation - stands apart from these four and concerns behaviours that may occur following the introduction of changes to the road – vehicle – user system and which were not intended by the initiators of the change (OECD, 1990).

1. Perception:	Does the road user perceive signs, signals and information?
2. Comprehensibility:	Does the road user understand signs, signals and information and what needs to be done?
3. Skills:	Is the road user able to perform the desired behaviour?
4. Willingness:	Is the road user motivated to perform the desired
5. Behavioural adaptation:	Does a traffic management measure lead to the road user's unintended change of behaviour?

Figure 2: The five main types of human factors

In the first place traffic signs, signals and information *en route* as well as *in car* have to be highly visible for road users. Drivers should be able to oversee the complete message without too much distraction around it. For instance, messages should not contain animations, moving images or alternating messages. Presenting animations or alternating (text) messages will attract attention from drivers and distract them from the driving task (Kroon et al., 2014).

When the traffic information is well perceived, the second step is that the traffic management measure has to be understandable for the road user. Is it clear for the road user what is expected and what needs to be done? If the traffic information does not match with the expectations of the road user, this will probably lead to uncertainty in his behaviour. In other words, after the road user perceived the information it should be immediately clear which behavioural tasks he should perform (Harms, Lambers & Westerman, 2011). At the same time the desired behaviour has to be consistent in signs, signals and information in order to achieve compliance from the road user. Traffic management operators have to keep in mind that the message has to be understandable for all road users, not only for the more experienced and highly intelligent ones (Van der Horst et al., 2008).

If the road user perceives and understands the traffic management information well and knows what he is expected to do then the following human factor to be looked at is whether he is able to perform the desired behaviour. The complexity of the task stipulated by the measure and the traffic conditions (intensity, weather, freight traffic etc.) continuously influences the skills of the road user and whether he is able to perform the behavioural task (Harms, Lambers & Westerman, 2011).

Finally the road user needs to be motivated to perform the desired behaviour. Acceptation, imitation and connection to the road user's own goals are of great importance in this human factor (Harms, Lambers & Westerman, 2011). Furthermore, the extent to which the road user is willing to perform the behaviour depends on the traffic situation and the driver's preferences. But the road user can also have a different degree of willingness in similar situations. For example a road user will be less willing to comply with a temporary local lower speed limit when he is in a hurry, than when he is not in a hurry.

Behavioural adaption in traffic context describes the collection of behaviours that occur following a change in a road traffic system (Rudin-Brown & Noy, 2002). In most cases this is about an adaptation that negatively impacts road safety. It is important for road and traffic engineers to keep behavioural adaptation effects in mind when considering the implications of such systems. These negative behavioural effects are not often studied and are therefore also underreported (Martens, 2013). Possible unintended negative side-effects are[4]:

- diminished attention level (when driving tasks are partly replaced by in-car systems the driver's attention for the driving task decreases);
- information overload (traffic management measures should not lead to an overload of information at the wrong moment and place)
- overestimating the in-car system (the driver's expectations of a traffic management measure must be realistic and he should not rely too much upon it)
- risk compensation (If a particular measure reduces the risk, some people are (subconsciously) inclined to take more risks in another way, resulting in a smaller net effect or, according to some, even reducing it to zero)

[4] SWOV Factsheet ITS (2010)

For example; when a road user consistently gets warned by a warning system in a modern vehicle he tends to trust on this warning system too much so that the road user will scan his surrounding less actively for possible dangerous situations. Risk compensation is about the tendency of road users to take more risk when a measure decreases the risk, for example by increasing their speed or performing an extra task. The net profit of the measure may be smaller or even gets lost. It is important to ensure that traffic management measures don't have these unintended side-effects.

3.2 Human factors in traffic: current practices and guidelines

3.2.1 Current practices and guidelines for road design

Application of human factor principles in road design is common (AASHTO, 2011; Campbell et al., 2012; ERASER, 2010), more common than in traffic management. A well-known example of bringing road users' needs, capabilities, and limitations into road design is the concept of self-explaining roads, which advocates a traffic environment that elicits safe behaviour simply by its design (Theeuwes, 2012). For example, a narrow road without the centre white line suggests a low speed limit and the possibility of meeting other vehicles head-on. Other examples of human factors recommended to consider in road design are: driver expectancy, driving habits, perception-reaction times, sight distance (AASHTO, 2011; Campbell et al., 2012).

3.2.2 Current practices and guidelines for traffic management

Application of human factors in traffic management is less common. Nevertheless we see some very interesting literature. Many of these stem from the Netherlands.

As stated at the beginning of this chapter road users are not a homogenous group. On the contrary; there is no such thing as an average road user (Godthelp et al., 2012). When designing and estimating the effects of traffic measures it is important to realise that road users are a group consisting of a variety of individuals with a great diversity of characteristics, such as age, driving experience, mental condition, but also information processing capacity and speed, reaction time or motor coordination. These biological characteristics and characteristics acquired through training and experience determine driver competence (Fuller, 2005). However, driver competence is not necessarily static - it is vulnerable to a number of human factor variables and therefore it evolves dynamically with time and context. These factors include attitude, motivation, effort, fatigue, drowsiness, time-of-day, drugs, distraction, emotion and stress (Fuller, 2005). Ideally, the traffic system should take into account all these factors and be geared to the 'weakest link'.

The Dutch Ministry of Infrastructure and the Environment used this approach to formulate *10 Golden Rules* (Godthelp et al., 2012). A group of Dutch experts on human behaviour in traffic compiled this booklet to offer the Dutch road engineers more insight in the road user's behaviour. Next to the starting premise that there is no average road user Van der Horst et al. (2008) also state that the traffic system should be based on the less endowed road user and therefore must be usable by every road user in society.

The Dutch Sustainable Safety Vision is a road safety approach based on five principles that together lead to a sustainably safe traffic system. Three of these principles are relevant for the design of traffic management measures. To prevent road users from unsafe behaviour the road system and its environment should therefore be predictable, recognizable and forgiving (Wegman & Aarts, 2005). A predictable layout of a road prevents unsafe actions in traffic as much as possible because it allows road users to know more clearly what to expect (types of road users, manoeuvres, road course) and what will be expected of them (speed, manoeuvres). A predictable road layout can be achieved by consistency in (traffic management) design and continuity in road course which leads to a recognizable system for the road user. The principle of predictability is also related to the credibility of the road layout, with regard to the rules as well as the road use (Wegman & Aarts, 2005). Godthelp et al. (2012) also underline that the road system should be consistent, uniform and more or less self-explanatory under all circumstances.

The 10 Golden Rules contributes to the understanding of the road user's behaviour in order to let the road user understand the traffic system in general. Figure 3 presents the 10 Golden rules in a shortened version.

Characteristics and idiosyncrasies of road users

Rule 1: Road users are quite selfish
Rule 2: Road users cannot do everything at the same time
Rule 3: You can tell road users to do something, but will they actually do it?

How road users view traffic and traffic measures

Rule 4: Road users only accept measures that they think are meaningful

How road users react to conditions on the road

Rule 5: Road users are full of surprises
Rule 6: Road users have expectations and behave accordingly
Rule 7: What happens if the system or the road user goes wrong?

What road users demand from the information that you give them

Rule 8: Tell road users what is really important
Rule 9: Do not confuse road users

The requirements to be met by the information

Rule 10: Information must be visible, clear and understandable for road users.

Figure 3: The 10 Golden Rules (Dutch Ministry of Infrastructure and the Environment, 2012)

Further, a (preliminary) human factor framework for traffic management measures was developed by the Dutch Ministry of Infrastructure and Environment (2011). Key definitions used in this framework to achieve the desired road user behaviour are more or less the same as the human factor criteria distinguished in this study; perception, comprehensibility, task complexity and willingness.

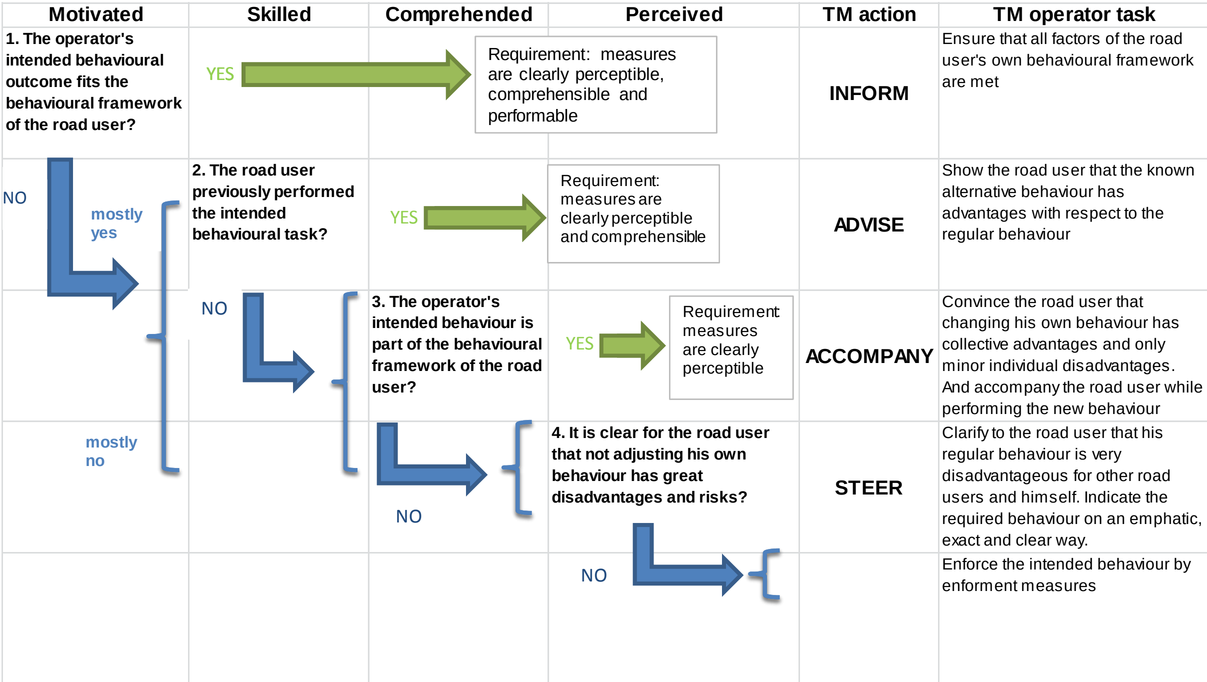


Figure 4: Human factors in traffic management framework (Harms, 2012)

The main approach of the framework from the perspective of the traffic management operator is to what extent the desired behavioural action matches the behaviour the road user wants to perform himself. The road user needs to be able to perceive and comprehend what is expected from him. Subsequently he needs to be able to actually perform the required behaviour and must be willing to perform it. Harms (2012) provides in her framework the opposite order to illustrate that more effort is needed for those road users that need to be advised, persuaded and to perform behaviour that is not natural or habitual for them. If one is not willing to change behaviour more is needed than presenting informative and comprehensible messages.

The framework distinguishes a number of tasks for the traffic management operators; informing, advising, accompanying and steering. In case of the informative task situation, the road user is already willing to perform the targeted behavior, but he does not know how to perform this action. The reason the road user has not already carried out this action is thus because of the lack of information. The only requirements of the informative measure are that it is highly visible, clearly understandable and that the road user is able to carry out the task (Harms, Lambers & Westerman, 2011).

The second task for traffic management operators concerns advising the road user. When informing the road user is not enough, the road user has to be advised by the traffic management measure to carry out the targeted actions. This takes more effort than informing, because the targeted behaviour might not be preferred by the road user himself, though this targeted behaviour is well known to the road user and thus easy to perform. Informing is therefore not always sufficient to persuade him and advising is needful. Naming the desired and targeted behaviour in the form of an advice is necessary. Route information is a good example of the task to advise.

If the targeted behaviour is neither known nor understandable to the road user also advising will not be enough to achieve this behaviour. Explaining why is central here. In this case the traffic management measure has to accompany the road user in performing the targeted actions. The emphasis in this task lays in the comprehensibility of the measure.

Finally, if the road user is not willing to perform the intended behaviour and this targeted behaviour is not habitual and not understandable to the road user, then it is necessary to steer or guide the road user (e.g. enforcement). In this steering task it is important that the measure and the information are very well perceivable. The road user will probably not be in search of this information and will also not expect it. Therefore traffic management measures with a strong guidance task have to be very notable (Harms, 2012).

3.3 Traffic management assessment parameters

To understand road user needs and behaviours in relation to traffic management measures we made an overview of assessment parameters for traffic management measures. We analysed relevant road user needs and behavioral effects and we reviewed effects of traffic management measures on effectiveness indicators such as reducing accidents, saving travel time and benefiting the environment.

3.3.1 Road user needs and behaviours identified

In general the literature that was found regarding road user needs can be divided into three main types; (1) the need of argumentation on why certain road user behaviour is wanted (2) the need of road users to comprehend the measure and its argumentation and (3) the need of road users to accept the behavioural task that needs to be performed.

First measures of traffic management have to provide reasons why a certain behaviour is wanted. For example, Godthelp et al. (2002) found that flashers next to matrix signs on motorways, with the aim to warn road users about queues, slippery roads or other reasons why they should diminish their speed are of great importance. When road users see flashers displayed next to speeds on variable message signs or matrix signs they associate these with queues (Godthelp et al., 2012). Also road users are in need of argumentation on (local) speed limits or lane closures. Finnish studies (Innarnaa, Vanhanen & Pursula, 2000; Ristikartano, Seppänen & Toiskallio, 2008) show that road users have a moderate positive attitude towards the traffic management system. For example, road users accept lower speed limits when the reason is safety. But the comprehensibility of the system suffers because of different messages given by the signs.

Thus road users are also in need of clarification on traffic management measures. On one hand these measures command and on the other hand they guide and inform. It is not always clear whether the measure is mandatory or an advice. Information given by the signs should always be correct and up-to-date so that the road users' confidence in the system is preserved. In cases where dynamic speed measures are not clarified the comprehensibility can be very low. For example, in the Netherlands a red cross on matrix signs above motorways is used to close lanes. In the past, this red cross was only applied in cases of visible danger (and thus understandable for the road user), but nowadays a red cross can also be used without any visible motive, for instance because of environmental reasons. Argumentation on why lanes are closed clarifies the situation for drivers and avoids possible dangerous situations (Harms, Lambers & Westerman, 2011). Godthelp et al. (2012) indicate the importance of plausible speed limits. Road users will be less inclined to adapt their speed behaviour when they do not understand the reason for it. The Dutch Dynamax evaluation study (on dynamic speeds limits, 2010) showed for example that motto signs (a short and powerful message alongside a speed limit) were useful to create plausibility in a lower speed limit for road users.

Third, road users have the need to see the benefits of a traffic management measure. In case of the red cross example, the lack of clarity can lead to diffusion and irritation of the road user and he may choose to ignore these red cross signs. If road users understand what is expected from them they will see the benefits of the measure more clearly which contributes to their willingness to comply with the traffic management measure. For example, Shirokoff & Vitikka (2001) show that Finnish drivers consider variable message signs, used for speed limits, to be worthwhile (96%) and useful (98%). The most usual benefits mentioned and thus known were increased traffic safety, better traffic flow and increased compliance with speed limits. A vast majority (87 %) of the respondents in a study on dynamic queue warning systems (Hautala & Raitio, 1999) in Helsinki find the variable message signs beneficial in case of disturbances when compared to normal signs. The variable message signs were seen to correspond better to the traffic situation, to improve traffic safety and to show the cause of the traffic disturbance and decreased speed limit. Next to that, a study on ITS in the Netherlands (Connekt ITS, 2011) shows that dynamic route information needs to be real-time, easily accessible and reliable for road users and can then lead to 35% of travellers willing to change their schedule (modality, time or route).

3.3.2 Reducing accidents

Very few studies evaluated the effects of traffic management measures on reducing accidents. Some examples are briefly described in this section. On the M42 motorway in the United Kingdom the Four Lane Variable Mandatory Speed Limit was introduced in 2006. This traffic management measure resulted in a reduction of the number of fatal and serious accidents from 0.82 accidents per month to 0.17 accidents per month three years later (Macdonald et al., 2011). Also in the Netherlands matrix signs (speed limits, red cross, green arrow) has led to on average 19% (range between 15% and 45%) fewer accidents (Taale & Schuurman, 2015). Finland shows more or less the same effects of variable speed limits (controlled by road weather conditions) with an injury accident risk decreased by 10% (winter) and 6% (summer) (Shirokoff & Lehtonen, 2011). An overtaking prohibition for heavy good vehicles during peak hours on approximately 50% of the motorway network in the Netherlands has led to fewer critical situations and probably less accidents. Unfortunately clear numbers on the effects of this measure are missing.

3.3.3 Saving travel time

Few studies were found regarding travel time savings, but those available suggest that time can be saved using traffic management. Variable speed limits are deployed across the respondent countries principally to ease congestion which saves travel time. In urban areas intelligent traffic lights are used to create green waves and reduce waiting minutes and travel time. The overtaking ban for heavy goods vehicles should also improve traffic flow and save travel time for road users. In Finland local traffic lane management leads to a reduction in travel time between -0.1% and -0.3%. Also incident management results in a 5% to 20% reduction in queues which undoubtedly has its effect on saving travel time (Shirokoff et al., 2013). In the United Kingdom the journey time reliability increased up to 25% because of hard shoulder running. Ramp metering systems have also proven successful in certain locations where unregulated entry would trigger flow breakdown. In the Netherlands 50% fewer shockwaves are reported as an effect of ramp metering (Taale & Schuurman, 2014). The merging measure (“ritsen”) does not improve traffic flow, but does improve merging in general.

3.3.4 Environmental benefits

Environmental effects of traffic management measures do not seem to be evaluated often. Shirokoff et al. (2013) show that variable speed limits have led to a reduction between 0.2 and 0.5% CO2 emissions in Finland. Also, gas emissions are reduced by 5% to 15% by applying incident management. In the Netherlands variable speed limits and hard shoulder running help to reduce emissions, although an accurate figure is not available (Taale & Schuurman, 2015). Ramp metering as a measure of local traffic flow management increases emissions varying from 1% to 4%.

Unfortunately we have not found relevant literature regarding the cost effectiveness of the four clusters of traffic management measures. In addition, this review shows further knowledge gaps. The questionnaire survey (Chapter 4) has sought to complete these gaps where possible. The Dutch traffic management program ‘No Regret’, which ran from 2007 to 2009 showed a cost effectiveness factor of 1.2 (Taale & Schuurman, 2015)

3.4 An indication of the costs and benefits of traffic management

Taken all these parameters together, evaluating the impact of traffic management measures is not a trivial task. It typically requires at least a before- and after observation, coupled to the measurement of various indicators related to traffic throughput and travel times, and the indirect estimation of external costs such as emissions, noise, and accidents. In addition, surveys for road users and operators also provide valuable clues into the efficiency and success of various traffic management measures. Coupled to model calculations and expert judgement this allows us to put concrete numbers on the total costs and benefits of such measures.

In what follows, we have consulted literature and tried to encapsulate some indications of costs and benefits that can be expected for the different groups of traffic management measures. For a good reference, a measure should be assessed as individually as possible, backed by a controlled experiment. In practice however, this is not always feasible. For the purpose of generalisation in this report, we restrict ourselves to providing indicative numbers of impacts related to for example travel times. These indications are based on what individual field tests and studies have estimated with respect to impacts on congestion[5]. Note that aside from costs required for, e.g., setup, implementation, and maintenance, the direct monetary benefits can be implied from the gains in travel times.

Looking at the impact of congestion on society, and the relation with traffic volumes, we know from traffic flow theory that a 5 – 10% increase in capacity (or diminution of demand), leads to a 20 – 30% reduction in vehicle loss hours. This clearly illustrates the non-linear character of congestion, and brings about the positive insight that congestion problems can actually be tackled to a large degree.

[5] See also “*Effecten van benutting in Nederland: Een overzicht van praktijkevaluaties. Henk Taale and Henk Schuurman, versie 3.3, 8 mei 2015.* URL: http://www.traffic-quest.nl/images/stories/documents/Evaluatie/effecten_benutting_v3.3.pdf

Finally, keep in mind that the EU has imposed the ITS Directive (2010/40/EG). This legal framework was adopted on 7 July 2010 and has the following general goals: (i) to accelerate development of innovative transport technologies, (ii) to establish interoperable and seamless ITS services, and (iii) to let Member States decide on where to invest in. The ITS Directive focuses on 6 priority areas, which are (1) optimal use of road, traffic and travel data, (2) continuity of traffic and freight management ITS services, (3) ITS road safety and security applications, (4) linking the vehicle with the transport infrastructure, (5) data protection and liability, and (6) European ITS coordination. The Directive then lists 6 priority actions, which are grouped as follows: (1) EU-wide multimodal travel information services, (2) EU-wide real-time traffic information services, (3) minimum universal road safety-related traffic information free of charge to users, (4) interoperable EU-wide eCall, and (5+6) information & reservation services for secure parking for trucks. The Directive itself also contains an interesting Annex that embeds detailed specifications for all these priority actions.

3.4.1 Dynamic speed management

The most impressive measure with an impact on congestion in this category are dynamic speed limits. Both with and without enforcement, the average speed can drop with some 13% to 5% depending on whether or not enforcement is foreseen. The capacity varies from -9% to 4% (with enforcement). The effects on congestion are the largest: from -24% to +36% (+2% on average). The fact that travel times seem to increase slightly due to the slower speeds in free-flowing traffic is also offset a number of times by the positive effects on shockwaves which lead to less congestion. In addition, the emissions also drop in these cases.

Regarding the impact of variable message signs, observations indicate that road users do change their route based on the information displayed. The number of people changing is within the range from 42% to 13% on ring road. Within cities, the number increases from 15% to 40%, as there are more possible and attractive alternatives available to them. In addition, this causes a huge positive effect on congestion, which drops with some 3% to 34% (one study even quoting 81% less congestion). Note that there is no directly observed impact on traffic safety, regarding the number of accidents.

3.4.2 Local dynamic warning systems

Examples of a local dynamic warning system are the measures taken in the presence of road works. This can lead to a drop in traffic demand up to some 11%. The area where the road works are less used (up to 38% less time). The most pronounced effect is an increase in the traffic volumes on deviation routes, with some 13% increase on motorways and up to 40% on the underlying road network of secondary and local roads. The latter can have a negative impact on traffic safety.

Swiftly dealing with incidents can increase the benefits to both road users and society. One experiment noted a decrease in vehicle loss hours of some 7%.

3.4.3 Local traffic flow management

Measures such as peak hour lanes have a drastic effect on capacity: going to an increase from 7% to 37% (20% on average). This additionally results in an up to 7% increase in traffic and lower travel times with 0 to 7 minutes less travel time per vehicle. There are less emissions, but the positive effect on traffic safety is less pronounced.

Interesting related measures are target lanes, intended from specific classes of users. When present, they are intensively used, bringing large benefits to these users. This sometimes goes at the cost of the other traffic participants, leading to travel time differences between 2 minutes loss and 5 minutes gain. Traffic safety is on the whole invariable, with the exception of the increased unsafe weaving area.

Imposing an overtaking ban on HGVs slightly increases the traffic safety, and has only ambiguous effects which are very location specific. Capacity can both decrease and increase from -4% to 4%, with corresponding changes in average travel speed ranging from 7 km/h faster to 14 km/h slower.

The measure of ramp metering has abundantly been discussed in previous research and existing literature. It is important to realise that this type of measure does not prevent congestion but only postpones it. Experiments show that motorway capacity increases with some 2% on average, accompanied by a 3 km/h increase in average travel speed (and hence lower travel times). More importantly is the measure's direct effect, i.e., there are up to 50% less shockwaves. There is 15 to 4% increase in emissions due to the introduction of stops on the on-ramp.

Local traffic management is also done by means of merging measures. Here we observe that closing an on-ramp leads to less congestion on the main motorway, e.g., 25% less congested traffic. Merging advice at the most downstream location of a bottleneck does not affect throughput nor does it have an impact on congestion. It does however lead to better merging behaviour.

A control measure that also fits in the scheme of local traffic management is traffic light control (including the so-called 'green waves'). However, the observed effects are deeply influenced by the governing policy. For example, travel times can drop with some 33%, as well as increase with some 10%. Especially if public transport and cyclists are involved and prioritised, than car traffic experiences fewer benefits from such traffic light control.

3.4.4 Network-wide traffic flow management

Information is the key to having better journeys[6]. Informing road users of the road network's current state and level of congestion, leads to 26% less accidents. Capacity and traffic volumes are equally increased by some 5%.

Moreover, such network-wide information measures can lead to changes in road users' chosen routes. The more information is available beforehand, the less traffic demand needs to be processed at critical times, e.g., the morning and evening rush hours (up to 22%).

Going one step further, more personalised information that is for example delivered in-car, has an even larger impact, with up to 34% of the people changing their itinerary.

Some back-of-the-envelope exercises indicated moreover that real-time public transport information requires an investment of 4.5 million euro (cf. 9292 service in The Netherlands), yielding a return of some 22.8 million euro (due to shorter trips and less traffic jams).

[6] Numbers are based on Maerivoet S., Akkermans L., and Delhaye E., Impact of the ITS Directive (in Belgium): Some Experiences with Real-Time Public Transport Information, Report done for ITS Belgium, 14 June 2012

3.5 Towards a preliminary human factor framework

Traffic management measures influence all three levels of the driving task that Michon (1985) describes. Because human factors play a role in each level (strategic, tactical and the control level) it is important to take human factors into account when designing, implementing and evaluating traffic management.

As described in this chapter, traffic management is effective when road users perceive the measure well, understand what needs to be done, have the driving skills to perform the driving task the measure demands and are willing to perform this task. Further, it is important that traffic management measures do not have unintended negative side effects. If circumstances change, people do as well. The possible negative side effects of behavioural adaptation should be prevented by the traffic management operators.

The 10 Golden Rules (van der Horst et al., 2008) contribute to the understanding of the road users' behaviour when interacting with traffic management. In addition, the framework for human factors in traffic management (Harms, 2012) aims to support the traffic management operator with relevant human factor knowledge. Both documents can significantly contribute to the development of a human factor framework in the second Work Package of the METHOD project.

4 Results from the questionnaire survey

This chapter describes the results of the questionnaire survey. This survey comprises the second and third task of this project, namely to conduct an inventory of current practices and experiences in a number of European countries, and to assess the effectiveness of traffic management measures from a human factors perspective. First (section 4.1) this chapter describes the type of traffic management measures currently in use. Subsequently (section 4.2) the estimated effectiveness of traffic management in the six countries that participated in the questionnaire survey are presented. Finally (Section 4.3) the extent to which human factors play a role in current national traffic management measures is discussed.

Note: Contributions for the UK come from the Highways Agency (now Highways England), which operates, maintains and improves England’s motorways and major A roads. As such, findings related to traffic management measures on non-highway roads across the UK, and highways and motorways in Scotland, Wales and Northern Ireland, should be interpreted as indicative only.

4.1 Traffic management measures currently in use

As described in our method section (2.2) the first part of the questionnaire survey was designed to gain insight into the deployment of current traffic management measures in practice. Earlier four categories of traffic management measures were distinguished and these will form the structure of this section. For each traffic management category the current practices and experiences will be discussed.

4.1.1 Dynamic speed management

Dynamic speed management refers to speed limits that take into account changing circumstances (such as real time traffic or the weather) and can be adjusted to unexpected situations such as weather conditions, congestions and incidents. Dynamic speed limits can be presented by matrix signs and variable message signs. When looking at the implementation of current measures of dynamic speed limits it turns out all countries make use of this type of traffic management. When one or more than one of the interviewees mentioned the application of the measure on a certain road type, the cell is marked with the green colour. If the concerning measure is not applied the cell is white.

Table 3: Application of dynamic speed management per road type

	Dynamic speed limits			Variable message signs		
	Rural roads	Urban roads	Motorways	Rural roads	Urban roads	Motorways
Belgium-Flanders						
Denmark						
Finland						
The Netherlands						
Norway						
United Kingdom						

Table 3 shows the application of dynamic speed limits and variable message signs per road type for the six countries participating in the questionnaire survey. Dynamic speed limits as well as variable message signs are applied on motorways in all countries. Dynamic speed limits are most often applied by the variable message signs above motorway lanes displaying the maximum speed (in some cases accompanied by a red circle). By making use of variable message signs argumentation on advisory or maximum speeds can be added. According to the response of Finland, Norway and the Netherlands dynamic speed management is applied in situations where traffic situations (congestion, queues, roadwork, tunnel (closures), school zones and opening bridges) and (bad) weather conditions vary a lot. On motorways dynamic speed limits are presented with matrix signs showing speed limits or variable message signs which can also contain argumentation. In the Netherlands dynamic speed limits are also displayed on traffic signs alongside the road through the use of panels.

In the United Kingdom the Smart Motorway concept makes the hard shoulder available for traffic and includes a range of new technology to vary speed limits in response to driving conditions. There are three sub divisions of the Smart Motorway concept:

(1) 'Controlled motorway' - Three or more permanent lanes with variable speed limits and the use of the hard shoulder in case of emergency,
(2) 'All-lane running' - All lanes are used (no hard shoulder) and variable speed limits must be obeyed and,
(3) 'Hard shoulder running' - The hard shoulder will be opened at busy times and can only be used when indicated by the overhead signs.

Dynamic speed limits that are applied in urban areas mainly concern *green wave traffic signs* to advise the road user on the speed limit, hence creating a green traffic light wave. In rural areas dynamic speed management is recognized by feedback signs that record and display the current speed of the road user. Variable message signs are used on all road types (except for rural roads in the United Kingdom) and contain argumentation on speed limits (motorways) or feedback on speed (rural and urban roads).

4.1.2 Local dynamic warning systems

Local dynamic warning systems can be divided into three measures; local queue warning, local incident warning and local weather warning systems. These measures all refer to systems with the main aim to warn the road users about these (un)expected situations on the road.

Table 4: Application of local dynamic warning systems per road type

	Local queue warning			Local incident warning			Local weather warning		
	Rural roads	Urban roads	Motorways	Rural roads	Urban roads	Motorways	Rural roads	Urban roads	Motorways
Belgium-Flanders									
Denmark									
Finland									
The Netherlands									
Norway									
United Kingdom									

In all six countries dynamic queue warning systems are in use. Some measures are applied at urban roads but particularly at motorways. Local queue warning measures at urban roads refer to warnings for possible queues in the surroundings of bridges or roadwork. In the Netherlands mobile variable message signs ('bermDRIPS') are sometimes used to warn for (motorway) queues. In general motorways make use of matrix signs and variable message signs above lanes or at the roadside to inform and warn the road user about queues. Denmark, Finland and Norway have not specified their measure types specific on local incident warning.

Automatic Incident Detection (AID) and Motorway Incident Detection Automatic Signalling (MIDAS) are used in The Netherlands and the United Kingdom for incident warning on the motorway system. Both systems automatically detect incidents and alert the traffic control centres and automatically set advisory speed limits. AID relies on video image processing to calculate speed, count, and occupancy. MIDAS works by a distributed network of traffic sensors and inductive loops.

Systems on local weather warning are mostly restricted to motorways. Only in the Netherlands this measure is also applied on rural and urban roads by using the mobile various message signs, which are also used for queue warnings. Local weather warning measures on motorways differ between countries. Finland and the Netherlands have weather condition warnings based on automatic weather stations.

4.1.3 Local traffic flow management

The cluster of local traffic flow management measures consists of five measures. The measures all refer to systems with the main aim to optimize the traffic flow on specific (local) road networks.

Table 5: Application of local traffic flow management measures per road type

	Lane closures			Peak hour lanes			Overtaking ban HGV			Ramp metering			Merging measures		
	RR	UR	MW	RR	UR	MW	RR	UR	MW	RR	UR	MW	RR	UR	MW
Belgium-Flanders		■	■			■	■		■					■	■
Denmark			■			■			■						■
Finland			■						■						
The Netherlands	■	■	■			■	■		■		■	■			
Norway	■	■	■					■	■		■	■			
United Kingdom			■			■			■			■			

Table 5 shows that lane closures are most often applied local traffic flow measure. Again it is mainly applied on motorways making use of matrix signs displaying a red cross. In Finland and Norway lane closures are mainly applied at tunnels, also on rural and urban roads. In urban areas in the Netherlands, one way bus lanes are applied differing in road direction and thus closing one direction of the lane for half of the time.

Peak hour lanes or hard shoulders are used on motorways in Belgium, Denmark, the Netherlands and the United Kingdom. In the United Kingdom the Smart Motorway concept is based on expanding the motorway network capacity by involving hard shoulder lanes. In the "All lane running" type the United Kingdom permanently converts the hard shoulder to become an additional running lane. Both the United Kingdom and the Netherlands use matrix- and variable message signs to inform on speed limits and availability.

Overtaking bans for heavy good vehicles are applied on motorways in all countries. In Finland and Norway overtaking bans for heavy good vehicles are limited to tunnels. In the United Kingdom it is not applied as standard because of the use of 3 or 4 lanes on motorways (i.e. smart motorway) and therefore not considered necessary. Denmark and The Netherlands have varying time limits (because of the selected timeframe) for the heavy good vehicle overtaking ban, but these signs are static. In Belgium there is a permanent overtaking ban on two lane motorways (with exceptions for this ban on some motorways between 19 PM and 6 AM) and in case of rainy weather.

Ramp metering measures are only applied in the Netherlands, Norway and the United Kingdom. In Norway the traffic flow in tunnels is controlled by traffic lights to prevent congestion in urban areas as well as on motorways. In the United Kingdom and the Netherlands in some cases ramp metering is applied on slip roads to motorways. In the Netherlands ramp metering is sometimes also in use in urban areas to give priority to roads with a high intensity traffic flow. This way the traffic flows entering cities are optimised.

Merging measures applied to manage local traffic flows are not very common. Respondents from Belgium and Denmark indicated that merging measures are applied, but did not specify how these measures are implemented.

4.1.4 Network-wide traffic flow management

Two traffic management measures can be distinguished referring to managing the traffic flow on a network-wide level. Dynamic route information and multimodal information are applied at roadsides and inside vehicles.

Table 6: Application of network-wide traffic flow management measures per road type

	Dynamic route information			**Multi modal information**		
	Rural roads	Urban roads	Motorways	Rural roads	Urban roads	Motorways
Belgium-Flanders		■	■			■
Denmark		■	■			
Finland	■		■			
The Netherlands	■	■	■		■	■
Norway		■	■		■	■
United Kingdom			■			

Measures of dynamic route information are applied on motorways in all countries. These measures mostly concern travel time information and network route guidance. An example of travel time information can be a display of how long it takes to reach a certain destination in how many kilometres / miles and in how many minutes (e.g. 50 miles / 32 minutes). Network route choices are displayed by navigation systems inside cars or by graphic variable message signs showing maps and possible routes. In some countries applications can be used (on mobile phones, tablets or in-car systems) to provide dynamic real time route information. The Practical Test Amsterdam ('Praktijkproef Amsterdam) is a large scale project carried out by the Dutch road authority with the aim to decrease queues around Amsterdam by using modern in-car and roadside techniques. One part of this project is a test where an app provides individual in-car travel information by taking into account actual data on queues, incidents and roadworks. Another measure of dynamic route information is the commercial community-based traffic and navigation app Waze[7] which can be used in all countries on mobile phones and tablets.

Most of these apps or in-car navigation systems can of course also be applied on rural and urban roads. Yet also other measures such as the Parking Route Information System (PRIS) are applied in Dutch urban areas. This system navigates the road user to parking places and at the same time informs on parking spots available. Park and Ride (P+R) measures are also applied in the Netherlands. This system is designed for car users to park their cars for an affordable price outside of the city centre and people can then travel directly to the city centre by means of public transport. On rural roads, mobile text cars are sometimes used in the Netherlands to inform on route information. Unfortunately a Finnish example of this type of measure is lacking.

[7] https://www.waze.com

Multi-modal information measures are less common. In Belgium and the Netherlands measures are applied that inform on parking availability and route choices. Alongside motorways these measures can also inform on travel options and times by train when parking at the P+R location. The Norwegian response unfortunately did not provide examples of multi modal information measures. Furthermore, practically each country, (except Norway) indicates to have (multiple) applications or websites on multi modal travel information.

4.2 Traffic management effectiveness assessment

This section presents the results of the effectiveness assessment carried out within the interviews. Per cluster of traffic management measures the respondents applied a score on five important outcomes indicating effectiveness of traffic management. These outcomes will be described per cluster of traffic management. All results are presented in tables which are coloured according to the degree of effectiveness according to the legend next to the table. This presentation provides a clear overview of the results per outcome and country. Finally, unintended behavioural outcomes as a (side) effect of traffic management are presented in this section.

Note: Norway did not answer this part of the questionnaire because not much dynamic traffic management is implemented in this country and the question is therefore not applicable.

4.2.1 Effectiveness of dynamic speed management

The results of the effectiveness assessment of dynamic speed management show that they are effective for most aspects. Table 7 shows an overview of the results.

Table 7: Effectiveness of dynamic speed management

Dynamic speed management effectiveness					
	Improving traffic flow	Reducing accidents	Savings costs	Optimizing road user behaviour	Improving environmental sustainability
Belgium-Flanders					
Denmark					
Finland					
The Netherlands					
United Kingdom					

Not effective at all

Very effective

No response

In all countries measures of dynamic speed management are assessed as effective on reducing accidents. When analysing cost effectiveness Finland and the United Kingdom report very effective results. Dynamic hard shoulder running in the United Kingdom is 40% cheaper than widening the motorway according to the response. All lane running is even more cost effective; 25% cheaper than dynamic hard shoulder running. The majority of these savings comes from the variable message signs which are spaced further apart (1500 m < > 1000 m). This also accounts for refuge areas (2500 m < > 1000 m). Further all lane running does not need supporting systems or monitoring cameras on hard shoulders.

Dynamic speed management is also assessed as effective on improving traffic flow and even more effective on optimizing the behaviour of the road user. Based on evaluation studies the respondents indicate, except for Denmark, that dynamic speed limits harmonize the speed level and ease congestion, which contributes to an improved traffic flow. Results on optimizing the road user behaviour are more strongly based on personal observation of the experts. Road users adapt to their speed limits when the credibility is significant, but tend to ignore these limits in case of no argumentation or lack of credibility. Effectiveness of dynamic speed management on environmental benefits in Finland is quite high because these measures lead to harmonized and lower speed limits and thus have a positive general environmental impact.

4.2.2 Effectiveness of local dynamic warning systems

The results of the effectiveness assessments on local dynamic warning measures show more differences between countries, especially between Finland, The United Kingdom and the Netherlands.

Table 8: Effectiveness of local dynamic warning systems

Local dynamic warning systems					
	Improving traffic flow	Reducing accidents	Saving costs	Optimizing road user behaviour	Improving environmental sustainability
Belgium-Flanders					
Denmark					
Finland					
The Netherlands					
United Kingdom					

	Not effective at all
	Very effective
	No response

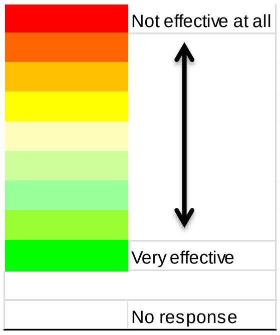
Local dynamic warning systems are quite effective in relation to improving traffic flow and reducing accidents. Experts from Belgium, The Netherlands and the United Kingdom indicate that these warning systems primarily aim to prevent for collisions and accidents and therefore on a secondary level also improve traffic flow. Finland states that dynamic warning measures are effective because of the argumentation these measures often include. The cost effectiveness aspect turns out to be difficult because it has a mutual effect of saving lives and improving traffic flow on the one hand and implementation costs on the other hand. In addition Dutch experts state that local dynamic warning systems do not intend to be cost effective. This also takes account for improving environmental sustainability. Finally, respondents find it hard to assess the effectiveness of these measures on optimizing road user behaviour. Finland, the Netherlands and the United Kingdom do indicate, based on personal observation, that local dynamic warning systems are quite effective in optimizing driving behaviour.

4.2.3 Effectiveness of local traffic flow management

By analysing the local traffic flow management cluster on the effectiveness indicators we find positive outcomes, except for the effectiveness on environmental sustainability. Denmark indicated not to know the effectiveness of this cluster of traffic management measures.

Table 9: Effectiveness of local traffic flow management

Local traffic flow management					
	Improving traffic flow	Reducing accidents	Saving costs	Optimizing road user behaviour	Improving environmental sustainability
Belgium-Flanders					
Denmark					
Finland					
The Netherlands					
United Kingdom					



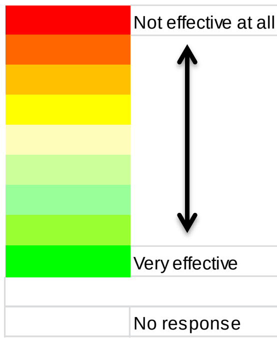
Analysing the results of the other four countries, Table 9 shows that lane closures, peak hour lanes, overtaking bans for heavy good vehicles, ramp metering and merging measures are assessed as being effective to very effective on improving traffic flow, reducing accidents (except for the Netherlands) and optimizing road user behaviour (except for the United Kingdom). Experts from the United Kingdom and The Netherlands indicate that local traffic flow measures are not effective in improving environmental sustainability but underline that these measures are not implemented with this intention. Other remarks were that it was not easy to assess local traffic flow measures as a whole against these effectiveness parameters. Further, the effectiveness scores for this cluster of traffic management measures are mostly based on personal observation.

4.2.4 Effectiveness of network-wide traffic flow management

Dynamic route information and multi modal information measures in general are assessed as quite effective. Table 10 shows the results of the effectiveness assessment for network-wide traffic flow measures.

Table 10: Effectiveness of network wide traffic flow management

Network-wide traffic flow management					
	Improving traffic flow	Reducing accidents	Saving costs	Optimizing road user behaviour	Improving environmental sustainability
Belgium-Flanders					
Denmark					
Finland					
The Netherlands					
United Kingdom					



Dynamic route information and multi modal information are both effective measures for improving traffic flow, saving costs, optimizing the road user behaviour and improving environmental sustainability. In Finland these measures appear to be very effective on all assessment parameters. Respondents from Belgium indicated that network-wide traffic management measures are not effective at all in reducing accidents, but unfortunately did not argue why. Most of the effectiveness scores are based on personal observation of the respondent experts.

4.2.5 Summary of traffic management effectiveness

It can be concluded that the traffic management measures in general are assessed as being fairly effective. Nevertheless, some relevant differences have appeared in effectiveness parameters between the clusters of traffic management measures and between countries.

Dynamic speed limits and variable message signs are indeed found to be effective on improving traffic flow, reducing accidents, saving costs, optimizing road user behaviour and improving environmental sustainability for practically all countries. The Smart Motorway concept in the United Kingdom makes hard shoulder lanes available for traffic which and has proven to be cheaper than widening the motorways. Local dynamic warning systems on queues, incidents and adverse weather are especially effective in terms of improving traffic flow and reducing accidents. Local dynamic warning measures are believed to be effective because road users well understand the reason why they, for example, have to reduce their speed. Lane closures, peak hour lanes, overtaking bans for heavy good vehicles, ramp metering and merging measures are the most effective cluster of traffic management measures. These measures are not effective for the improvement of environmental sustainability according to the Netherlands and the United Kingdom, but are also not intended to address this. Measures of network-wide traffic flow turn out to be effective as well. In general, countries had difficulties with assigning effectiveness scores to the cost effectiveness and environmental sustainability parameters. Some respondents mentioned that they were not able to provide an substantiated indication regarding the effectiveness of these parameters. Also, in some cases, measures were not designed for environmental sustainability purposes, as a result of which it was not obvious for the respondents to come up with an effectiveness score on this parameter. Unfortunately, many indications of respondents are missing with regard to whether they based their assessment on personal observation or evaluation studies. It cannot be obtained from the data whether the interviewer did not clearly asked for this indication or what any other reasons for this missing data might be. Of the respondents that did provide indications on their assessments, most were based on personal observation, since often no research or other formal evaluation study has been performed on the various effectiveness aspects.

When comparing country outcomes we see that all clusters of traffic management measures are assessed as (very) effective in Finland. In the Netherlands traffic management measures turned out to be judged as less effective in relation to the other countries. On average, the results nevertheless do not appear to be ineffective. This result may be related to the amount of the different traffic management measures applied in the Netherlands, which can be a breeding pond for early stage mistakes in these measures leading to unintended outcomes. Unfortunately it proved to be hard for Denmark to assign an effectiveness score to most of the traffic management clusters. Norway indicated not to have much dynamic traffic management implemented and therefore was not able to respond to this question.

4.3 The current role of human factors in traffic management

4.3.1 Use of human factors in designing traffic management

Now an inventory of current traffic management measures across the six European countries is made and their effectiveness is assessed, the use of human factors in designing these measures will be determined. Each country respondent indicated to what extent (‘Yes’, ‘Sometimes’ and ‘No’) the five main human factors were used as standard practice when designing clusters of traffic management measures. Figure 4 includes an overview of the six tables – one per country.

Figure 4: Are human factors used as standard when designing traffic management measures?

*Note: Because countries are represented by more than one expert individual scores (1='Yes', 2='Sometimes', 3='No') are summed possibly resulting in average scores in the response categories (I.e. 1.8 = between 'Yes' and 'Sometimes').

Denmark indicated use of the five human factor aspects as a standard practice when designing traffic management measures of each cluster. Unfortunately it was not explained by the respondent how this standard practice is incorporated in procedures or documents. Flanders (Belgium) stated use of perception as a standard practice when designing traffic management. Also comprehensibility and skills are used as standard when designing dynamic speed measures. Willingness and behavioural adaption are sometimes to always used as a standard practice when designing all clusters of traffic management measures (each respondent gave contra-indications). According to the Finnish response, evaluation studies are conducted in several countries and based on interviews and questionnaires human factors are taken into account, at least sometimes. Evaluation studies on network-wide traffic flow measures are less often conducted and there is a lack of generalizable evaluations. Standard practices of human factor usage for this cluster of measures is less common, as can also be seen in figure 4. Finland did not accurately indicate how human factors are incorporated in procedures but did mention that properties (dimensions of text displayed, available time to perceive and the text and the traffic sign placement) of the location where signs are implemented and are taken into account according to common standards.

In the Netherlands, where the most relevant literature and documents regarding human factors practice in traffic management were found (see paragraph 3.2.2. and 3.5), it was perhaps surprising to find that human factor assessments are applied less-commonly when actually designing traffic management measures. Three Dutch experts indicated that in most cases, but not always (='sometimes') human factors are used as a standard practice. The exception is for behavioural adaptation, because this aspect becomes apparent only after implementation of the measure. When human factors are addressed the Dutch road authority uses the framework presented earlier in this report (see paragraph 3.2.2).
The United Kingdom uses perception, comprehensibility, skills and willingness as a standard practice for designing measures of dynamic speed management as well as measures of local traffic flow management. Behavioural adaption is also used as standard when designing local traffic flow management measures but only with regard to dynamic speed management. It is noted that the human factor aspects are not reported to be used in the United Kingdom when

designing local dynamic warning systems or network-wide traffic flow measures. In the light of the Smart Motorways development virtual reality driver tests were extensively performed taking into account human factor aspects. However, these virtual reality simulator tests are not standard. Another expert from the United Kingdom stated that very little human factors work is carried out, which contradicts to the questionnaire results on dynamic speed management and local traffic flow management described earlier.
Finally, the figure shows only red blocks referring to human factor practice in designing traffic management measures in Norway indicating no standard practice of any human factor aspect discussed in this report at all.

In general three out of six countries indicated use human factors as a standard practice. However, some remarks from experts from these countries are contrary to these outcomes. Perception and comprehensibility are most often taken into account when designing traffic management measures and behavioural adaptation the least. Possibly this is related to unintended effects which most often are determined after the implementation of the measure than before. Also human factors are mostly taken into account when designing dynamic speed management measures and local traffic flow management measures. Except for the Netherlands, no documentation of the human factors framework used was provided.

4.3.2 Behavioural adaptation

It is possible that measures of traffic management measures lead to road user behaviours that were not intended by the measure. In most cases this is about an adaptation that negatively impacts road safety but unintended behaviours can also be positive (OECD, 1990). All countries indicated that they experience unintended effects of traffic management measures. This paragraph will describe some examples.

Dynamic speed limits, in particular, can lead to behavioural adaptation. Finland reports that drivers tend to follow the dynamic speed limits better than the static speed limits. Therefore, if the dynamic speed limits are for some reason too high, drivers tend to consider those still as safe speed – and in those cases dynamic speed limits are actually increasing the average speed leading to unsafe traffic situations. Dynamic speed warnings at bridge openings that are applied too far before the bridge itself lead to increased speeds because drivers think they can make it to the bridge before it opens (Bos & Hagenzieker, 2012). Another unintended effect in the Netherlands is that trajectory controls at motorways with a speed limit of 80 km/h may lead to traffic flows that are too homogeneous causing merging problems and hence decreasing traffic flow and possibly congestion. In line with this unintended effect, speed limits displayed on variable message signs (80 km/h) applied for safety reasons (lanes too small) and environmental benefits at the Prins Clausplein in the Netherlands also led to negative behavioural adaption. Because road users were afraid to get fined the average driving speed became 76 km/h loosing dynamics in overall traffic flow. Road users did not dare to overtake, which resulted in queues because changing lanes became impossible. Drivers who had to take the exit needed to brake causing shockwaves and resulting in queues.
Measures to manage local or network-wide traffic flows such as dynamic route information on variable message signs may lead to drivers thinking they should not take the alternative route presented because probably everyone else will take that route also and therefore decide to stay on the original route with actually the largest queue.

5 Conclusion and recommendations

In this chapter we summarize the main results and conclusions of this report. First, the most important results from the literature review as well as the questionnaire survey (section 5.1) are summarized. Subsequently (section 5.2) the main conclusions derived from these results are described and knowledge gaps, best practices and limitations of this study are discussed. Finally, (section 5.3) this chapter provides recommendations for further work in the METHOD project.

5.1 Summary of the results

The aim of WP1 was to identify current best practices as well as knowledge gaps in the area of human factors considerations in traffic management. In order to meet this aim three tasks were conducted in this project:

1. Analysing road user needs and behaviours in relation to traffic management measures
2. Conducting an inventory of current practices and experiences in a number of European countries
3. Assessing the effectiveness of traffic management measures from a human factors perspective

The literature review focussed on the first task to identify road user needs and behaviours in relation to traffic management measures. Different needs and attitudes were considered and assessment parameters useful for the effectiveness assessment of traffic management measures were determined.

It must be realised that road users are a group consisting of a variety of individuals with a great diversity of biological characteristics and characteristics acquired from training and experience (Fuller, 2005). Therefore this report states that human factors must be addressed when designing traffic management measures in order to take into account the wide variety of road user competence and habits and to achieve high compliance rates for these measures.

General models on driving behaviours are, in isolation, not sufficient for understanding road user behaviour. This study also advocates adherence to five human factor aspects. Four of these aspects are conditional for achieving the desired road user behaviour: *perception, comprehensibility, skills* and *willingness*. The fifth human factor aspect concerns *behavioural adaptation*. Since unintended negative behavioural effects are not often studied and probably underreported this aspect is crucial to take into account.
Relevant aspects which were determined to assess the effectiveness of current traffic management measures were optimising road user behaviour, reducing accidents, saving travel time (by improving traffic flow), environmental benefits and cost effectiveness.

The questionnaire survey among a number of national experts gave us insight into the deployment of current traffic management measures in practice. This allowed us to understand their perceived effectiveness, current integration of human factors thinking in their application and potential cultural differences in this respect.

The inventory shows that many practices and experiences of traffic management measures are applied in Belgium-Flanders, Denmark, Finland, the Netherlands, Norway and the United

Kingdom. Dynamic speed management measures are the most often applied of all traffic management measures. In particular, variable message signs are frequently implemented: on motorways, urban roads and on rural roads. Local dynamic warning systems are applied on motorways in each country. With regard to local traffic flow measures, ramp metering and merging measures are not often applied. However, our study finds that lane closures and overtaking bans for heavy goods vehicles are implemented on motorways in each country. Dynamic route information measures are also applied in all countries. Network route choices and travel times are frequently displayed, both in-vehicle and at roadsides. Moreover, apps providing these types of information become more common. Next to ramp metering and merging measures, multi modal information is the least often applied traffic management measure. Most types of traffic management measures are found in the Netherlands and the fewest in Finland. In the Netherlands traffic management measures are most frequently applied.

This study finds that traffic management measures are assessed to be fairly effective. However, some relevant differences in effectiveness parameters between clusters of traffic management measures and between countries exist. Local traffic flow management measures are assessed as the most effective cluster of all four traffic management clusters closely followed by dynamic speed management. Local dynamic warning systems and measures of network-wide traffic flow management are also assessed as effective, but in comparison to the other clusters to a lesser extent. Warning systems, developed to warn road users about queues, incidents and weather are assessed as most effective on reducing accidents and network-wide traffic flow measures are assessed as most effective on improving traffic flow. Further, some between-country differences in the effectiveness assessment were found with Finland assessing their traffic management as most effective and the Netherlands as least effective. Unfortunately many of the respondents did not indicate whether their effectiveness assessments were based on personal observation or on formal evaluation studies. The respondents that did give this indication based their assessment mainly on personal observation.

Finally, this study assessed to what extent the five human factor aspects are used as standard practice when designing traffic management measures. Many differences were found between countries. Experts from Belgium, Denmark and Finland indicated use of all five human factor aspects as standard practice. In the Netherlands and the United Kingdom differences were found in standard use between these aspects. Perception and comprehensibility are typically used in the Netherlands in contrast to skills, willingness and behavioural adaptation. The United Kingdom indicated that all human factor aspects are used as standard practice in case of designing dynamic speed management measures and local traffic flow management measures, but at the same time none of these aspects are used when designing local dynamic warning systems or measures of network-wide traffic management. The Norwegian response indicated to not use human factors as standard practice at all. In general, human factors are mostly taken into account when designing dynamic speed management measures and local traffic flow management measures. Perception and comprehensibility are the most common human factor aspects in standard practices. A salient finding is that, except for the Netherlands, no documentation of a human factors framework used was provided.

5.2 Main conclusions

The summary of the results of the questionnaire shows that many different traffic management measures are applied in the six European countries that were involved in our survey. In general (1), these traffic management measures are assessed as being fairly effective. Second (2), this study finds that, according to the interviewed experts, each of the six countries, except Norway, uses human factor aspects, to different degrees, as standard practice when designing traffic management measures. These conclusions both must be seen in the light of the following comments:

1. In a majority of the effectiveness assessments it is not clear to what degree the assessments made by the country respondents are based on personal observation or on evaluation studies. If the respondent did provide an indication, most assessments were based on personal observation.

2. Although most countries indicated (to a different degree) use of human factor aspects as standard practice when designing traffic management measures, the Netherlands is the only country that provided documentation on the specific framework used.

With regard to the first comment, the lack of sufficient indications on whether the effectiveness assessments were based on personal observation or evaluation studies is a shortcoming in this study. More than half of these indications are missing. In addition, for those indications that were given and were based on evaluation studies, the majority did not include sources (studies / reports). Some exceptions exist for certain responses from Finland, which mentioned the 2Decide online Toolkit; the Netherlands, which referred to a national evaluation study on dynamic speed limits (Dynamax, 2010) and a document on traffic management deployment effects (Taale & Schuurman, 2014), and the United Kingdom, referring to evaluations on the M42 Smart Motorway scheme (Macdonald et al., 2011). However, most of these evaluations are only applicable for dynamic speed management effectiveness assessments.

The second comment refers to this study´s outcome that nearly all countries indicated use of some, or all five human factor aspects as standard practice when designing traffic management measures, but also cannot provide documentation on the human factors material used. Belgium, Denmark and Finland report to use the five human factors as standard practice but none of them clearly refers to specific documents or procedures. The only country able to provide documentation on human factor aspects is the Netherlands. The Dutch respondents referred to the Human factor in Traffic Management framework (Harms, 2012) and the 10 Golden Rules booklet (Dutch Ministry of Infrastructure and the Environment, 2008) also mentioned earlier in this study (see paragraph 3.2.2). Despite of the findings that most countries indicated use of human factors as standard practice, it must be said that only one country can actually provide the documents used for this practice.

5.3 Recommendations

The aim of this study was to identify current best practices as well as knowledge gaps in the area of human factors considerations in traffic management. As discussed earlier in this study, the lack of relevant evaluation studies as a source for the effectiveness assessment of traffic management measures carried out can be seen as a shortcoming. Furthermore, countries indicated finding it difficult to assess the effectiveness of traffic management measures on environmental sustainability and cost effectiveness. In addition, in explaining the differences between countries in the overall effectiveness assessment, further research is necessary. Is traffic management really less effective in the Netherlands in comparison with other countries, or is this related to a lack of good evaluation practices? Also the effectiveness assessments can be dependent on the experts that were interviewed in the different countries. Carrying out more interviews with different experts can therefore be recommended in further research to come to a more reliable view on the effectiveness of traffic management.

Next to that, official documentation and frameworks on the use of human factor aspects as standard practice for designing traffic management are lacking in most countries. From a historic perspective, cultural differences regarding the incorporation of human factors in traffic (management) design will undoubtedly exist. Though, in this study it is remarkable that Norway, a country that is rather acquainted with traffic psychology, appears to not use human factor aspects as standard practice at all when designing traffic management. It cannot be excluded that this result is biased by personal opinions or personal standards of the interviewed expert. Again, more experts should be interviewed in each country in order to make sure to collect all relevant human factor documentation used for designing traffic management available.

As reported earlier in this study (3.2.2, 3.5 and 4.3) the best practices found are the Human factors in traffic management framework (Harms, 2012) and the 10 Golden Rules booklet of the Dutch Ministry of Infrastructure and the Environment (2008). Both documents can be used as relevant input for the remaining work in the METHOD project.

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7 References

AASHTO. (2011). *A Policy on Geometric Design of Highways and Streets*. American Association of State Highway Transport Officials, Washington, D.C.

Alppivuori, K., Anila, M., & Pajunen, K. (1995). *The influence of route guidance system on highway 4 between Järvenpää and Mäntsälä*. Helsinki: Finnra reports 86/199. 55 p. + apps. 19 p.

Anttila V., Luoma J., Rämä P. (2000). *Visual demand of bilingual message signs displaying alternating text messages*. Transportation Research Part F Traffic Psychol. Behav. 3(2) 65-74 (2000). http://virtual.vtt.fi/virtual/proj6/fits/impacts/BILINGUA_final.pdf

Bos, Y.R. & Hagenzieker M.P. (2012) *Veilig stoppen van wegverkeer bij beweegbare bruggen in beheer van Rijkswaterstaat*. SWOV, Leidschendam.

Campbell, J.L., Lichty, M.G., Brown, J.L., Richard, C.M., et al. (2012). *Human Factors Guidelines for Road Systems*. National Cooperative Highway Research Program, Report 600. Transportation Research Board, Washington, D.C.

Connekt ITS. (2011). *ITS in the Netherlands*. Ministerie van Infrastructuur en Milieu.

De Goede, M., Van der Horst, R., Wilmink, I., Taale, H. (2013). *De ontwerpweggebruiker; kenmerken van de weggebruiker en de relatie met verkeersmanagement.* TrafficQuest, Delft.

Departement afdeling Verkeerscentrum (2012). *Uitbouw van Dynamisch Verkeersmanagement op het Vlaamse autowegennet*. Ministerie van Mobiliteit en Openbare Werken.

Departement afdeling Verkeerscentrum. (2013). *Beleidsbrief Mobiliteit en Openbare Werken, Beleidsprioriteiten 2013-2014*, Ministerie van Mobiliteit en Openbare Werken.

Dutch Ministry of Infrastructure and the Environment, Rijkswaterstaat & Connekt. (2011). *ITS-Plan the Netherlands 2013-2017*. Ministerie van Infrastructuur en Milieu.

Dutch Ministry of Infrastructure and the Environment. (2006). *Effecten Verkeersmanagement: Cijfers van meer dan 100 praktijkevaluaties uit Nederland*". Rijkswaterstaat, Adviesdienst Verkeer en Vervoer (AVV), 30 november 2006, version 1.7

Dutch Ministry of Infrastructure and the Environment. (2011). *Human factors bij verkeersmanagement; Het bundelen van krachten*. Rijkswaterstaat.

Dutch Ministry of Infrastructure and the Environment. (2012). *Gedrag weggebruikers; Een handreiking om beter grip te krijgen op gedrag*. Rijkswaterstaat.

Dutch Ministry of Infrastructure and the Environment. (2014). *Human Factors aspects and requirements regarding Road Works Warnings on the ITS corridor (PPT)*. Rijkswaterstaat.

ERASER (2010). *SER and SER Approaches: State-of-the-art*. WP01-01.

European Commission. (2011). *Impact Assessment. Accompanying document to the white paper; Roadmap to a single European transport area – Towards a competitive and resource efficient transport system*. Brussels.

European Commission. (2012). *Easyway, Traffic Management Services. Deployment Guideline: Dynamic Lane Management.* Brussels

European Commission. (2012). *Easyway, Traffic Management Services. Deployment Guideline: Hard Shoulder Running.* Brussels

European Commission. (2012). *Easyway, Traffic Management Services. Deployment Guideline: HGV Overtaking Ban.* Brussels

European Commission. (2012). *Easyway, Traffic Management Services. Deployment Guideline: Incident Warning and Management.* Brussels

European Commission. (2012). *Easyway, Traffic Management Services. Deployment Guideline: Ramp Metering.* Brussels

European Commission. (2012). *Easyway, Traffic Management Services. Deployment Guideline: Traffic Management Plan for Corridors and Networks.* Brussels

European Commission. (2012). *Easyway, Traffic Management Services. Deployment Guideline: Variable Speed Limits.* Brussels

Fuller, R. (2005). *Towards a general theory of driver behaviour.* In: Accident Analysis and Prevention, vol. 37, p. 461-472.

Godthelp, H., de Goede, M., Hogema, J., Van der Horst, R., Martens, M., en Rasker, P. (2012). *Human Factors in Traffic Management*. TrafficQuest, Delft.

Harms, I, Lambers, M., Westerman, M. (2011). *Het Raamwerk van Human Factors in Verkeersmanagement*. Dienst Verkeer en Scheepvaart.

Harms, I. (2012). *Het raamwerk van human factors in verkeersmanagement; aan de slag in de praktijk.* Rijkswaterstaat, Dienst Verkeer en Scheepvaart.

Hautala, R., Raitio, J. (1999). *Effects of the queue warning system at the Helsinki Western Artery between Haukilahti and Katajaharju*. (1999). Finnra reports 48/1999. http://virtual.vtt.fi/virtual/proj6/fits/impacts/A31_2_Lansivaylan_ruuhkavaroitus_vali_abs.pdf

Hautala, R., Schirokoff, A. & Lehtonen, M. (2001). *Effects of the weather-controlled variable speed limits and warning signs on a two-lane Main Road 1 (E 18).* Traffic flow analysis and interview study between Salo – Sammatti. Finnra reports 51/2001. http://virtual.vtt.fi/virtual/proj6/fits/impacts/VMS_effectsFI_f2529.pdf

Hoogendoorn, S., Taale, H., Wilmink, I., Bertini, R.L., Van Katwijk, R., Immers, B., Schuurman, H. (2012). *The Future in Traffic Management – State of the Art, Current Trends and Perspectives for the Future*. TrafficQuest, Delft.

Horrey, W.J., Wickens, C.D. and Consalus, K.P. (2006). *Modeling Drivers' Visual Attention Allocation While Interacting With In-Vehicle Technologies*. In:Journal of Experimental Psychology, Vol. 12, No. 2, p. 67–78.

HSE Information sheet, "Crossing high-speed roads on foot during temporary traffic-management works".

Innarnaa, S., Vanhanen, K., & Pursula, M. (2000). *Effects of Automatic Traffic Control System of Länsiväylä on Traffic Flow*. Helsinki 2000. Finnish National Road Administration, Finnra Reports 5312000. 82 p. + app. 8 p. http://virtual.vtt.fi/virtual/proj6/fits/impacts/satu.pdf

ITS Initial Report. (2010). *Overview of national and regional activities and projects in the priority areas*, Belgium.

ITS Report 2012. (2012). *Reporting on national and regional ITS actions envisaged over the following five year period*, Belgium.

Macdonald, M., Wilson, S., Amey Consulting and CIRIA. (2011). M42 MM Monitoring and Evaluation; *Three Year Safety Review.* Highways Consultancy Group/Highways Research Group. Highways Agency, London.

Maerivoet, S., Akkermans, L., & Delhaye, E. (2012). Impact of the ITS Directive (in Belgium): Some Experiences with Real-Time Public Transport Information. ITS Belgium, Brussels.

Martens, M. (2013). *Behavioural Adaptation to Roadway Intelligent Transport Systems*. In: Rudin-Brown, C.M. & Jamson, S.L. (red.), Behavioural Adaptation and Road Safety; Theory, Evidence and Action. CRC Press, Boca Raton, p. 135-161.

Michon, J.A. (1985). *A critical view of driver behaviour models: What do we know, what should we do?* In, L. Evans & R. C. Schwing (Eds.). Human behavior and traffic safety (pp. 485-520). New York: Plenum Press

OECD. (1990). *Behavioural adaptation to changes in the road transport system*. Organization for Economic Co-operation and Development, Paris.

Penttinen, M., Harjula, V., & Luoma, J. (1999). *Effects of variable speed limit signs on speed behaviour and recall of signs – part2. Finnish Road Administration, Finnra reports 45/1999. Helsinki 2000. http://virtual.vtt.fi/virtual/proj6/fits/impacts/vms_tech_2.pdf*

Rämä, P. (1997). *Effects of the weather-controlled traffic management system in the motorway section between Kotka and Hamina*. Helsinki 1997: Finnish National Road Administration. 64 p. + apps. 23 p. ISBN 951-726-311-2 http://virtual.vtt.fi/virtual/proj6/fits/impacts/Effects_of_weather_controlled_traffic_management.htm

Rämä, P., Kulmala, R., Heinonen, M. (1996). *The effect of variable road condition warning signs*. http://virtual.vtt.fi/virtual/proj6/fits/impacts/effect_of_variable_road_condition_warning_signs.htm

Rämä, P., Luoma, J., Harjula, V. (1999). *Distraction due to variable speed limits.* Traffic Engineering + Control 41/1999. http://virtual.vtt.fi/virtual/proj6/fits/impacts/dist.pdf

Rämä, P., Raitio, J., Harjula, V., Schirokoff, A. (1999). *Effects of the weather-controlled traffic management system on single-carriageway road section of E18*. Finnra reports 44/1999. http://virtual.vtt.fi/virtual/proj6/fits/impacts/finnra4499_abs.pdf

Recarte, M.A. & Nunes, L.M. (2003). *Mental workload while driving: Effects on Visual Search, Discrimination and Decision Making*. In: Journal of Experimental Psychology, Vol. 9, No. 2, p. 119–137.

Ristikartano, J., Seppänen, L.M., Toiskallio, K. (2008). *Impact study of telematics on route 1 between Lohja and Ring III*. Helsinki 2008. Finnish Road Administration, Central Administration. Finnra reports, 66 p. + app. 30 p. http://alk.tiehallinto.fi/julkaisut/pdf2/3201097-v_telematiikan_vaikutustutkimus_vt1.pdf

S.n. (1998). *The evaluation of Helsinki Western Artery queue warning system*. Helsinki 1998,Finnish National Road Administration. Finnra reports 30/1998. http://virtual.vtt.fi/virtual/proj6/fits/impacts/A31_2_ruuhkavaroitus_abs.pdf

Schirokoff, A., Silla, A., Hänninen, S., Kallberg, V.P., & Askola, H. (2013). *The effect of traffic management on road, railway and maritime traffic*. VTT Technology 111. 64 s. + liitt. 5 s.

Schirokoff, A., Vitikka, H. (2001*). Drivers' opinions on variable speed limits - a driver interview on main road 9*. Finnra reports 50/2001. http://virtual.vtt.fi/virtual/proj6/fits/impacts/VIKING_P4D_A31_5_Muuttuvat_nopeusrajoitukset_vt9_%28E63%29_a.pdf

Sector Scheme Advisory Committee for Traffic Management. (2009). *National Highways Sector Schemes for quality management in Highway Works 12A & 12b For static temporary traffic management on motorways and high speed dual carriageways including on-line widening schemes*, United Kingdom Accreditation Service.

Sector Scheme Advisory Committee for Traffic Management. (2009). *National Highways Sector Schemes for quality management in Highway Works 12C For Installing, maintaining and removing temporary traffic management on rural and urban roads*, United Kingdom Accreditation Service.

Sector Scheme Advisory Committee for Traffic Management. (2009). *National Highways Sector Schemes for quality management in Highway Works 12C For mobile lane closure traffic management on motorways and other dual carriageways*, United Kingdom Accreditation Service.

Stelling, A. & Hagenzieker, M.P. (2012). *Afleiding in het verkeer.* R-2012-4. SWOV, Leidschendam.

Stevens, A., Cynk, S. (2011).*Checklist for the Assessment of In-Vehicle Information Systems*, Transport Research Laboratory.

Stevens, A., Quimby., A., Board, A., Kersloot, T and Burns, P. (2002). *Design Guidelines For Safety Of In-Vehicle Information Systems*, Transport Research Laboratory.

SWOV. (2010). *Factsheet ITS.* SWOV, Leidschendam.

Taale, H., Schuurman, H. (2015). *Effecten van benutting in Nederland; een overzicht van meer dan 190 praktijkevaluaties. Versie 3.3.* TrafficQuest, Delft, mei 2015.

Theeuwes, J. (2012). *Self-Explaining Roads and Traffic System*. In: Theeuwes, J., Van der Horst, R. & M., K. (red.), Designing Safe Road Systems: A Human Factors Perspective. Ashgate, Farnham, Surrey, UK.

Theeuwes, J., Horst, A.R.A., Van der Kuiken, M. (2012). *Designing safe road systems: a human factors perspective.* Ashgate.

Van der Horst, A.R.A., et al. (2008). *10 gouden regels*; *om rekening te houden met de weggebruiker*. Rijkswaterstaat.

Wegman, F. & Aarts, L. (red.) (2006). *Advancing Sustainable Safety; National Road Safety Outlook for 2005-2020.* SWOV, Leidschendam.

Wickens, C.D., et al. (2004). *An introduction to human factors engineering*. Second edition. Pearson.

Annex A: Response sample

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The United Kingdom				
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Mark Pooley	UK Highways Agency	mark.pooley@highways.gsi.gov.uk	Road Worker Safety Programme Manager	
Paul Mitchell	UK Highways Agency	paul.mitchell@highways.gsi.giv.uk	Head of Health and Safety	
Max Brown	UK Highways Agency	max.brown@highways.gsi.gov.uk	Smart road Team Leader, Network Services	X
Phil Proctor	UK Highways Agency	phillip.proctor@highways.gsi.gov.uk	Future Technologies Team Leader	
Ian Patey	Mouchel (Road builder/operator)	ian.patey@mouchel.com	Business Unit Director	
Samantha Jamson	Leeds ITS	S.L.Jamson@its.leeds.ac.uk	Principle Research Fellow	X

Annex B: Questionnaire

Questionnaire CEDR METHOD

Inventory of the current practices and experiences in traffic management in European countries from a human factors perspective

Summary

This survey is conducted in behalf of The Conférence Européenne des Directeurs des Routes/ Conference of European Directors of Roads (CEDR) transnational road research programme. This research programme promotes co-operation between European national road administrations to contribute to the development of safe, effective, sustainable and efficient practices in road engineering. The aim of our study is to realise the benefit of the implementation of innovation in traffic management solutions for national road administrations by embracing new techniques to get the most out of existing road networks.
Human Factors is one of the areas that has been identified where CEDR are seeking proposals for research that could improve traffic management through the design and optimisation of measures that may influence road user behaviour.

Respondents information

Country:

Name:

Position:

Institution:

E-mail address:

Part 1: Inventory of current traffic management measures

Q1: Can you indicate if the given traffic management measures are applied in your country? If yes, please specify on what type of roads these measures are implemented and also give examples of these practices in the rightmost column.

Traffic management measure	On what type of roads is the measure applied?				Example of practice
Dynamic speed management	Rural roads	Urban roads	Motorways	Not implemented	(e.g. electronic speed limits alongside roadworks)
Dynamic speed limits *(Speed limits that take into changing circumstances (such as real time traffic or the weather) and can be adjusted to unexpected situations such as weather conditions, congestions and incidents)*	O	O	O	O	
Variable message signs *(Electronic traffic signs with the aim to advise and enforce on speed limits)*	O	O	O	O	
Other (specify)	O	O	O	O	
Local dynamic warning systems (by means of electronic signs)					
Local queue warning *(warning signs on queues)*	O	O	O	O	
Incident warning *(warning signs on incidents)*	O	O	O	O	
Weather warning *(warning signs on weather conditions)*	O	O	O	O	

Other (specify)	O	O	O	O	

Local traffic flow management					
Lane closures *(closure of lanes by (electronic) signs)*	O	O	O	O	
Peak hour lanes *(use of (extra) shoulder lane(s) to optimize traffic flow during peak hours)*	O	O	O	O	
Overtaking prohibition HGV *(At some locations or at some times heavy good vehicles are prohibited from overtaking)*	O	O	O	O	
Ramp metering *(Traffic light or two-section signals to regulate access to motorways)*	O	O	O	O	
Merging measures *(advise in following distance, best speed and best moment to merge in or allow merging)*	O	O	O	O	
Other (specify)	O	O	O	O	
Network-wide traffic flow management					
Dynamic route information *(Provide up to date travel(time) information via dynamic route information panels (outside car) and navigation (in car) to influence route choices)*	O	O	O	O	
Multi-modal information *(Provide up to date travel(time) information on travel alternatives so that people can combine and compare travel options, e.g. roadside, websites or applications)*	O	O	O	O	
Other (specify)	O	O	O	O	

Part 2: Effectiveness of current traffic management measures

The primary purpose of traffic management measures is to optimize the movement of people and goods reliably and safely by keeping the transport system available, uncongested, safe and environmentally sustainable. Question 2 is about the effectiveness of the four groups of traffic management measures on the outcomes given in the first (leftmost) column.

Q2: Can you indicate the various types of effectiveness of the traffic management measure by checking the appropriate box on the effectiveness scale? (1 = not effective at all to 5 = very effective). It's allowed to mark more than one box if several measures (e.g. dynamic speed limits and VMS) have different degrees of effectiveness. Then please indicate which type of measure has which effectiveness score and whether this is based on personal observation or on evaluation studies/reports. If it's based on evaluation studies then specify the source and - if possible - please send the reports (e.g. by inserting web links).

								Based on		
Dynamic speed management	1 (Not effective at all)	2	3	4	5 (Very effective)	Don't know		Personal observation	Evaluation studies	Remarks / Source
Improve traffic flow	o	o	o	o	o	o		o	o	
Reduce accidents	o	o	o	o	o	o		o	o	
Save costs	o	o	o	o	o	o		o	o	
Change to desired behaviour of road user	o	o	o	o	o	o		o	o	
Improve environmental sustainability	o	o	o	o	o	o		o	o	
Local dynamic warning										
Improve traffic flow	o	o	o	o	o	o		o	o	
Reduce accidents	o	o	o	o	o	o		o	o	
Save costs	o	o	o	o	o	o		o	o	
Change to desired behaviour of road user	o	o	o	o	o	o		o	o	
Improve environmental sustainability	o	o	o	o	o	o		o	o	

								Based on		
Local traffic flow management	1 (Not effective at all)	2	3	4	5 (Very effective)	Don't know		Personal observation	Evaluation studies	Source
Improve traffic flow	o	o	o	o	o	o		o	o	
Reduce accidents	o	o	o	o	o	o		o	o	

Save costs	O	O	O	O	O	O		O	O	
Change to desired behaviour of road user	O	O	O	O	O	O		O	O	
Improve environmental sustainability	O	O	O	O	O	O		O	O	
Network wide traffic flow managing										
Improve traffic flow	O	O	O	O	O	O		O	O	
Reduce accidents	O	O	O	O	O	O		O	O	
Save costs	O	O	O	O	O	O		O	O	
Change to desired behaviour of road user	O	O	O	O	O	O		O	O	
Improve environmental sustainability	O	O	O	O	O	O		O	O	

Q3: **Do the traffic management measures listed above lead to behaviours which are not intended by the measure (both positive and negative), for example decreased attention, greater risk taking or increased navigational efficiency?**
(If yes, please specify which measure(s) and to what kind of behaviour it leads)

O No

O Yes

Part 3: Use of human-oriented frameworks in traffic management

In this last part of the questionnaire we look at how the following human factor aspects have been taken into consideration regarding traffic management measures.

- **Perception**: Does the road user perceive signs, signals and information in the desired way?
    - Is the road user able to (over)see everything?
    - Is there not too much distraction?
    - Are the road users' perceptions in line with the expectations?

- **Comprehensibility**: Does the road user understand what's expected and what needs to be done?
    - Does the measure lead to uncertainty in the road user's behaviour?
    - Is the desired behaviour consistent?
    - Is the measure understandable for all road users?

- **Skills**: Is the road user able to perform the desired behaviour?
    - Does the environment evoke the desired behaviour?
    - How do other road users behave in this situation?
    - Does the road user feel safe in this situation?
    - Is the desired behaviour (very) different from the behaviour the road user is used to?
    - Is the desired behaviour possible to perform in relation to the weather conditions, traffic intensity and task complexity?

- **Willingness**: Is the road user motivated to perform the desired behaviour?
    - Is the road user motivated to perform other behaviour?
    - Is the road user limited in this freedom?
    - Is other- than the desired behaviour very attractive for the road user?

- **Behavioural adaptation:** Does a traffic management measure lead to the road user's unintended change of behaviour?
    - Which unintended behaviours occur following a change in a road traffic system?
    - Does the adapted behaviour positively or negatively impact road safety?

Q4: **Are human factor criteria used for the design of traffic management measures as a standard practice? Please indicate per human factor criterion and per group of traffic management measures whether it's used and applied or not. If answered 'yes', or 'sometimes' please explain how this criterion is incorporated in procedures by giving an example. (If *not* used, the specification on the incorporation does not have to be given).**

Human factor criterion	Dynamic speed management	Local dynamic warning	Local traffic flow management	Network-wide traffic flow managing	How is it incorporated? (Please specify)
Perception	O Yes O Sometimes O No	O Yes O Sometimes O No	O Yes O Sometimes O No	O Yes O Sometimes O No	
Comprehensibility	O Yes O Sometimes O No	O Yes O Sometimes O No	O Yes O Sometimes O No	O Yes O Sometimes O No	
Skills	O Yes O Sometimes O No	O Yes O Sometimes O No	O Yes O Sometimes O No	O Yes O Sometimes O No	
Willingness	O Yes O Sometimes O No	O Yes O Sometimes O No	O Yes O Sometimes O No	O Yes O Sometimes O No	
Behavioural adaptation	O Yes O Sometimes O No	O Yes O Sometimes O No	O Yes O Sometimes O No	O Yes O Sometimes O No	
Other (specify)	O Yes O Sometimes O No	O Yes O Sometimes O No	O Yes O Sometimes O No	O Yes O Sometimes O No	

Further remarks:

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Thank you for participating in this survey.