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Malte Risto

Cooperative In-Vehicle Advice

A study into drivers' ability and willingness to follow tactical driver advice

COOPERATIVE IN-VEHICLE ADVICE

A STUDY INTO DRIVERS' ABILITY AND WILLINGNESS TO FOLLOW TACTICAL DRIVER ADVICE

Malte Risto

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Contents

1 Introduction

1.1 The costs of traffic congestion

The mobility of people and goods plays an essential role in societies and economies. A substantial part of this mobility is provided by road transportation. From the total of travelled kilometres in the Netherlands, about one third is accumulated in passenger vehicles (Kennisinstituut voor Mobiliteitsbeleid, 2013). Since 2005 the growth in car mobility (number of trips and kilometres travelled by individual passenger vehicles) has declined. However, until 2017, the Dutch "Kennisinstituut voor Mobiliteitsbeleid" expects an increase in road traffic volumes by 1.5 percent (Kennisinstituut voor Mobiliteitsbeleid, 2013). In 2014, the number of kilometres annually driven on Dutch national roads has reached an all-time peak at 65.3 billion kilometres (van Veluwen & de Vries, 2014). This prediction is based on the expectation of further economic recovery and an expected reduction in oil price relative to 2012 (CPB, 2012). A problem associated with rising traffic volumes is the increased societal cost of road congestion, traffic accidents and environmental pollution. For 2012, the total cost has been estimated at between 19.9 and 20.9 billion Euro (Kennisinstituut voor Mobiliteitsbeleid, 2013). In 2012 the cost of congestion on Dutch roads due to delay has been estimated at between 1.8 and 2.4 billion Euro (Kennisinstituut voor Mobiliteitsbeleid, 2013).

1.2 Causes of traffic congestion

When studying traffic flow breakdown and the forming of congestion, a central role is given to the ratio of vehicles on a given road (denoted as traffic intensity or demand) and the road capacity (Faber et al., 2011; Tadaki et al., 2013). Despite the lack of a general definition of capacity, it has been described as the maximum number of vehicles that a road can facilitate without congestion forming (Kerner, 2009). When traffic demand reaches the maximum road capacity, traffic flow disturbances can lead to congestion forming (Treiber & Kesting, 2013). Such disturbances are events in traffic that lead to fluctuations (usually a reduction) in vehicle speed. When these disturbances are not dampened out (e.g. in situations where the inter-vehicle distances are too small to have a damping effect), they can propagate through traffic as shockwaves and can lead to congestion.

The American Federal Highway Administration reported seven "sources" of congestion on motorways (FHWA, 2005). These sources are separated in three clusters. First, traffic-influencing events, including traffic incidents, work zones and adverse weather conditions. Second, traffic demand, including day to day fluctuations in normal traffic and special events that cause "surges" in traffic demand (e.g. holidays, sport-events). And third, fixed highway features, including traffic control devices and fixed bottlenecks (e.g. lane drop, bridges) (FHWA, 2005). These clusters can be linked to the concepts of demand, capacity and disturbance. They can either lead to an increased traffic demand, a reduced road capacity or lead to disturbances in traffic flow.

Three broader categories of congestion are differentiated: shockwaves, incidental congestion, and infrastructural congestion (Faber et al., 2011). Shockwaves are characterized as locations of low speed (lower than 60 km/h) that are surrounded by locations of higher speed (above 70 km/h) in both directions. A shockwave propagates against the driving direction through traffic and can either be unrelated to the congestion, be the result of congestion, or lead to congestion. Incidental congestion is related to incidental bottlenecks such as, for instance the closing of a driving lane due to an accident. Infrastructural congestion is related to infrastructural bottlenecks (e.g. end of motorway lane, intersections, uphill gradients) and therefore occurs at a fixed location.

The effect of infrastructural bottlenecks can be regarded as a major factor in reducing the capacity of a given road and causing traffic flow disturbance (Kerner, 2009). Congestion usually forms upstream of a bottleneck when traffic density on a road is high (Treiber, Hennecke, & Helbing, 2000). Bottlenecks may become active or inactive depending on the proportion of traffic demand to road capacity (Daganzo, 1997). This means that a reduced road capacity in itself, as created by a bottleneck, may not lead to congestion as long as the traffic demand does not exceed that capacity. The most iconic bottlenecks (incidental or infrastructural) include variants that force road users to perform merging manoeuvres, due to the blockage or restriction of one or more lanes on a road (e.g. lane drop, accident, construction zone). These bottlenecks reduce the capacity of the road while they also cause disturbances by forcing a greater number of vehicles to merge into another lane (Ahn & Cassidy, 2007).

1.3 The role of humans in congestion

Despite an increased interest in automated driving (Hoogendoorn, van Arem, & Hoogendoorn, 2014; Meyer & Beiker, 2014; Thrun et al., 2006; Urmson et al., 2008), driving on public roads is an activity that is still predominantly carried out by humans. Therefore, when studying congestion, a central role must be given to the behaviour of the human driver. The behaviour of a single driver can be sufficient to cause congestion. As Chandler, Herman and Montroll stated in 1958, in dense traffic “driving is done on the verge of instability” (p.1). A single driving manoeuvre can introduce disturbance in traffic flow that, in dense traffic conditions, can develop into a shockwave or a traffic jam. Furthermore, disturbances can have an effect on traffic flow that is similar to physical capacity restrictions by creating “temporary losses in capacity” (FHWA, 2005). Several situations can be identified where driver behaviour introduces disturbances in traffic flow or temporarily decreases the capacity of a road.

1.3.1 **Variability in vehicle control behaviour**

Individual drivers show a degree of variability in parameters regarding vehicle control (e.g. speed, gap size, lateral lane position). For example, studies in car following have shown that drivers tend to oscillate around a preferred gap size (Brackstone, Sultan, & McDonald, 2002; Brackstone, Waterson, & McDonald, 2009; Kim, Lovell, & Park, 2007). In dense traffic this variability in following behaviour can lead to disturbances and may cause traffic flow breakdown (Sugiyama et al., 2008; Tadaki et al., 2013).

1.3.2 **Lane changes and merging in dense traffic**

In dense traffic, drivers may be motivated to change lanes under the assumption that other lanes are moving at a higher speed (Redelmeier & Tibshirani, 1999). Lane changes in dense traffic may result in small gap sizes between vehicles after the lane change has taken place (Daamen, Loot, & Hoogendoorn, 2010). This can cause braking manoeuvres and traffic flow disturbances (Redelmeier & Tibshirani, 2000). Road users changing lanes and merging into a small gap force drivers in the adjacent lane to decelerate (Ahn & Cassidy, 2007). In a study on lane change behaviour when merging into motorway traffic, Daamen et al. (2010) observed that the smallest accepted gap between vehicles before merging varied between 0.75 and 1.0 seconds. After merging had taken place this resulted in time-gaps smaller than 0.25 seconds from the merged vehicle to the new leader or the new follower. Also, merging with speed differences, such as merging into heavy motorway traffic with lower speeds, can be a cause of traffic flow disturbances and lead to congestion (de Waard, Dijksterhuis, & Brookhuis, 2009; Duret, Bouffier, & Buisson, 2010).

1.3.3 **Distribution of vehicles over driving lanes**

Poor lane utilisation, as reflected in the inefficient distribution of vehicles over driving lanes, influences traffic flow (Faber et al., 2011). That is, overuse of a particular lane can lead to an inefficient utilisation of the road’s capacity (Knoop, Duret, Buisson, & van Arem, 2010). For example, at the start of the core area of a weaving section, where two motorways merge, the left lane on the right motorway and the right lane of the left motorway may be overused, as drivers who want to switch motorways occupy these lanes. In addition, during the joining of the two motorways, frequent lane changes introduce disturbances to the lanes that have already reached maximum capacity.

1.3.4 Vehicles entering a traffic jam at high speed and exiting it at low speed

When congestion has already formed, driver behaviour can increase the likelihood that it will grow into a larger traffic jam and cause spillback to other roads. Drivers' ability to anticipate upcoming traffic situations is restricted since drivers can only perceive the traffic situation in close proximity to their vehicle. This causes a problem in case of a needed reduction in speed due to disturbances around a bottleneck further down the road. Drivers, approaching the bottleneck, are not aware of the reduced speed ahead. This leads to situations where the in-flow rate of a traffic jam is higher than it's out-flow rate. More vehicles enter the traffic jam, at the same time interval, than vehicles exit the traffic jam. It is argued that this relation of the out-flow rate at which vehicles exit a traffic jam, and the in-flow rate at which they enter a traffic jam, affects the life-time of the traffic jam (Vergeest & van Arem, 2012).

In sum, congestion on motorways is related to road demand, by passenger and cargo traffic, that exceeds a roads capacity. When a road is near its capacity, disturbances in flow can lead to traffic flow breakdown and congestion. The examples above show that driving behaviour plays a role in congestion forming by increasing road demand, creating disturbances in traffic flow and temporarily reducing capacity.

1.4 Approaches to solve traffic congestion

Until the end of the 20th century, interventions targeting congestion reduction in the Netherlands mainly involved generating road capacity by building and expanding the road infrastructure in order to accommodate the rising traffic demand. In the last decades, the focus has shifted towards a better management of traffic in the existing road network in order to make more efficient use of the available capacity. Noteworthy in this context is the use of dynamic route-information panels (DRIP), ramp metering and the use of the emergency lane as additional lanes on motorways during peak hour traffic (peak hour traffic lanes also known as 'spitsstroken'). Also noteworthy has been an initiative (called 'spitsmijden') rewarding drivers to shift their commuting trips out of peak hours. A first test started in 2005 and by 2007 a first evaluation showed a reduction of the number of trips in rush hour periods (Spitsmijden, 2007). At last, the goal of the "Beter Benutten" initiative, that started in 2011, has been to reduce congestion in problem areas in the Netherlands by 20 percent by 2014 (Rijkswaterstaat, 2013). To achieve this goal, a set of diverse measures is implemented that include fine-tuning of traffic light phases, the promotion of flexible working hours, supporting the adoption of alternatives to the automobile (e.g. e-bikes) as well as the application of Intelligent Transport Systems.

1.5 Cooperative Intelligent Transport Systems

Intelligent Transport Systems (ITS) refer to the application of information and communication technology in the domain of road transport in order to manage traffic and mobility more efficiently (Nowacki, 2012). Enabled by developments in information and communication technology, cooperative forms of ITS have been developed. The cooperative aspect stems from the active sharing of information between entities in order to achieve a common goal. A definition of cooperative systems in road traffic has been provided by the European Commission:

"Road operators, infrastructure, vehicles, their drivers and other road users will co-operate to deliver the most efficient, safe, secure and comfortable journeys. The vehicle-vehicle and vehicle-infrastructure co-operative systems will contribute to these objectives beyond the improvements achievable with stand-alone systems." (*Third eSafety Forum*, 2004)

The effects of applications of cooperative systems in traffic have been studied in several European projects such as CVIS (Kompfner, 2010), COOPERS (Bankosegger, Fuchs, & Frötscher, 2010) and SAFESPOT (Andreone et al., 2010). In these projects the main focus of cooperative systems was on improving traffic safety and improved management and control of the road network.

Other projects, such as SPITS (e.g. van den Broek, Netten, & Lieverse, 2011) and Connect & Drive (e.g. Ploeg, Serrarens, & Heijenk, 2011) have developed and studied applications of cooperative, in-vehicle systems for improving traffic efficiency on roads. Vehicles were equipped with the ability to exchange information about acceleration and speed with other vehicles in a platoon in order to improve the vehicles' reaction to driving manoeuvres (e.g. braking, accelerating) of other vehicles. These cooperative systems enabled driving behaviour that has been shown to dampen shockwaves and counteract congestion forming (Netten, van den Broek, Passchier, & Lieverse, 2011; van Arem, van Driel, & Visser, 2006; van den Broek, Netten, et al., 2011).

It is expected that, in the long-term, cooperative in-vehicle systems, that take over parts of the driving task in order to improve traffic flow efficiency, will be implemented on a large scale (Hellendoorn, de Schutter, Baskar, & Papp, 2011; van den Broek, Netten, Hoedemaeker, & Ploeg, 2010). However, until these systems are market ready they face a series of challenges with regard to technical, human factors and legal issues.

To have considerable effect on traffic efficiency, the penetration rate is a crucial factor in determining the effectiveness of a system. That means a certain number of vehicles needs to be equipped with the technology. In real road applications, it is crucial to quickly increase penetration levels in order to find any effects after implementation. However, since some of these applications need to take (at least part of) the control over the vehicle, these systems must be integrated inside the vehicle and interact with the vehicle controls. Therefore, it seems only logical that these systems will not be introduced as aftermarket systems, but as systems built in by vehicle manufacturers. In addition, an after-market implementation might not be feasible with some (especially older) vehicles. Also, cooperative driving technologies, such as those studied in SPITS and Connect & Drive, are still under development and are not market-ready within the coming years for the larger public. These challenges make the short term implementation of semi-automated, cooperative in-vehicle systems to improve traffic efficiency unlikely.

Furthermore, systems that assume control over the vehicle face a series of human factors issues (for an overview see Jones, 2013). Automation applied to vehicle control can fundamentally change the nature of the driving task. This can result in dangerous situations as drivers adapt to their new role in the task (Martens & Jenssen, 2012; Patten, 2013). For example, in response to higher levels of automation drivers are taken more and more out of the control loop because their task changes from actively operating to monitoring the vehicle (Bainbridge, 1983; Dehais, Causse, Vachon, & Tremblay, 2012). Associated with this phenomenon are different human factors problems such as loss of situational awareness, too high or too low workload, and the possible loss of skills (Endsley & Kiris, 1995; Endsley, 1995; Onnasch, Wickens, Li, & Manzey, 2013; Stanton & Young, 1998). In case of system failures, the human monitor suddenly needs to become an active driver again, requiring a rapid response to a potentially dangerous event. In such situations, the possibility of human error may increase (Moray, 1986; Parasuraman & Manzey, 2010; Sheridan, 2012). Although the partial allocation of the driving task to automation aims to solve problems, it can introduce others, stemming from new forms of driver-system interaction.

From a legal point of view, automated driving introduces questions with regard to the liability in case of system failure and damage caused by using the system. According to the Vienna Convention on Road Traffic a driver must always be in control of the vehicle (UN Economic and Social Council, 1968). However, with regard to automated driving it has been argued that current law is not able to adequately allocate responsibility to the party that caused an accident (Gurney, 2013).

In sum, cooperative systems have the potential to improve traffic flow efficiency. However, the state of technological development, the need for communication with board electronics, human factors and liability issues, all pose challenges to the fast market introduction of in-vehicle systems that assume control over the vehicle. There is a need for cooperative, in-vehicle systems that can be introduced on the short- or mid-term (van den Broek, Netten, et al., 2011). Faster market penetration may be achieved by systems that are easily implemented, without taking an active role in controlling the vehicle.

1.6 Cooperative In-Vehicle Advice

As an alternative to intervening in the control of the vehicle, cooperative systems may inform, warn and advise drivers in order to improve traffic flow efficiency in the short-term. The SPITS and the Connect & Drive project also presented first approaches to use cooperative, in-vehicle technologies to influence the behaviour of drivers instead of directly controlling the vehicle. In these examples, a human-machine interface is used to guide driver's acceleration (SPITS) or speed behaviour (C&D). Results show that an improvement of traffic efficiency may be reached by influencing driver behaviour (Netten, van den Broek, & Koenders, 2011; van den Broek, Netten, et al., 2011).

An overview of the human role in congestion has shown that various forms of driver behaviour can lead to congestion. Advisory systems, focussing on speed and acceleration behaviour, have shown beneficial effects on traffic flow(Netten, van den Broek, & Koenders, 2011; van den Broek, Ploeg, & Netten, 2011). It may therefore be promising to explore the effect of advice on other forms of driver behaviour, such as gap and lane choice.

In the Connected Cruise Control project, a Cooperative In-Vehicle Advisory (CIVA) system has been developed that aims to improve traffic flow efficiency and reduce congestion by advising drivers on their speed, gap size and lane choice with the goal to prevent or solve suboptimal traffic flow conditions (Schakel & van Arem, 2013). The prospective users of the system would be commuting traffic that would use the system in rush hour traffic. The advice is generated at a traffic management centre based on real-time information about the traffic state. The research that is presented in this thesis was carried out in the course of the project.

1.7 Research objective

The effect that the CIVA system can have on traffic flow is dependent on the number of vehicles that are equipped with the system, as well as factors that are related to drivers' compliance with the advice. The objective of the current research was to evaluate system design decisions with regard to their effect on drivers' ability and willingness to use the system and their ability and willingness to follow the given advice. Therefore the attitude of drivers towards the system was studied using questionnaires. Furthermore, the behavioural as well as the cognitive/affective reaction to advice messages was studied during direct interaction of drivers with the system in driving simulators and on the real road.

1.8 Outline of the introduction chapters

After introducing the role of driving behaviour in forming congestion in Chapter 1, Chapter 2 introduces the CIVA system. First, the system is categorized according to existing categories for ITS. A broader description of the advice (e.g. advice strategy, advice generation, advice presentation) is provided. Furthermore, two important determinants for the effectiveness of the system (i.e. penetration rate of the system and compliance rate to the advice) are introduced. Chapter 3 provides a background on influencing the driving task in congested motorway traffic through driver advice. Chapter 4 defines the scope of the research and describes which research questions were studied at different stages in the development process. This chapter also presents the outline of the research chapters of the thesis.

2 System description

In this chapter the CIVA system will be introduced. First, the concept of the system will be described along the line of criteria that have been used before to describe existing ITS applications. The strategy behind the advice and the process of advice generation by the CIVA system the project will be described. The human-machine interface is introduced and human factors aspects are discussed. At last, it is discussed how the system may be characterized and what aspects determine the success of the implementation of the CIVA system.

2.1 Comparison of CIVA to existing ITS

2.1.1 Purpose of the system

The purpose of ITS products may be to improve the comfort, fuel efficiency and safety of driving. However, they can also contribute to societal objectives such as the reduction of congestion (van Driel & van Arem, 2010).

The purpose of the CIVA system is to reduce congestion in motorway peak hour traffic by changing driver behaviour. Therefore, the main focus of the system is not necessarily to improve driver comfort or safety but traffic flow efficiency (Schakel & van Arem, 2014). However, traffic flow efficiency should not come at the cost of driver safety and comfort.

2.1.2 Connectedness

Intelligent transport systems may connect people, infrastructure and vehicles in a network through the use of information and communication technology (Nowacki, 2012). On the other hand, ITS that use information processing technology but that are not connected, rely on on-board sensors and processors to generate needed data autonomously. Examples of such systems can be found among the so called Advanced Driver Assistance Systems (ADAS) such as Adaptive Cruise Control, Lane Departure Warning, Fuel Efficiency Support or Crash Avoidance Systems. In connected systems, people, vehicles and road infrastructure are part of a network, sending, receiving or exchanging data. Cooperative systems belong to the connected systems. These systems exchange data with other cooperative systems, rather than only send or receive it (Bishop, 2005). For cooperation, the type of data that is sent does not have to be identical to the type of data that is received.

2.1.3 **Task in the transport system**

In a network of connected systems, data from different sensors (e.g. in vehicles and in the road infrastructure) can be combined in order to improve the safety, efficiency or environmental impact of transport. Different sources, such as induction loops, floating cars, speed cameras, collect and share data. In the network data streams are combined, processed and transmitted to systems that act on it (as it often is the case with traffic demand data, weather data or dynamic speed-limit data). A connected system may carry out one or a combination of the above tasks. For example Cooperative-ACC systems collect, process, transmit but also received data. C-ACC systems are similar to common ACC systems, which use distance measurement to keep a constant time gap to the vehicle in front. In addition C-ACC systems also exchange speed and acceleration data with other C-ACC equipped vehicles to allow for faster reactions to longitudinal vehicle movement. Further examples of systems that carry out several tasks are traffic lights that receive and process speed and braking status data from approaching vehicles and send a signal to either stop or pass through, or vehicles that communicate their position and route information to a traffic management centre and receive a coordinated route advice that is optimized for network utilisation.

2.1.4 **Locus of components**

A distinction can be made between road-side and in-vehicle components of a system. Road-side components can collect data (e.g. traffic cameras, induction loops) or broadcast information, warnings, advice messages or directives (e.g. by means of variable message signs, dynamic route information panels, dynamic speed limit). In-vehicle systems can collect data (e.g. vehicle state, environment and image data) or engage in the driving task through automation, information, advice or warnings.

With a single stationary sign, a message can be delivered to all drivers at a specific location. This makes them suitable for situations where all drivers need to adjust their driving behaviour in response to current traffic, weather or road conditions. Stationary signs can also target sub-groups of drivers (e.g. depending on their lane position). However, providing different messages to drivers on a single lane or targeting individual drivers can be difficult.

In-vehicle systems can provide messages to individual drivers through a human-machine interface. This allows for the message to be individually tailored to the driver, the driver’s environment or the type of the vehicle (e.g. passenger car or commercial vehicle). The interface can provide a message via different modalities. In addition to visual messages, in-car applications can make use of the auditory (e.g. spoken text, sound signals) and haptic modality (e.g. force feedback on gas pedal or steering wheel). Furthermore, in-car systems provide a higher resolution in time and space to issue an advice compared to the stationary road side systems. In-car advisory systems can be retrofitted as aftermarket applications to achieve fast market penetration. However, for the use of haptic or tactile cues the system needs to communicate directly to the vehicle electronics and requires additional hardware.

The CIVA system makes use of an in-vehicle HMI (Human Machine Interface) to deliver the advice to the individual drivers. The modalities of the advice will be restricted to the visual and the auditory to ensure that the system can be implemented as a retrofit system into existing vehicles.

2.1.5 **Types of data**

Components in an intelligent transport system can collect, process and exchange different types of data in the network. Vehicles can collect state data (e.g. speed, gap size, acceleration, braking activity), environment data (e.g. radar, lidar, light, slope) or image data (e.g. in-vehicle cameras). Roadside systems can collect image data (e.g. traffic cameras), inductive loop data, or floating car data. Different data types can also provide redundant information. So an in-vehicle camera system can provide lane position data through image processing, while the same information may also be obtained by high precision GPS data and an accurate map of the road environment.

Disconnected, in-vehicle systems rely on the available data from equipped sensors (e.g. radar, brake activity, light, image) to obtain a representation of the vehicle state and the environment around the vehicle. Connected systems may receive data from any other connected system through wireless communication (e.g. Dedicated Short Range Communications (DSRC), 3G, Bluetooth). Therefore the types of data that are available to connected vehicles can be greater than that of disconnected vehicles.

In addition to floating car data and inductive loop data the CIVA system uses vehicle state data (i.e. acceleration, speed, gap size) gathered by in-vehicle sensors. Also, image data from a front facing camera is processed to determine the lane position and gap size. In addition the final system will also use high accuracy GPS location data and dynamic map data. Furthermore, the final version of the system may also consider route choice information to further adapt the advice.

2.1.6 **Communication partners**

In the context of cooperative ITS, information is shared by means of Vehicle to Vehicle (V2V), Vehicle to Infrastructure (V2I or I2V) or Infrastructure to Infrastructure (I2I) communication.

In V2V communication, vehicles can share information about their state (e.g. position, speed acceleration, gap size etc.). For instance, in a platoon of vehicles, information about the speed and acceleration of several leading vehicles can be communicated to a following vehicle. This information can then be used to improve the performance of previously disconnected vehicle technologies, such as Adaptive Cruise Control. In other applications, V2V communication can be used to prevent accidents in situations where a drivers' view is blocked (e.g. street corner, bus stop), systems may sense and broadcast their position or the position of other vehicles or pedestrians (Bishop, 2000).

With V2I and I2V communication, vehicle data can be sent back and forth between the vehicle and intelligent infrastructure (such as traffic lights, traffic signs or toll stations) that may interact with the vehicle based on the shared communication. Furthermore, vehicles may communicate with traffic management centres. In these centres data-streams from several vehicles may be combined to detect specific events such as rain (by means of window wiper activity), slippery road conditions (by means of activity of the traction control system) or congestion (by detecting low speed or braking activity). Information about an event can then be communicated back to other drivers.

In I2I communication road side systems (such as induction loops, traffic cameras or traffic signs) may exchange information with each other or with traffic management centres. For instance, the information that a traffic management receives from induction loops can yield a refined representation of the traffic situation that can be communicated back to message signs along the road.

The CIVA in-vehicle human-machine interface will receive the advice message data via mobile broadband (3.5G) from a central server at a traffic management centre. Also the in-vehicle system will be used to transmit floating car data to the traffic management centre; these aspects of the system use V2I/I2V communication. Furthermore, in the traffic management centre traffic loop data is used to generate the advice. Therefore this aspect of the system also includes an I2I communication component.

2.1.7 **Longitudinal / Lateral**

A common classification of in-vehicle systems is based on whether they support the longitudinal or the lateral driving task (Bishop, 2005). Generally, the longitudinal driving task includes the choice and maintaining of speed and inter-vehicle distance. Systems that support the longitudinal driving task are, for instance, Adaptive Cruise Control, Forward Collision Warning or Intelligent Speed Assistance. The lateral driving task includes lane change and merging behaviour as well as maintaining the lateral position on a lane. Systems that support the lateral driving task include Lane Departure Warning or Blind Spot Monitoring (Tideman, van Der Voort, van Arem, & Tillema, 2007).

By advising drivers on their speed, gap size and lane choice, the CIVA system engages in the lateral as well as longitudinal driving task.

2.1.8 **Level of support**

The level of support of ITS has been categorized as intervening/controlling, informing, warning/advising and instructing (SWOV, 2010). A way of classifying Advance Driver

Assistance Systems (ADAS), In-Vehicle Information Systems (IVIS) and Active Traffic Management (ATM) based on their level of support has been proposed by Van Koningsbruggen, Daalderop and Nootenboom (2011) and is shown in Figure 2.1.

Intervening / Controlling	**Informing**	**Warning / Advising**	**Instructing (directive)**
• Electronic stability control • Cruise control systems • Lane keeping assistance • Collision avoidance	• Travel times • Traffic jams (location & length) • Weather • Obstructions	• Traffic conditions • Road surface conditions • Weather conditions • Route guidance • Speed alert • Sleepiness detection	• Managed intersections and junctions • Dynamic speed limits • Opening / closure of traffic lanes, hard shoulder etc. • Diversions

← ADAS → ← IVIS → ← ATM →

Figure 2.1 Levels of support of ITS systems (Van Koningsbruggen et al., 2011)

By informing, warning and advising drivers, according to the categories shown in Figure 2.1, the system may be classified as IVIS on the border to ATM. However the classification of the system as driver support or traffic management is not straight forward. This will be discussed later in this chapter (see system characterisation).

2.1.9 Level of automation

For in-vehicle systems there is a spectrum of automation between the outer positions of fully manual and fully automated driving. The Society of Automotive Engineers (SAE) has divided this spectrum into six levels: no automation, driver assistance, partial automation, conditional automation, high automation and full automation (SAE International, 2014).

No automation means that the human driver performs all aspects the dynamic driving task at all times, even when enhanced by warning or intervention systems. For instance, this is true for intelligent speed advice, lane departure warning or acoustic warning systems for parking. Driver assistance means that a driver assistance system takes over either steering or acceleration/deceleration using information about the driving environment. The human driver still performs all remaining aspects of the dynamic driving task. Examples of that are the Adaptive Cruise Control, a Lane Keeping Assistant or manoeuvring aids for low speed operations (e.g., parking system). Partial automation means that one or more driver assistance systems take over both steering and acceleration/deceleration using information about the driving environment. The human driver still performs all remaining aspects of the dynamic driving task. Examples of partial automation are the combination of active lane keeping assistance with Adaptive Cruise Control. Driver action is still required for performing, for instance, lane change manoeuvres. Conditional automation means that the automated driving system takes over all aspects of the dynamic driving task. The human driver is freed from most of the driving task but responds to a request by the system to intervene (e.g. at system limits). High automation means that the automated driving system takes over all aspects of the dynamic driving task. The system performs the driving task even if a human driver does not respond appropriately to a request by the system to intervene. Finally, full automation means the full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver. The driver is no longer a driver but a passenger and infrastructural and on-board equipment as well as traffic management centres take over the manoeuvring of the vehicle (e.g. Toffetti et al., 2009).

The CIVA system will not intervene in the vehicle control, but instead it will provide information and advice to the driver. Therefore, on the automation spectrum, driving with the CIVA system classifies as no automation.

2.2 Description of the system

2.2.1 **Advice strategy**

There are existing applications of advisory systems that influence driver behaviour with the goal of improving traffic flow. An example from Japan is a road-side lane advice, which is provided by a variable message sign to balance lane-use on a carriageway with an approaching on-ramp. Drivers on the carriageway are advised whether to stay in their lane or change lanes anticipating vehicles from the on-ramp. Drivers on the on-ramp are advised to stay on their initial lane after merging onto the carriageway. In an experiment the measure resulted in a slightly more balanced distribution of vehicles on the carriageway after the on-ramp location (Xing, Muramatsu, & Harayama, 2013). Also an in-vehicle system has been studied that provides lane advice to reduce congestion in up-hill sections of motorway that cross a valley (Hatakenaka et al., 2004). The system issues a lane advice to drivers approaching the up-hill section in order to reduce imbalances in lane utilization. Also a road-side speed advice has been studied that targets drivers at the head of a cue in congestion. As a an effect of to the system the discharge flow rate improved at the head of congestion (Murashige, 2011; Sato, Xing, Tanaka, & Watauchi, 2009). An example of in-vehicle advice targeting speed choice is the CSA system, that was developed in the Connect & Drive project (Happee, Saffarian, Terken, Shahab, & Uyttendaele, 2011).

Each of the systems mentioned above targets only a single type of driving behaviour such as speed-choice or lane-use. A system targeting different types of driver behaviour and coordinating which advice is provided to individual drivers on a lane level may have a greater beneficial effect compared to a single-behaviour system. An advice strategy is required to determine what advice drivers receive on a particular lane and in which order various advice messages should be presented. Several approaches of how the CIVA system may influence driver behaviour in order to optimize the use of available road capacity and avoid disturbances have been provided by Schakel (2014). The following approaches are the basis for the systems advice strategy:

- In situations where traffic demand on individual lanes is high, the distribution of intensity over lanes may be optimized by improving lane choice behaviour.
- Lane change behaviour may be improved to allow for smoother lane changes creating fewer disturbances. This includes improving gap sizes on target lanes to facilitate merging, as well as reducing speed differences speeds of merging vehicles to the target lane.
- Driver behaviour at the end of shockwaves and traffic jams may be improved. This includes drivers speeding up at the head of a traffic jam in order to reduce the split between the number of vehicles that enter a traffic jam and those who exit it at the same time.
- Anticipation behaviour can be improved to help drivers recognize potential disturbance-creating situations and act to avoid them. An example is changing lanes to the left in order to avoid spillback from an off-ramp.

Schakel (2014) illustrates how the combination and coordination of several forms of advice (i.e. lane-use, speed-choice and choice of gap size) can have a beneficial effect on traffic flow efficiency. Following this advice strategy, the system adapts its advice dynamically to individual drivers. This means that drivers are advised differently depending on their current lane, speed and gap size. Also the system coordinates the behaviour of equipped drivers. For example, not all drivers on a lane may receive an advice to change lanes at the same time.

Improving traffic efficiency on a road level, by targeting individual drivers with combinations of different advice messages, falls within the description of Microscopic Dynamic Traffic Management (MDTM). The most prominent distinction between a macroscopic and a microscopic traffic management scheme is that the focus changes from a network level to an individual driver level (Habtemichael & Santos, 2012). The MDTM approach has shown beneficial effects on traffic efficiency in simulation studies (Daamen, van Arem, & Bouma, 2011).

Here, several questions with respect to the advice strategy can be posed:

- Do drivers regard system's advice strategy as an effective solution to improve traffic efficiency in dense commuter traffic?
- In what traffic situations would drivers want to be advised?
- What do drivers expect from tactical driver advice that aims to improve traffic efficiency?

2.2.2 **Advice generation**

The advice is generated in a traffic management centre. To generate the advice, two algorithms are applied: first, a traffic state prediction algorithm, second, an advice algorithm.

To predict the traffic state in order to provide an appropriate CIVA, the current traffic state is estimated based on data from inductive loop detectors in the road (I2I), as well as floating car data (V2I) from equipped vehicles. Loop detector data provide minute averages of traffic intensity and speed. Floating car data provide the speed and position of individual vehicles. CIVA estimates the current traffic state and predicts the future traffic state based on individual lanes and in cells with a length of about 100 metres (Schakel & van Arem, 2014).

The advice algorithm follows an approach consisting of the four following steps. First, infrastructural properties (e.g. ending lane, inner lane at an upcoming weaving section, left/right lane at the next split section after weaving) are assigned to the cells on each lane. Second, different advice principles generate advice regions around a predicted trigger such as high flow or low speed. The principles are:

- Acceleration advice principle
- Distribution advice principle
- Spillback advice principle

The three advice principles are based on the advice strategy by Schakel (2014). Based on these principles, it is defined where, when, what, and how many advices need to be given in each advice region in order to improve traffic flow efficiency.

The goal in the acceleration advice principle is that drivers accelerate more efficiently out of the downstream end of congestion. It is argued that the average driver will accelerate only if the actual gap size is larger than the desired gap size (Schakel & van Arem, 2014). Advice should make drivers more attentive of changes in traffic flow in order to notice increasing gap sizes and close the gap earlier. This may reduce the capacity drop (i.e. the fact that outflow from congestion is lower than the maximum stable flow before traffic flow breakdown), that reduces traffic flow efficiency.

The distribution advice principle triggers in case of higher predicted demand on a single lane, compared to the other lanes, for example as a response to lane changes at a lane-drop, weaving section or an on-ramp. The goal is it to distribute traffic more equally over the lanes. Depending on the section, advice may be given in order to allow smoother lane changes, minimizing the disturbance on the busy lane and reducing the probability of traffic flow breakdown (i.e. traffic slowing down resulting in congestion).

The spillback advice principle aims to avoid predicted spillback from off-ramps that causes congestion on freeways. Advice will be given to divert traffic away from the right lane when approaching an off-ramp.

The three advice principles operate independently. Therefore the third step of the advice algorithm is to filter the overlapping advice regions. The fourth step is to coordinate the assignment of different users of the system to different advices (For an in-depth description of both algorithms see Schakel & van Arem, 2014).

Depending on the assignment in step four of the advice algorithm, an advice message is sent from the server (I2V) to the in-vehicle device of an equipped driver. On the device the advice is further adapted to accommodate for the vehicle's current speed, gap size and lane position, and speed limit before it is presented to the driver. Figure 2.2 gives an impression of the flow of information involved in the generation and dissemination of the advice.

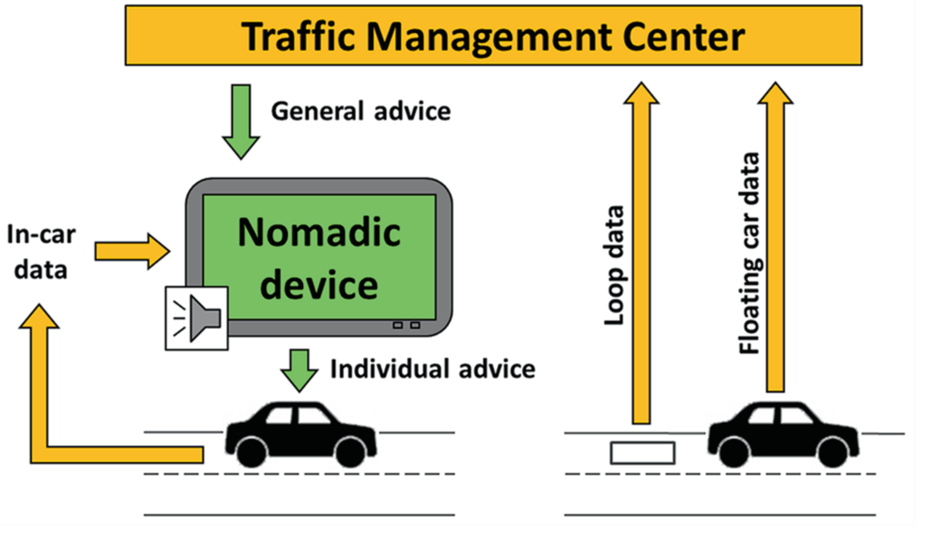

Figure 2.2 Communication of traffic information and advice information

Loop detector data is aggregated and sent to the traffic management centre once every minute. Therefore the traffic state prediction and advice generation algorithm are executed every minute on a new batch of loop detector data. This also means that the traffic state is predicted about one minute into the future and that advice messages are based on this prediction. From a standpoint of technical feasibility it is therefore possible to produce an advice every minute. However, the optimal frequency for driver advice from a traffic management point of view as well as a human-factors point of view has not been determined yet. From a human factors point of view the advice should be designed to maximise behavioural effects but minimise the additional workload and distraction for the driver. Furthermore, a high perceived effort as well as annoyance due to frequent advice may lower the acceptance of the system. Therefore, a lower advice frequency is preferred over a higher one.

2.2.3 Advice presentation

To drivers the advice messages are presented via the in-vehicle human-machine interface (HMI). To present the advice in the vehicle the most commonly used modalities are the visual, auditory and tactile (Sarter, 2006). To ensure the retrofitting ability of the CIVA system, while using market ready technology, its communication capabilities are restricted to the auditory and visual modality which are commonly used in nomadic driver assistance systems, such as navigation systems.

The auditory modality includes sound signals and spoken text. Discrete sound signals can be used to warn drivers of an approaching situation by playing a sound. The sound may convey information about the reason for an alert by using sounds of everyday events (i.e. auditory icons, Graham, 1999). More information can be transmitted by using spoken text that is played to the driver.

The visual modality is commonly used to inform drivers about the state of a system, indicating different states with lights. For example when a blind spot warning system has detected a vehicle in the blind spot a light turns on in a corner of the side view mirror. More information can be transmitted by using different coloured lights, such as traffic lights where each colour conveys a different meaning. For visual information displayed on a screen, a distinction is made between images and written text.

Past research has highlighted the detrimental effects of visual distraction and visual overload on driving performance due to in-vehicle information systems (Engström, Johansson, & Ostlund, 2005; Jamson & Merat, 2005; Lansdown, Brook-Carter, & Kersloot, 2004). Compared to text written on a screen, spoken text does not require drivers to take their gaze off the road. However, spoken text messages have a limited duration which makes them transient (Wickens & Hollands, 1999). The message is played whether the driver is in the right condition to receive it or not. After a message has been played it must be replayed to provide the information a second time. The pace at which the message can be received is less controllable by the driver (Seppelt & Wickens, 2003). Preferably the spoken message should be short and simple, as longer messages require longer periods of continuously focussed attention (Spence & Ho, 2008; Verwey, 1996). The multimodal presentation of information may reduce the mental load of drivers by harnessing the advantages of each form of presentation (Reeves et al., 2004).

According to the multiple-resource theory (Wickens, 2002, 2008), tasks can be executed concurrently when they utilize different modalities for input or response. Each modality can be processed consuming its own mental capacity. Driving is considered a visually demanding task (Evans, 1991; Sivak, 1996). Arguing from this theory, additional information should therefore be offered via the auditory modality, since the driving task is mainly consuming the driver's visual capacity. Support for this argument is provided by Baldwin and Coyne (2003). The authors showed that for performance in a visual as well as an auditory sensory detection task during driving in dense traffic, the visual detection task was perceived as more loading, compared to the auditory detection task.

Several human-machine interface guidelines have been developed to ensure the safety of in-vehicle information systems (Campbell, Richman, Carney, & Lee, 2004; ESoP, 2006; Green, Levison, Paelke, & Serafin, 1995; Schindhelm et al., 2004). These guidelines can support the design of the advice messages with regard to usability and safety. Beyond the scope of these guidelines are decisions concerning the willingness and ability to adhere to the advice by the individual driver.

With regard to CIVA, several questions can be posed such as:

- Should the advice be presented via the auditory, the visual or both modalities?

- Is driver workload increased by following the advice, compared to regular driving?
- Does exclusive visual advice presentation lead to higher workload than exclusive auditory advice presentation?
- Does the advice distract drivers from the driving task?
- Does experience with the advice messages affect workload?

2.2.4 System characterization

The CIVA system relies on the general willingness of drivers to improve traffic flow efficiency and reduce congestion by changing their driving behaviour. This willingness may be described as an additional trip goal, besides, for instance, driving safely, taking the fastest route, or saving fuel. However, the system does not persuade drivers to have that trip goal; it supports the achievement of their goal.

Oinas-Kukkonen (2010) introduced the concept of behaviour change support systems. According to this definition "A behaviour change support system (BCSS) is an information system designed to form, alter or reinforce attitudes, behaviours or trigger an act of compliance without using deception, coercion or inducements" (p.4). This definition extends the concept of persuasive technology by Fogg (1999), stating that these systems may not only target lasting changes in attitudes (A-Change) or behaviours (B-Change) but can also induce single acts of compliance (C-Change) (Oinas-Kukkonen, 2010). The outcome of a C-Change is that the user complies with a request of the system. The system provides a cue for the user to take action, in the same way that the CIVA system requests acts of compliance to the advice.

A difference of C-Changes to A- or B-Changes is that the user is not required to proactively initiate the goal behaviour. With CIVA advice, the driver will not even be able to determine what goal behaviour to show in a given situation, as the system may send different advice messages to different drivers in the same traffic situation. This illustrates a distinction between persuasive technology targeting lasting behaviour change and targeting acts of compliance. Lasting behaviour change implies that the driver, at one point, may be able to show the desired behaviour without the help of the system. Therefore, the system needs to show a consistency in the advised behaviour in particular situations. There must be a situation-response relation that a driver can learn. For an act of compliance, drivers are merely required to follow the advice. However, in order to show behaviour that is beneficial for traffic flow, the driver will at any time be dependent on the system that advises the desired behaviour.

Question that arise here include:

- Do drivers feel dependent on the system in order to show the desired behaviour?
- Are users able to learn situation-advice relations and anticipate an advice?

2.2.5 Penetration and compliance rate

Whether the CIVA system will have the desired effect on traffic flow efficiency is dependent on the percentage of vehicles on the road that are equipped with the system (i.e. the penetration rate of the system) and the number of drivers that adhere to the given advice (i.e. the compliance rate of drivers). Both rates are influenced by the drivers' ability and willingness to use the system. Usage includes the decision to acquire the system, have it operating during trips and comply with the advice messages.

2.2.5.1 System penetration

Penetration rate may be defined as the number of vehicles on a particular road in which the system operates in a state where it can provide advice to the driver. This implies that penetration rate is subject to constant change. Penetration rate is determined by installing the system into the vehicle, by turning it on (or not turn it off) before a trip, and by turning it on repeatedly over successive trips. All these stages involve a conscious decision of the driver to obtain, use and keep using the system. Furthermore, penetration rate may fluctuate for any given road section depending on the number of equipped vehicles that are on that road at any time. At some point in time, on a particular part of a road, there may be a penetration rate of 20% while later it may drop to 5% or rise to 30%. While it may be possible to determine the penetration rate in the entire population of road users, the moment to moment penetration rate may be subject to constant fluctuations, while at the same time having a strong influence on the systems effectiveness.

As stated earlier, penetration rate is determined by the amount of active systems on a given road in relation to the absolute number of vehicles on the same road at a given point in time. A drivers' ability to have a correctly operating system in the vehicle includes, for instance, the ability to obtain the system, including the financial ability to purchase the system in case it is expensive. Furthermore, it includes the ability to have the system installed and operational in the vehicle, and to start the system with the correct settings. Willingness to operate the system during a trip is determined by factors such as the acceptance of the system, including for example, the acceptance of the advice strategy that is used by the system (acceptance will be introduced in chapter 5). Furthermore, it includes the expected effect of the system for a particular trip and the expected benefit from using the system during that trip. A driver's support for the system may change over time, depending on past experiences with the system. Initial support of the idea does not guarantee sustained support after the system has been used (e.g. Happee et al., 2011; Morsink et al., 2006).

Research question that can be posed here are:

- What factors influence the adoption or rejection of the system?
- Do drivers feel responsible for their involvement in congestion formation?
- Are drivers willing to use the system on their daily commutes?
- What factors influence the decision to turn the system on or leave it off before and during a trip?

- Do drivers have the impression to gain an advantage or disadvantage over drivers that are not using the system?
- Is there a willingness to pay for the system?
- How acceptable is a measure that targets tactical driver behaviour to improve traffic flow efficiency?
- Can the acceptance of the system be influenced?

2.2.5.2 Compliance with the advice

The goal of the CIVA system is to change driver behaviour by invoking acts of compliance to the advice messages. On a road, the compliance rate describes the number of acts of compliance by drivers in equipped vehicles against the number of advice messages that are not complied with. However, besides a quantitative component (i.e. how many advice messages are carried out), compliance also has a strong qualitative component (i.e. how is an advice message carried out). Due to this qualitative component it can sometimes be difficult to clearly determine an individual driver’s compliance with a particular advice message.

Determining whether or not a driver has complied with an advice is often difficult to answer with yes or no. For instance, it may be straight forward to determine whether a lane change advice has been complied with, by determining whether the advised lane change has taken place. However, when the lane change is carried out two minutes after the advice has been given, can this still be regarded as compliance with the advice? Often compliance must be determined on a continuum from “no compliance” to “compliance”. For instance, by determining whether a speed advice has been complied with by looking at the difference between actual speed and advised speed.

Compliance rate on a road level can be broken down into the individual compliance rate of each equipped driver. Compliance rate on an individual driver level is the number of acts of compliance by an individual driver against the number of advice messages that the driver receives. Compliance rate on the individual driver level can again be divided into the compliance with different categories of advice messages and, within a category, with the individual advice messages. Some drivers or advice categories may show higher compliance rates than others. The factors that influence compliance to the CIVA system and research questions will be the subject of the following chapter.

3 Influencing driver behaviour in nearly congested motorway traffic

3.1 The driving task

To understand in which ways an advisory system can influence driver behaviour, it is necessary to have a closer look at the driving task. Driving is not a uniform activity but can be viewed as a series of decisions on different hierarchical levels. From top to bottom, the hierarchy consists of strategic, tactical and operational driver decisions (Michon, 1985). An understanding of where in the hierarchy the CIVA system will interact with the driving task helps in developing suitable advice messages for that particular level.

On the strategic level (also called the navigation level) decisions are made concerning the general planning of a trip. Among others, these include the choice of the route, the time to leave and the choice of trip goals (e.g. minimise travel time, maximise safety). On the tactical level (also called the manoeuvring level), decisions are made concerning the interaction with other road users and the road layout. These include the behaviour in specific traffic situations (e.g. entering a motorway, passing another vehicle, reacting to a change in traffic flow). The operational level (also called the control level) concerns basic vehicle control behaviour. This involves applying gas, braking, changing gears or making steering corrections.

The three levels are hierarchical in that they influence each other in a top-down manner. Higher level decisions can influence subsequent decisions on lower levels. Chosen trip goals on the strategic level (e.g. minimising travel time) can influence decisions on the tactical level (e.g. driving on the left lane, passing slower vehicles). The other way around, feedback from lower levels might also influence decisions on higher levels. For example, the inability to perform a lane change to the right lane and take the exit forces the driver to adjust his/her decision on the strategic level (e.g. take another route). Here the interruption during the execution of an action at a lower level demands an update of tactical or strategic decisions on a higher level (Schaap, 2012).

Janssen (1979) noted that the time margin available for a decision gets shorter from the top of the hierarchy to the bottom. Drivers may have hours or even days for strategic decisions (e.g. about the preferred route or time frame of a trip). Decisions on the tactical level are usually made within minutes to seconds and on the operational level even within seconds to milliseconds. When designing advice messages on tactical driver behaviour this time frame must be taken into consideration. The advice should be given at a time that allows the driver to adequately prepare for the advised manoeuvre.

In chapter 1, several examples have shown how driver behaviour can reduce traffic flow and cause congestion. These behaviours can be categorized according to the three levels of the driving task. Drivers' decisions to choose a certain route and a certain departure time would be considered strategic decisions. Many of the presented examples, illustrating the role of human behaviour in congestion forming (chapter 1), describe interactions with other vehicles and may therefore be characterized as tactical decisions (e.g. changing lanes, making room for merging vehicles). The variability of gap size and speed of individual drivers may stem from imperfections in basic vehicle control behaviour and would therefore be categorized as operational behaviour. However, Kim and colleagues (2007) argue that gap size variability in car following is also caused by an inability to perceive small changes in relative speed and inter-vehicle distance to a lead vehicle. This observation would imply a component of interaction with other vehicles, usually associated with tactical driver behaviour.

Rasmussen (1983) distinguishes three levels of task performance, referring to the level of skill and automation in the execution of a task. His taxonomy differentiates knowledge-based, rule-based and skill-based performance. At the knowledge-based level every action is thought about consciously with an absence of stimulus-response automation. Feedback is used to correct the performance of every action. In rule-based performance a certain response is chosen more or less consciously according to a rule that has been proven to be successful in the past. Less attention is required for the response compared to the knowledge-based level. An example is driving when the traffic light turns green. Performance is considered skill-based when a task is highly overlearned and can be carried out automatically with minimum attention required by the driver.

After a certain amount of practice, performance on a task transitions from the knowledge-based level to the rule-based level, and possibly on to the skill-based level. With every transition to the next level, task performance becomes more automatic and less attention demanding. For example, changing gears is considered knowledge-based performance on the first driving lesson. With more experience this performance becomes more automatic until it is skill-based (Patten, Kircher, Ostlund, Nilsson, & Svenson, 2006). However, some tasks may never transition to a skill-based level, such as finding a route in an unfamiliar environment or deciding when it is safe to overtake. In turn, performance can also decrease due to the influence of external factors. For example driving a British car leads to a decrease in task performance when changing gears even (or especially) for an experienced foreign driver. The task performance level therefore describes the current performance given the experience and external influence factors.

Hale, Stoop, and Hommels (1990) merged Michon's task hierarchy and Rasmussen's skill-rule-knowledge framework into a matrix of driver tasks. Compared to Michon, they refer to planning instead of strategic level, manoeuvre instead of tactical level and to control instead of operational level. Table 3.1 provides examples of driving behaviour at each combination of the task hierarchy and the performance levels.

Table 3.1 The relation between performance levels (rows) and hierarchy of driving tasks (columns). After Hale et al. (1990, p. 1383)

	Planning (Strategic)	Manoeuvre (Tactical)	Control (Operational)
Knowledge	Navigating in unfamiliar areas	Controlling a skid on icy roads	Novice on first lesson
Rule	Choice between familiar routes	Passing other vehicles	Driving an unfamiliar vehicle
Skill	Home / work travel	Negotiating familiar junctions	Vehicle handling in curves

Finally, three stages of information processing can be distinguished for the driving task: perception, processing and action (Theeuwes, 1993). Connected to the matrix of driver tasks, this leads to a representation of the driving task as shown in Figure 3.1.

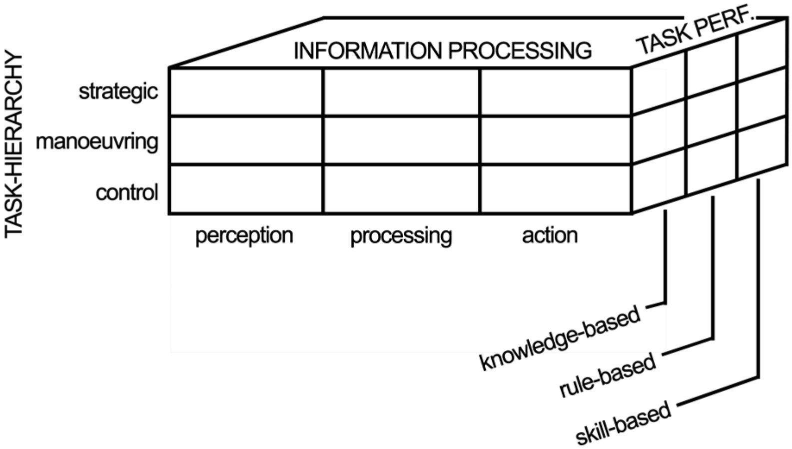

Figure 3.1 The task of the road user in three dimensions (a.o. Theeuwes, 1993)

Alexander and Lunenfeld (1986) argued that the driving task has different layers of complexity (e.g. keeping a car between the lines is less complex than finding a route in an unfamiliar environment) and different layers of primacy (see Figure 3.2). Urgent situations can capture a driver's attention on a lower level at the expense of attention on higher levels. As an example, a sudden strong side wind will get all attention at the lowest level (control level). This may reduce performance on the strategic or the tactical level (e.g. attending to road signs, keeping a constant inter-vehicle distance).

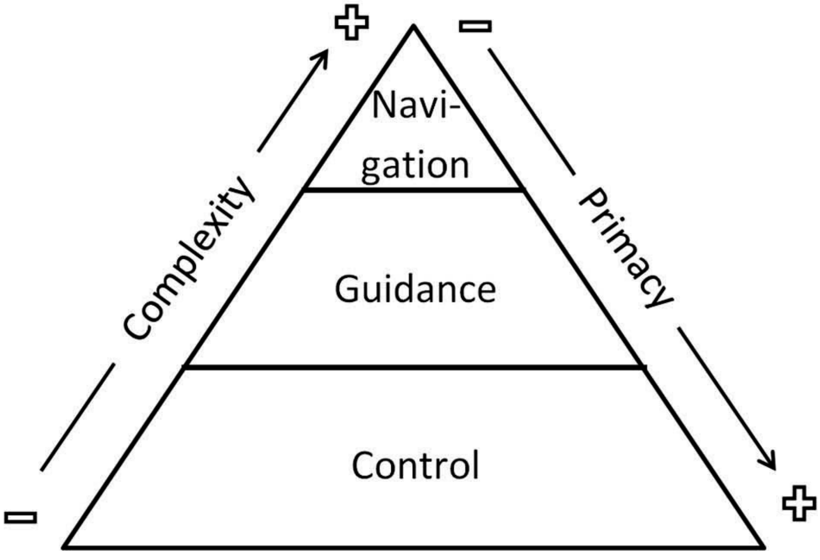

Figure 3.2 The three levels of the driving task according to Alexander and Lunenfeld (1986)

Michon's task hierarchy and Rasmussen's skill-rule-knowledge framework can be used to determine, how the CIVA system influences the driving task with the advice messages.

Existing advisory driver assistance systems can be classified according to the task hierarchy. For instance, traditional navigation systems influence the driving task on the strategic and the tactical level by taking over route choice decisions and influencing the manoeuvring of the vehicle through advice (e.g. keep right, take second exit). Furthermore, there have been attempts to provide an advice on the operational level in order to achieve a change on the tactical level. The advisory system that was developed in the SPITS project targeted acceleration and deceleration behaviour (operational level) in order to achieve an improvement in following behaviour (tactical level).

However, it may be argued that the operational level is less suitable for giving advice to drivers. Vehicle control (i.e. operational) behaviour is often carried out on a short time scale, often in response to the traffic situation changing rapidly (Janssen, 1979). An advice regarding vehicle control behaviour requires frequent advice messages and fast compliance by drivers in order to remain relevant. Frequent advice messages may cause annoyance and lead to elevated workload. This can lower the acceptance of the system. A questionnaire study on driver needs (N = 495) showed that over 70% of participants indicated 'driving in a relaxed way' as an important driver need, only surpassed by safety which was important to over 80% of participants (Hoedemaeker, 1999). Drivers may refuse to use the CIVA when they perceive it as inducing stress due to frequent advice. Furthermore, a requirement for fast compliance could put drivers under pressure. As a result they may omit to check whether an advice can be carried out safely. This could lead to dangerous situations.

The CIVA system targets driving behaviour on the tactical level. Drivers may have several seconds or even minutes to carry out advice on the tactical level. Also, giving advice on the tactical level leaves the execution of the advice on the operational level to the driver. For instance, an advice to change a lane leaves the control over acceleration and steering to the driver. On the one hand this allows for a lower advice frequency, on the other it reduces the control that the system may have on the way a given advice will be carried out.

With regard to commuting traffic, tactical driver behaviour on a motorway may be considered rule-based. Drivers have over time developed a set of rules that help them in choosing a certain lane at the right time, or a certain gap size when traffic becomes congested.

Minderhoud (1999) proposed a control model of car driving. In this model the driving task is represented as a continuously repeating sequence of steps, which are perception, state prediction, decision-making and action execution. As an informing and assisting system, the CIVA may influence the future state prediction and decision-making stages. A schematic representation of how the driving task could be influenced by the CIVA system, according the control model by Minderhoud (1999), is shown in Figure 3.3.

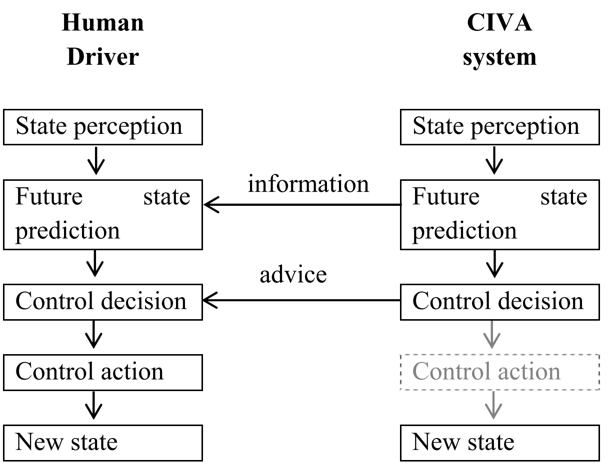

Figure 3.3 Schematic representation of the driving task supported by CIVA (adapted from Minderhoud, 1999, added lines for information and advice)

However, it can be argued that the schematic model provides an idealized description of the mental processes that are involved in the choice of a behavioural response by a driver to a given environment. It is uncertain whether drivers constantly engage in every step of the proposed steps and even if they would, whether they will do so in the proposed order. For instance, the control model does not take into account the skill-based level of performance. If a task is highly-practiced, there is a direct link between perception and action, skipping the levels of prediction and decision. Also, in contrast to the system, drivers may lack a degree of elaborateness in performing the mental action that is required at each step, due to the lack of information and processing capacity.

The processes that lead to a control action may be more realistically described in a model that follows the principle of bounded rationality (Simon, 1955). Bounded rationality acknowledges that in human decision-making, the rationality of individuals may be limited by the information they have, their cognitive capabilities, and the finite amount of time they have to make a decision (Schilirò, 2012). For example, in some situations restricted time may demand fast actions and may not allow for elaborate future state prediction. In another situation a driver may fail to completely perceive a situation in its dynamic character or to process that information in order to make a correct prediction of a future traffic state.

3.2 Driver behaviour in congestion

The CIVA system aims to influence driver behaviour in nearly congested motorway traffic. It is therefore important to get an understanding of the circumstances that drivers are dealing with in this situation.

Traffic flow theory distinguishes between different traffic flow conditions such as free-flow, transitional-flow or congested-flow (May, 1990). On a macroscopic level the transition between these conditions can be characterised by changes in traffic density and speed. On a microscopic (or individual) driver level, flow conditions determine the driver's freedom with regard to such factors as speed choice, lane choice and choice of an inter-vehicle distance (Dijker, Bovy, & Vermijs, 1998). Therefore, it can be assumed that driver behaviour may also vary between traffic-flow conditions.

Under free-flow conditions or non-congested traffic, drivers are relatively free in their choice of desired speed, lane or inter-vehicle distance. They are able to drive at their preferred speed and pass vehicles that drive at slower speeds. In congested traffic drivers are more constrained by other road users. Individual choices of speed, lane or inter-vehicle distance are now severely restricted as drivers are forced to follow a vehicle in front of them and adjust their driving behaviour in response to changes made by the lead vehicle (Dijker et al., 1998).

Ranney (1999) proposes an influence model of different factors in a car-following situation. In this model three "levels of service", that resemble the three flow conditions proposed by May (1990) are compared (see Figure 3.4). As traffic density increases, driving changes gradually from self-paced, where it is controlled by the driver, to forced-paced, where the actions of other vehicles increasingly dictate the behaviour of the driver. The influence of situational and individual factors on car following behaviour decreases as traffic becomes more congested.

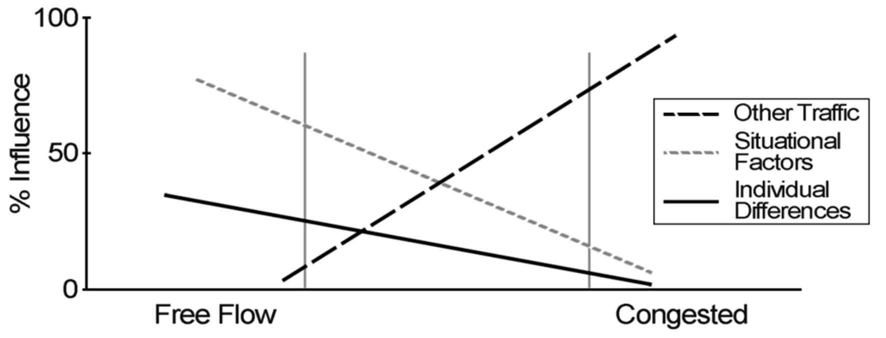

Figure 3.4 The importance of influence factors in car following (after Ranney, 1999)

Similar to the influence of situational and individual factors the influence that the CIVA system can exert on driver behaviour may decrease. A driver may lack the opportunity to follow an advice despite a general ability and motivation to do so.

3.3 Influencing driver behaviour through driver advice

A distinctive aspect of changing driver behaviour through the CIVA system is that the driver does not initiate the behaviour change. The change in behaviour is the response to a request by the system. There are several theories that describe the determinants of an individual's behaviour, some well-known examples being the Theory of Reasoned Action (Ajzen & Fishbein, 1980) or the Theory of Planned Behaviour (Ajzen, 1991). Also there are theories that describe the change in attitudes or behaviour such as the Self-Efficacy Theory (Bandura, 1977), the Social-Cognitive Theory (Bandura, 1986), the Elaboration Likelihood Model (Petty & Cacioppo, 1986), the Cognitive Dissonance Theory (Festinger, 1962) or the Goal Setting Theory (Locke & Latham, 2002). While these theories describe lasting changes in attitudes and behaviour, it is not clear how they relate to a C-Change, where the end-user only has to comply to the request of a system (Oinas-Kukkonen, 2010).

A model describing behaviour change in the context of persuasive technology has been proposed by Fogg (2009). To show a target behaviour a person must be motivated and have the ability to perform the target behaviour. The presence of a trigger is needed to initiate the behaviour. According to the author, ability and motivation can trade off. High levels of motivation lead to a target behaviour even when it is difficult. In turn a behaviour that is easy will be performed even at lower levels of motivation (Fogg, 2009). Persuasive technology can facilitate behaviour change by increasing motivation, reducing task difficulty and acting as a trigger. Applied to the CIVA approach, the system may act as a trigger, while the driver must be willing and able to show traffic flow efficient driving behaviour. Furthermore, the system may motivate and support the driver in showing a certain behaviour.

Tertoolen, Grotenhuis and Lankhuijzen (2012) describe the process of influencing driver behaviour within dynamic traffic management information. They argue that four factors determine the driver's compliance with traffic management messages. The driver must perceive the information, the driver must understand the information, the driver must be able (and feel able) to show the desired behaviour and the driver must be willing to follow the advice and show the desired behaviour. These factors resemble the classic information processing model of sensing, perceiving, deciding and acting (Wickens & Hollands, 1999).

3.3.1 Perception of the advice

The driver must be able to perceive the advice. However, driving in dense traffic is already an attention demanding task and the system should not capture the driver's attention for too long. Performance on the driving task may decrease when too much attention is devoted to secondary tasks, resulting in potential unsafe situations. Knipling (1993) estimated that driver inattention contributed to roughly 60% of automobile crashes. Attention has been described as a limited and allocable resource that can devoted to various aspects of the driving tasks (Wickens, 2002). A driver's visual attention is especially occupied with receiving and actively searching for information regarding the environment, the traffic situation and the vehicle state. Furthermore, a driver's attention resources may already be devoted to other secondary tasks such as, for instance, listening to music, talking to a co-driver, thinking about work or observing the environment. In this environment, the CIVA system competes for attention resources with the driving task and other secondary tasks. The advice has to be presented in a way that it can be perceived by the driver without forming too much distraction from the driving task. For this the aforementioned design guidelines for in-car systems play a central role.

The question that is relevant here is:

- Are drivers able to perceive the advice in dense motorway traffic?

3.3.2 Comprehension of the advice

Several forms of advice comprehension can be distinguished. First, comprehension of the advice message itself is required. With an advice message the CIVA system communicates a behavioural goal. A driver must be able to understand what behaviour is expected. If the advice is not correctly understood by the driver, compliance may not lead to the intended behavioural change. With written or spoken advice, the formulation of the advice determines its comprehensibility to a large extent. For advice that is presented in the form of an image, the driver must be able to recognize its meaning, either by a learned relationship or its meaning must be clear from the image itself.

Second, an understanding of the reason for an advice can be an important determinant for a driver to accept the advice. When a driver feels that the advice does not correspond to his/her perception of the traffic situation, he/she may reject the advice as faulty. The system may need to clarify why it requests certain behaviour in anticipation of a predicted traffic situation that the driver may not yet be able to perceive. Therefore, the systems may need to provide additional information about the anticipated traffic situation that triggered the advice.

Support for providing additional information can be found in the literature. According to Oinas-Kukkonen (2010) an important factor in the acceptance of persuasion (through behaviour change support systems) is that the process of advice generation should be transparent. Furthermore, information about downstream traffic conditions on motorways was the most frequent request in a survey querying user needs for driver assistance (van Driel & van Arem, 2005). Also in tests with a dynamic maximum speed limit it was shown that drivers wanted to know why they had to adapt their speed in certain situations (Burgmeijer et al., 2010)

A third form of comprehension is that of the intention behind the advice. Although the reason for an advice may be understood, it can be difficult for a driver to see how the advice will help in resolving the problem that has been provided as a trigger for the advice. For this, it may not be enough to merely inform drivers about the underlying advice strategy that is used by the system as drivers may not agree with the used advice strategy.

Questions that are relevant here:

- Is the advice understood correctly?
- What mental model do drivers have of the system?
- Do drivers understand why an advice is given to them?
- How much information is needed / wanted by the driver about the cause of an advice?

3.3.3 **(Anticipated) Ability to follow the advice**

When a driver has successfully perceived and understood an advice message, the ability to follow the advice is an important prerequisite for compliance. Here a distinction can be made between anticipated and actual ability. While actual ability affects the outcome of an action, anticipated ability may affect the decision to initiate the action. It can be argued that the quantitative aspect of compliance is more influenced by a driver's anticipated ability while the qualitative aspect of compliance is influenced by a driver's actual ability to follow the advice.

The way a behavioural goal is formulated in an advice messages may have an effect on a driver's anticipated as well as actual ability to follow the advice. For instance, given that a driver is required to attain a specific gap size, the advice may directly communicate the behavioural goal as a specific target gap size (i.e. "Choose a gap size of 2 seconds"). This would be a rather straightforward presentation of the advice. A different form would be to communicate only whether the gap size should be increased or decreased and when to stop adjusting one's gap size (e.g. "Increase your gap size" followed by a signal when the desired gap size is reached). With regard to speed behaviour, an advice may request that a driver attains a specific speed in order to merge without speed differences while the same behavioural goal might be achieved with a less specific advice to adjust one's speed to the speed of another vehicle on the target lane.

Both advice forms, the specific and the less specific advice, have advantages and disadvantages. The specific advice allows more control over the target behaviour, but also requires that drivers are and feel able to show the specific behaviour. A less specific advice may be easier to follow, however in turn may result in a higher variety between drivers with regard to the actual behaviour. Furthermore, the behavioural response to non-specific advice may be influenced by personal preferences of drivers. For example, there are inter-driver differences of what constitutes a safe inter-vehicle distance (Ossen & Hoogendoorn, 2011). In sum, the form of an advice may influence both the likelihood that an advice will be carried out as well as the manifestation of compliance behaviour. Empirical comparisons of different advice message designs can help in determining the suitability of an advice for particular driving scenarios (Adell, Várhelyi, Alonso, & Plaza, 2008; Adell, Várhelyi, Fontana, & Bruel, 2008).

The assessment of driver's actual ability to follow a given advice may involve a comparison of a driver's behaviour with the behavioural goal. When, for instance, the behavioural goal to keep a gap size of 2 seconds, the deviation of the chosen gap size from the advised gap size can indicate a driver's performance in following the advice. With some advice messages this requires a decision about the allowed deviation of the actual from the advised behaviour. An ability threshold may be determined relative to the goal of the system. The ability to follow an advice may be deduced from the extent that the actual behaviour helps in creating the intended effect on traffic flow efficiency. Given that a target behaviour would indeed have a beneficial effect on traffic flow efficiency in a particular situation, the ability of a driver to show the behaviour would be determined by the extent that the shown behaviour actually helps in improving traffic efficiency. However, the effect of a single act of compliance on traffic flow is difficult to isolate. This can make it difficult to empirically determine the ability.

Here modelling of traffic can help in exploring the effect of system compliant behaviour on traffic flow. Empirically determined compliance behaviour may be integrated in driver models of motorway traffic. The modelled compliance behaviour may then be compared to regular driving behaviour based on its potential to improve traffic flow efficiency. Also, traffic simulation can determine the maximum acceptable deviation of actual from advised behaviour that still produces a beneficial effect on traffic flow efficiency.

Besides individual ability to carry out an advice, there may be environmental factors that can facilitate or complicate the task. For example, while a driver may show a certain accuracy in keeping a specific gap size in good weather conditions, the same driver may experience a performance drop in foggy weather. Also the behaviour of other road users can reduce a driver's ability to comply. Driving in congestion may reduce a driver's opportunity to carry out a lane change, due to a lack of space on the target lane.

Support systems in the vehicle may help drivers to carry out an advice. For instance, the speedometer supports a driver in choosing and keeping a certain speed, by providing constant feedback of the actual speed. A means of gap size feedback in not commonly built into vehicles. Therefore, it may be argued that it is more difficult for drivers to attain a certain gap size than it is to attain a certain speed.

Several questions that are relevant here are:

- Do drivers have difficulties in carrying out the advice?
- Should the system support the driver in carrying out the advice, and if so how?
- Can feedback about driver performance improve the performance over time?
- How do driver-related factors (e.g. age, gender, driving experience, time of day, education level, personality) influence compliance behaviour?
- How do environmental factors (e.g. weather, road condition, light) influence compliance behaviour?
- Should a specific or un-specific target behaviour be advised?
- How far in advance of an expected behavioural response should the advice be presented?
- Should related advice messages (e.g. adapt speed and change lanes) be combined or given with a pause in between?
- How does traffic density influence the behavioural response to the advice?
- Does following the advice lead to safety-critical situations?

3.3.4 **Willingness to follow the advice**

The CIVA system is intended to be used voluntarily by drivers. Without the use of coercion and enforcement, drivers are free to choose whether or not to follow any individual advice message. A driver's decision whether or not to follow an advice may be influenced by several factors such as anticipated outcome, experience, habit or anticipated ability/opportunity.

Anticipated outcome has a central role in motivating behaviour (Adell, Várhelyi, & Nilsson, 2014; Fogg, 2009). It can promote compliance if the outcome is expected to be positive (e.g. monetary reward, time saving, praise). However it can also prevent compliance if the outcome is expected to be negative (e.g. time loss, reduced safety, social rejection).

The outcome anticipation can take the form of either an intrinsic motivator or an extrinsic motivator. Intrinsic motivation stems from the anticipated reward or satisfaction of doing the task itself. This also applies to the anticipated dissatisfaction from doing something or not doing something. For instance, the money saved through a fuel efficient driving style is an intrinsic motivator to drive fuel efficient in the future. Also the satisfaction of saving time on one's commute can be an intrinsic motivator to avoid rush hour periods. Extrinsic motivation stems from an anticipated reward or punishment, by an external entity, for action or inaction. For instance monetary fine acts as an extrinsic motivator to reduce speeding behaviour.

It has been argued that lasting, self-sustaining behaviour change is the product of intrinsic motivation, while behaviour change that is extrinsically motivated lasts only as long as a reward or punishment can be expected (Thøgersen, 2009).

In a study by Merrikhpour, Donmez, and Battista (2012a, 2012b), an in-vehicle system gave drivers feedback on their speed and gap choice and provided a monetary reward for speed limit compliance and safe gap size. Speed and gap size compliance improved during a test period but dropped after the feedback and monetary reward was removed.

In several Dutch research projects, external rewards have been shown to promote a behaviour change. In the Belonitor project, in-vehicle technology was used to deliver persuasive messages that promoted safe driving behaviour and rewards (points exchangeable with presents) were used to promote compliance with the advice (Mazureck & Hattem, 2006). Rewards were effective in changing behaviour, however only during the test phase. After the rewards had stopped a low persistence in behaviour was observed.

In the Spitsmijden project rewards were used to motivate people to avoid rush hour traffic. The measure was effective, but only as long as rewards were provided (Spitsmijden, 2007). However, a follow-up study showed how intrinsic reward schemes could develop from extrinsic reward. The reward was seen as the initial motivation to avoid rush hour traffic. During the test phase participants found alternative travel options that were rewarding in itself, leading to intrinsic motivation to sustain the behaviour. Those who did not find attractive alternatives and therefore did not develop an intrinsic motivation to sustain the new behaviour would fall back to their old behaviour when the reward ceased (Ben-Elia, Ettema, & Boeije, 2011).

3.3.5 **Experience and habit**

The fact that the CIVA system will be used in peak hour traffic can have implications for drivers' compliance with the advice. Commuters are usually experienced with using a particular route. Prior experience with a particular road in congestion can enable drivers to anticipate where and when relevant information is likely to appear and what other road users are likely to do in the near future. As Bainbridge (1997) points out, expert control behaviour is often directed at ensuring that future states will be acceptable, rather than correcting present unacceptable situations.

Also, with experience, drivers may have developed a set of decision shortcuts (or habits), in the form of if-then rules, to choose from an arsenal of possible behavioural responses in a given situation. According to Rasmussen's framework (1983) such rule based behaviour is characterized as a certain response that is chosen according to a rule, which has been proven to be successful in the past. Drivers that have substantial experience with a given road may not agree that the behaviour that is advised by the system is the optimal reaction to the given situation. Therefore, they may be less likely to comply. This has been shown previously in tests with a dynamic maximum speed limit (Rijkswaterstaat, 2010). Compliance was reduced when the projected speed limit did not correspond with the traffic situation that drivers observed on the road.

3.3.6 **Other factors that influence compliance with the advice**

Tertoolen et al. (2012) name several factors that influence a road user's willingness to comply to dynamic traffic management. The authors note that the feeling of autonomy, competence and the relation to the provider of the message determine the willingness to comply to a request (Tertoolen et al., 2012). These factors are based on the self-determination theory of Deci and Ryan (1985). According to this theory humans have, besides basic physical needs (e.g. food, water, air), a set of psychological needs, these being autonomy, competence and relatedness. The need for autonomy includes the freedom to act as it pleases the acting individual. Often this includes behaviour that serves the individuals benefit. The need for competence requires that the individual receives the information and advice to make the optimal decision under the given circumstances. The need for relatedness demands a relationship (with an emphasis on trust) with the provider of the information and the advice. According to the authors, trust is created through transparency in the communication (e.g. motivation for a certain advice). In addition, as a fourth cornerstone for compliance with traffic management advice, the authors name the feedback that drivers receive from adapting their behaviour. This feedback can assume different forms, such as a message from the system, the reaction of other road users or the perceived effect of compliance. If drivers receive no feedback on their adapted driving behaviour or if the feedback is negative, they fall back to their regular behaviour (Tertoolen et al., 2012). The authors also state that basic needs can weight differently depending on the psychological characteristics of different target populations. For instance, commuting traffic and business traffic, that is familiar with the region, may value individual autonomy, competence and feedback higher that the relatedness with the provider of the information or the advice.

Question that may be posed here are:

- What do drivers expect for their compliance to the advice?
- Can compliance to the advice be intrinsically motivated? Are drivers able to perceive a benefit from using the system?
- How do drivers respond in situations where they do not agree with the advice?
- Does compliance to the advice lead to an outcome that is regarded as advantageous or disadvantageous by drivers?
- How do driver related factors (e.g. age, gender, driving experience, time of day, education level, personality) influence willingness to comply?

- How does direct experience with the system influence the acceptance of the system?
- How does experience with a route influence the likelihood of compliance to the advice on that route?
- How does experience with the system affect an individual driver's compliance rate to the advice?
- Does anticipated ability to comply influence drivers' willingness to comply with the advice?
- What is the influence of trust in the system on willingness to comply? / Do drivers comply with an advice even when they think it is unsafe?
- How is willingness to comply influenced by errors of the system?

3.4 The social dilemma of traffic flow improvement through driver advice

When the penetration rate and the compliance rate are sufficiently high, it may still be that the system creates a general benefit for the traffic system as a whole but not necessarily for the individual driver who complies with the advice. The outcome of a driver's action may only be experienced by the collective of road users behind the driver. In turn the individual driver is dependent on other drivers in front of him/her, that are also equipped with the same system, to create a beneficial effect for this driver. As a result, each driver is exposed to the effect of the collective actions of the drivers in front of him/her. Already in 1971, Schelling articulated how this applies to inconsiderate behaviours that may harm the flow of traffic, by stating: "Unorganized, they [the drivers] are at the mercy of a decentralized accounting system according to which no […] driver suffers the losses that he imposes on the people behind him" (p.66). The same mechanisms also apply to efforts to improve traffic flow. The beneficial effect that is created by an individual driver's compliance to the advice will not pay itself back to the same driver. Without feedback from an external observer, drivers will never directly perceive the effect that their compliance has on traffic flow. It may even be that a driver experiences a direct individual disadvantage when following the advice. For example, a driver complies with an advice to merge from a dense middle lane to the right lane. The effect that he/she creates on traffic flow might be beneficial for other road users, although he/she now finds her-/himself between trucks on a slow right lane. Therefore, drivers might perceive the outcome of their compliance as disadvantageous.

Drivers may be aware of the interdependence between road users in creating a collective benefit through the improvement of traffic flow. Even if a sufficient penetration rate could be guaranteed (for instance through a government mandate to use the system), the potential effect that such a system can have on traffic flow would still be dependent on the collective compliance of a sufficient number of drivers. In other words, to achieve an effect for traffic flow, drivers that use the system are dependent not only on their own ability to follow the advice, but also on the ability (and willingness) of other equipped drivers to comply. Only when penetration and compliance rate are sufficient, the driver will benefit from collective compliance of other traffic. A challenge for these systems is to generate the necessary compliance rate that will cause a beneficial effect on the whole traffic stream in order to justify the use of the system for the individual drivers.

The situation described here shares similarities with that of a social dilemma (Dawes, 1980; Kollock, 1998). Each driver may benefit from improved traffic flow when all road users cooperate by using the system and complying with the advice. However, individually a driver may not gain anything from following the advice and may be better off free-riding (i.e. not following any advice, while benefitting from the effect created by more compliant drivers). Even if drivers are willing to cooperate in the first place, they may fear that the overall compliance rate is not sufficient to actually lead to an improvement of traffic flow. To avoid having the cost of using the system without benefiting from it, due to low overall compliance, drivers may cease to comply themselves.

Questions that may be posed here are:

- Will drivers at any time perceive an individual benefit from following an advice?
- Are drivers aware of the role of their own behaviour in congestion forming?
- Can feedback about the effect of compliance influence drivers' willingness to comply?
- How does a low perceived compliance rate influence drivers' willingness to comply?
- Is the behavioural response to advice messages perceived by other road users?
- Are drivers able to perceive fluctuations in penetration/compliance rate?

4 Research questions and approach

4.1 The research project

The Cooperative In-Vehicle Advisory system was developed in the Connected Cruise Control research and development project. The aim of the project, to develop a functional prototype of the CIVA system that would work in real world traffic, included the following activities:

- The development of the system architecture for the road-side and in-vehicle components.
- The integration of the data from the information sources (i.e. sensors, camera, digital map, GPS) into a digital representation the vehicle environment.
- Development of the systems advice strategy to improve traffic flow efficiency and reduce congestion on motorways.
- Evaluation of the effect of advice messages on driver behaviour and exploration of the factors that influence system acceptance and compliance to the advice, which is the subject of the present thesis.
- Evaluation of the effect of CIVA on traffic flow efficiency in traffic simulations under different simulated penetration and compliance rates.

The research that is presented in this thesis was carried out in the course of this project. The research aim was to support system design by empirically answering fundamental questions regarding the human machine interaction with and the acceptance of the in-vehicle advisory system. First, the concept of the system was the subject of a user-survey. Then the advice messages were studied in several driving simulator experiments. At last, a functional prototype was studied in real motorway traffic.

4.2 Research questions

The extent to which the CIVA system can improve traffic flow efficiency and reduce congestion will depend on penetration rate of the system and compliance rate to the advice. With regard to these two concepts some basic questions may be formulated. For penetration rate, basic questions are:

- Will drivers acquire the system?
- Will drivers use the system during their commute?
- Will drivers continue to use the system after an initial experience with it?

With respect to compliance rate, basic questions are:

- Are drivers able to follow the advice?
    - Are they able to perceive the advice?
    - Are they able to comprehend the advice?
    - Are they able to carry out the advice?
- Are drivers willing to follow the advice?

The basic questions can be broken down into several related sub-questions. During the presentation of the system specification and the background of related research several of these sub-questions have been formulated. Answers to these sub-questions can provide information to answer the more basic questions above.

4.3 Scope

Given the time frame of the project, a selection of the potential research questions must be made. The present research focuses mainly on factors influencing drivers' response to the advice. Here, factors related to quantitative (response decision) as well as qualitative (response behaviour) aspects of compliance to the advice are studied in driving simulator and real road experiments.

However, during the conception and development of the CIVA system it is important to focus not only on questions regarding drivers' ability and willingness to follow individual advice messages, but keep in mind broader questions regarding the adoption and day to day use of the system. While the former mainly influences compliance rate to the advice, the later has an effect on penetration rate. Especially in the early stages of development, given the preliminary state of the system, factors that influence penetration rate (e.g. long-term adoption, day-to-day use) are difficult to study in driving simulator experiments. Therefore, in this research, questions regarding drivers' early impressions of the CIVA system were studied using a survey among potential users as well as post-experimental questionnaires.

Furthermore, the literature and guidelines regarding human-machine interface design is extensive. Therefore no iterative testing of the human machine interface was done to determine the optimal form of presentation of the advice (e.g. modality, icon choice, voice, colour scheme etc.). Design choices in the prototype system were based on existing HMI guidelines and expert evaluation.

The experiments are focussed on drivers' initial response to the advice messages, while comparing different forms of advice formulation. The effects of long-term use of the system on the behavioural response as well as willingness to comply are not studied.

Traffic flow improvement requires a collective effort of road users. While a single act of an individual driver can deteriorate traffic flow, a single driver following an advice is not enough to improve traffic flow. Therefore the effect of compliance to an advice on traffic flow was not studied in driving simulator experiments. Also drivers' perception of the effect of their own behavioural response on traffic flow is not studied. It is assumed that drivers would seldom directly perceive the effect of their own compliance on traffic flow.

The CIVA system will provide advice to the whole population of commuters. Therefore, the present research will focus the entire target population. Individual differences in driver personalities that may influence penetration or compliance rate are not studied.

4.4 Approach and outline of the research chapters

In the early stages of the development process, a survey among potential users of the system is carried out. Before a prototype of the system is available, the focus of the survey is on the evaluation, by potential users, of the idea to use CIVA to improve traffic flow efficiency. The initial reaction of drivers to a description of the concept behind the system can provide important information on the aspects of the system that is important to potential users. Also factors that would influence the anticipated use of the system can help in identifying areas of interest for further research. The following research questions are addressed here:

- How acceptable is a measure that targets tactical driver behaviour to improve traffic flow efficiency?
- Does the system target driver behaviour that is seen as problematic among road users?
- What factors influence the adoption or rejection of the system?

The user survey that explores the attitude of potential users towards the concept system and that identifies factors that can influence adoption of the system is presented in chapter 5.

Given the preliminary state of the early system and its development throughout the project, some questions (e.g. system acceptance) are studied repeatedly at different stages of the development process.

During the experimental phase the focus is first placed on drivers' ability to follow certain advice messages, while later experiments shift the focus to factors influencing drivers' willingness to comply with the advice.

In the driving simulator experiments, the approach for studying the behavioural response to advice messages is to first study the ability of drivers to follow a specific advice on a motorway in relative isolation from other traffic. In that phase, the drivers' general ability to follow an advice is studied, without hindrance of other traffic.

It is assumed that drivers are able to change lanes on an empty motorway with relative ease. It is also assumed that, with the support of a speedometer, drivers are able to attain a specific target speed with relative ease. However, the ability of drivers to attain a specific target gap size to a lead vehicle is unclear. Therefore, the first experiment deals with drivers' ability to follow gap advice. At this stage the following research questions are addressed:

- Do drivers have difficulties in carrying out the advice?
- Should a specific or un-specific target behaviour be advised?
- Should the system support the driver in carrying out the advice, and if so how?

To be able to study gap choice behaviour in the driving simulator of the University of Twente, a validation of the simulator for the studied task had to be carried out. Chapter 6 describes the validation of the driving simulator for instructed gap choice experiments. The experiment regarding the ability of drivers to carry out specific gap instructions is described in chapter 7.
In the following experiment the behavioural response to advice messages on speed, lane and gap size is studied with the influence of other traffic present. The behavioural response to the advice is evaluated with regard to its potential to annoy other road users based on the descriptions from the user survey. Research questions that are addressed here are:

- Do drivers have difficulties in carrying out the advice?
- Are drivers able to perceive the advice in dense motorway traffic?
- Is the advice understood correctly?
- How does traffic density influence the behavioural response to the advice?
- Should related advice messages (e.g. adapt speed and change lanes) be combined or given with a pause in between?
- Is driver workload increased by following the advice, compared to regular driving?
- How does direct experience with the system influence the acceptance of the system?

The experimental evaluation of drivers' behavioural response to the advice in dense motorway traffic is described in chapter 8.
In the following experiments the focus turns from the behavioural response to the advice towards questions related to the acceptance of the system as well as the willingness of drivers to follow the advice.

The interdependence between road users with regard to traffic flow improvement emphasizes the compliance behaviour of other road users to the advice as a deciding factor for individual drivers to use the system themselves. Therefore, an experiment is devised that investigates participants' ability to estimate compliance rates of other road users to tactical driver advice. Research question that are addressed here are:

- Is the behavioural response to advice messages perceived by other road users?
- Are drivers able to perceive fluctuations in penetration/compliance rate (based on observations of surrounding traffic)?

To generate the advice, the systems follows a relatively complicated set of decision rules, that driver may not be able to comprehend without further information. Therefore, it is tested whether additional information about the advice strategy can influence the perceived usefulness and satisfaction with the advice. Also the effect of information on drivers' ability to estimate compliance rates is studied. Research questions that are studied here include:

- Do drivers regard system's advice strategy as an effective solution to improve traffic efficiency in dense commuter traffic?
- Is there a willingness to pay for the system?
- How does direct experience with the system affect the acceptance of the system?
- Can the acceptance of the system be influenced?
- Does compliance to the advice lead to an outcome that is regarded as advantageous or disadvantageous by drivers?
- Can compliance to the advice be intrinsically motivated? Are drivers able to perceive a benefit from using the system?

Chapter 9 describes the first part of an experiment that investigates the effect of additional information about the systems advice strategy on the ability of drivers to estimate compliance rate to the CIVA system. The second part of the experiment, investigating the effect of information about the advice strategy on variables related to system acceptance, is described in chapter 10.

When a first functional prototype system is implemented, it is studied on a real road. An important question at this stage is whether the driver accepts the advice that is provided by the system in real traffic. Therefore, drivers' evaluations of the advice messages in realistic traffic situations are studied. The study contributes to the answers of the following questions:

- Are drivers able to perceive the advice in real world motorway traffic?
- Is the advice understood correctly?
- How does experience with a route influence the likelihood of compliance to the advice on that route?

- How do drivers respond in situations where they do not agree with the advice?
- How does direct experience with the system affect the acceptance of the system?
- In what traffic situations would drivers want to be advised?

A real road study, that assessed user's cognitive response to the advice messages in real traffic, is described in chapter 11.

Chapter 12 provides a discussion and conclusions based on the findings from the presented studies and offers recommendations for further research on in-vehicle, advisory systems to improve traffic efficiency on motorways.

5 User survey[1]

5.1 Introduction

This chapter presents the results from an online survey among potential users of the cooperative in-vehicle advisory (CIVA) system, which was introduced in chapter 2. At the time of the survey a functional prototype of the system had not yet been developed. A description of the system was provided to participants in order to assess their attitude towards tactical driver advice in the context of traffic flow improvement on motorways. In addition, drivers were asked to indicate the level of annoyance with different driving situations on motorways and name situations when they were annoyed by the behaviour of other road users. Their responses can be used to avoid giving advice messages that lead to further annoyance among other road users.

5.1.1 **Acceptance**

Successful interventions to improve traffic efficiency, requires the participation of a certain percentage of road users. For an in-vehicle system the penetration rate of the system determines the maximum amount of potential recipients of an instruction. When the use of the system is not mandatory, the attitude of potential users towards the system influences the

[1] Parts of this chapter are based on the following publication:

Risto, M. & Martens, M. H. (2011). Early user participation in the identification of use case scenarios for 'Connected cruise control'. In ITS (Ed.), *8th European Congress and exhibition on Intelligent Transport Systems and Services*. Lyon, 6-9 June, 2011 (pp. 1-9). Lyon: ITS.

decision to purchase and use it. This attitude can be expressed as the acceptance of the system. User acceptance is a central success factor that remains important from the initial decision to purchase the system, over day to day use to long term adoption.

An evaluation of user acceptance can give developers a better understanding of the attitude that drivers have towards a technology. Early in the process, users experience a preliminary version of the system, often with restricted functionality. Nevertheless, these initial acceptance ratings can provide valuable information about the potential user acceptance of the concept underlying the system. An early identification of factors that shape acceptance of a system is needed to ensure that these factors can be considered in the design of the system.

Several studies discuss factors that are important for the acceptance of driver support systems. A range of different measurement tools and methodologies to measure acceptance has been developed, which produced divergent and often incomparable results (Adell, 2007). This has been ascribed to the lack of a unified theory of acceptance. Several attempts have been made to develop a broader framework of acceptance (Chuttur, 2009; Venkatesh, Morris, Davis, & Davis, 2003). A recent one being the unified concept of acceptability (Vlassenroot, Brookhuis, Marchau, & Witlox, 2010) incorporating the main influence factors found in existing theories of acceptance.

Within this concept, Vlassenroot acknowledged the distinction between acceptance before and after first time use that has been proposed earlier by van der Laan and colleagues (1997) and Schade and Schlag (2003). In this framework, a potential user's attitude towards a certain system that is measured before use, based on for example a description of the system, is called acceptability. The attitude towards a system after it has been experienced is called acceptance. Regardless of the time of assessment both concepts define acceptance as an attitude towards a system, therefore both concepts may be assessed with the same acceptance scales. Still, substantial differences between attitude before and after use are common. Often, it is difficult for users to imagine using an unknown form of driver support. Therefore, direct experience of the fully functional system in the intended context may increase as well as decrease acceptance (Beggiato & Krems, 2013; Brookhuis, van Driel, Hof, van Arem, & Hoedemaeker, 2009; Comte, Wardman, & Whelan, 2000). In the example of a tutoring system that detected and gave feedback on traffic violations, younger drivers' evaluation of the system improved after actually experiencing the system, while evaluations of elderly drivers decreased after actual system use (van der Laan et al., 1997). This suggests that although drivers may generally show a favourable attitude towards the idea behind a system, the actual interaction with the system under realistic conditions leads to more valid acceptance ratings. This also shows that acceptance of a given technology can depend on the demographics of the tested population.

Aside from the distinction between acceptance and acceptability there is a distinction between attitudinal and behavioural acceptance (Franken & Lenz, 2004). The former is connected to the cognitive or affective reaction towards a system. The latter is described as the behavioural response to a system. While acceptability and attitudinal acceptance can be assessed using questionnaires, behavioural acceptance can only be assessed through behavioural observation.

Table 5.1 gives an overview of the three discussed acceptance concepts. All three concepts of acceptance are important and need to be assessed at certain stages during the development of a system.

Table 5.1 Three concepts of acceptance of advisory systems

Concept	Acceptability	Acceptance	Behavioural acceptance
Subject matter	Attitude	Attitude	Behaviour
Time of assessment	Before use	After use	While using
Predicts	Penetration rate. Purchase decision and first use	Penetration rate. Intention to keep using the system	Compliance rate per given instruction

Acceptance with regard to advisory systems concerns all three of the previously covered aspects. Acceptability is important to raise penetration rate. Behavioural acceptance is closely related to the compliance with a given advice. However, compliance depends on more factors than acceptance of the advice (e.g. ability to comply). Attitudinal acceptance can be related to the driver's tendency to keep using the system after an initial experience.

The questionnaire that is presented here was set out to measure the attitude towards the preliminary advisory system based on a description of the system and can therefore give an indication about the systems acceptability.

5.1.2 **Annoyance with driver behaviour**

The goal of the described system is to improve traffic flow and throughput on motorways by giving in-vehicle advice on driving speed, gap size and driving lane in anticipation of a future traffic state. The system makes a prediction of potential bottlenecks based on traffic state data. The system's "perceptual horizon" and the resulting amount of information exceed that of the driver. This inequality of available information may pose a risk to the acceptance of the advice. In situations in which a driver does not understand the system's "motivation" for a given advice, compliance rate may suffer. Even when the given advice is preceded by a form of motivation (i.e. additional information that the driver does not have), the driver may still have a different opinion about the optimal behaviour in a given situation. In such a situation, compliance would require a certain amount of trust that following the advice will create an outcome that is seen as desirable by its user. However the development of trust is a continuous process, where trust can diminish through negative experiences (Hancock, Billings, & Schaefer, 2011). Therefore, the perceived outcome of compliance to an advice may be important in forming a judgement.

Other road users may not be aware that a driver is following the advice of an in-vehicle system. To them the compliance behaviour may seem unreasonable and may even trigger an aggressive response (e.g. honking, tailgating, blocking or aggressive gestures). Such negative reactions to compliance behaviour can cause dangerous situations and should be avoided. Furthermore, negative feedback for following an advice, for which the reason may not be understood and which usefulness may be in doubt, can decrease trust in the system and in the future make compliance to similar advice less likely.

An awareness of the problem has been shown to influence the acceptance of a solution to the problem (Eriksson, Garvill, & Nordlund, 2006; Steg & Vlek, 1997). A system that targets behaviour that is deemed highly problematic among road users may be regarded as more useful than a system that targets behaviour that is regarded as less problematic. However, self-reports of driving behaviour have been shown to be biased towards a favourable presentation of one's own driving behaviour (Lajunen & Summala, 2003). Drivers may be less aware of problems regarding their own driving behaviour. By asking participants to name the most annoying behaviour of other road users, an indication of problematic behaviour on motorways can be obtained without the requirement for drivers to refer to their own behaviour.

An on-line questionnaire has been devised that assesses the acceptability of an in-vehicle advisory system that is used for traffic flow improvement. Also, factors influencing the future adoption or rejection of the presented system were assessed. Furthermore, the questionnaire assesses what behaviour on motorways is deemed annoying among road users.

5.2 Method

5.2.1 Participants

The primary focus is on improving driving behaviour during rush hour on motorways. This includes for a large part commuting traffic. Therefore, participants were recruited that drove at least 10.000 kilometres per year and had experience with situations in dense commuter traffic (i.e. rush hour) on a motorway. A total of 237 complete responses were used for further analysis. Table 5.2 gives an overview of the questionnaire population.

Table 5.2 Demographics of the sample population

Category	Count	%
Completion		
Complete	237	
Incomplete	134	
Gender		
Female	56	23,6
Male	181	76,4
Age (years)		
18 – 24	12	5,1
25 – 39	93	39,2

40 – 65	125	52,7
> 65	7	3,0
Possession of a driver's license (years)		
< 3	8	3,4
3 – 7	24	10,1
> 7	205	86,5
Annual mileage (km)		
10.000 – 20.000	64	27,0
20.001 – 30.000	72	30,4
> 30,000	101	42,6
Possession of driver support systems*		
Navigation System	167	70,5
Cruise Control	126	53,2
Adaptive Cruise Control	2	0,8
Blind spot warning	0	0,0
Lane departure warning	0	0,0

* More than one answer allowed

5.2.2 Questionnaire design

The questionnaire consisted of three major parts. The first part concerned demographics (general data about the participant). In the second part of the questionnaire, participants were asked in an open question to report problematic driving behaviour on motorways. In addition to the open question, a list of potentially annoying behaviour was presented. The items on that list were separated in one of three environments where tactical driver advice may be given (i.e. dense traffic on a regular road, lane-drop and on-ramp/off-ramp). The Dutch law enforcement (Landelijk Parket) has a tradition of assembling and publishing an annual top ten list of annoyances in traffic. The list does not only include driving behaviour that is directly observable but also other problematic behaviour such as drunken driving or a tendency for aggressive driving. The top ten lists of 2010 and 2009 where used as an inspiration to develop examples of inappropriate driving behaviour for this questionnaire. Participants were then asked to estimate the level of annoyance they would experience when encountering these example behaviour on the road. That rating was given on a 5-point Likert-scale, where 1 meant ―not annoying and 5 meant ―very annoying. Table 5.3 gives an overview of the driver behaviour that had to be rated by participants completing the questionnaire.

Table 5.3 Examples of inappropriate driving behaviour in three traffic situations

Traffic situation	Driving behaviour	
Dense traffic	**Example 1**	Other road users not adhering to the current speed limit.
	Example 2	Other road users changing lanes in congestion under the assumption that the other lane is progressing at a faster pace.
	Example 3	Getting stuck behind a truck on the right lane because other traffic is making no space to re-enter the left lane.
	Example 4	Other road users in front of you, leaving too much space in front of them, thereby giving other driver's the chance to enter the lane, which slows down the whole traffic on that lane.
	Example 5	Other road users that keep driving on the leftmost lane making it impossible to pass them.
	Example 6	Being tailgated by a following car.
	Example 7	Driving in shockwaves, requiring you to decelerate from 100 km/h to 60 km/h, and then accelerate back to 100 km/h only to decelerate again seemingly without any reason.
Lane-drop (3 to 2 lanes)	**Example 8**	Late mergers on a lane drop in dense traffic.
	Example 9	Other road users that make no room on the middle lane as you try to merge from the right lane.
	Example 10	Other road users that make room for two or more late mergers in dense traffic.
	Example 11	Other road users that brake hard to make room for a merger.
On-ramp / Off-ramp	**Example 12**	Other road users that make no room as you try to enter the motorway.
	Example 13	No possibility to switch to the left lane and give room to vehicles entering the motorway.
	Example 14	Other road users that change lane to the middle lane and occupy the room that I have made for vehicles entering the motorway.
	Example 15	Other road users that initially change to the most left lane after entering the motorway.
	Example 16	Other road users that change several lanes at once to take an off-ramp.
	Example 17	Other road users that enter the motorway at a low speed causing traffic on the right lane to slow down.

The third part of the questionnaire concerned an assessment of the attitude of potential users towards the concept system. Therefore, participants were shown a Dutch translation of the following description of the system:

> *"At this moment we are developing a system that can give you advice on the optimal driving lane, speed and gap size to choose in order to better distribute traffic on the motorway. As an example, it is known that congestion in dense traffic develops later and resolve earlier when everybody adjusts his speed a little. The new system knows the exact state of the traffic situation further down the road and how drivers should adapt their driving to reduce the chance of congestion. This may sometimes result in advice that does not work in your individual benefit, yet, when followed, can improve the overall traffic situation. The more people adhere to the advice the higher the chance that traffic flow will improve."*

After reading the description, participants filled in an acceptance scale developed by Van der Laan et al. (1997). The scale uses semantic differential items (e.g. good-bad, useful-useless) to assess the perceived usefulness and satisfaction with a driver support system. In addition to the scale, participants were asked to name factors that would influence their likelihood to adopt or reject the described system. These factors provide a first impression of the aspects of the system that influence long term acceptance.

Two links to the web-questionnaire were published. One on the website of the Royal Dutch Touring Club ANWB, another one on a Dutch, traffic related web forum.

5.3 Results

5.3.1 **Types of annoying behaviour**

Participants' responses to the open question, describing the most annoying driver behaviour on motorways, were grouped by similarity and ordered by frequency. Table 5.4 gives an overview of the top ten answers and compares them to those found by the annual survey of the Dutch law enforcement.

Table 5.4 Observable annoyances in Dutch traffic (compared to 2010 and 2009)

#	Questionnaire (2011)	Annual survey Dutch police (2010)	Annual survey Dutch police (2009)
1	Late, aggressive merging at a lane drop, motorway entrance or exit	Tailgating	Driving left without cause
2	Driving left without cause	Drunk driving	Tailgating
3	Tailgating	Aggressive driving behaviour	Slow driving
4	Excessive lane changing in congestion	Driving left without cause	Incorrect use of the headlamps
5	Hindrance with merging at a lane drop, motorway entrance or exit	Slow driving	Overtaking trucks
6	Incorrect or no use of the indicator	Long-lasting passing manoeuvres	Incorrect or no use of the indicator
7	Early merging at a lane drop, motorway entrance or exit	Hindrance with motorway entrance or exit	Passing on the right side
8	Merging with speed differences at a lane drop, motorway entrance or exit	Evading traffic jam via emergency lane	Incorrect entering or exiting of the motorway
9	Long-lasting passing manoeuvres	Hindrance with lane change	Driving under influence
10	Deviating from the general speed limit	Incorrect use of the indicator	Fast driving near construction sites

Note For a more detailed list see Appendix A.1.

5.3.2 Annoyance ratings

Table 5.5 gives an overview of the average level of annoyance that participants experienced with the example behaviour depicted in Table 5.3 on a 5-point Likert-scale. Recall that 1 represents “not annoying” and 5 “very annoying”.

Table 5.5 Average level of annoyance by location

	Dense traffic	Lane drop	On/Off-ramp
Mean	3.6	3.3	3.5
SD	0.5	0.6	0.5

The results show only minor differences in average estimated annoyance between environments. A detailed representation of average annoyance caused by a particular behaviour example is shown in Figure 5.1.

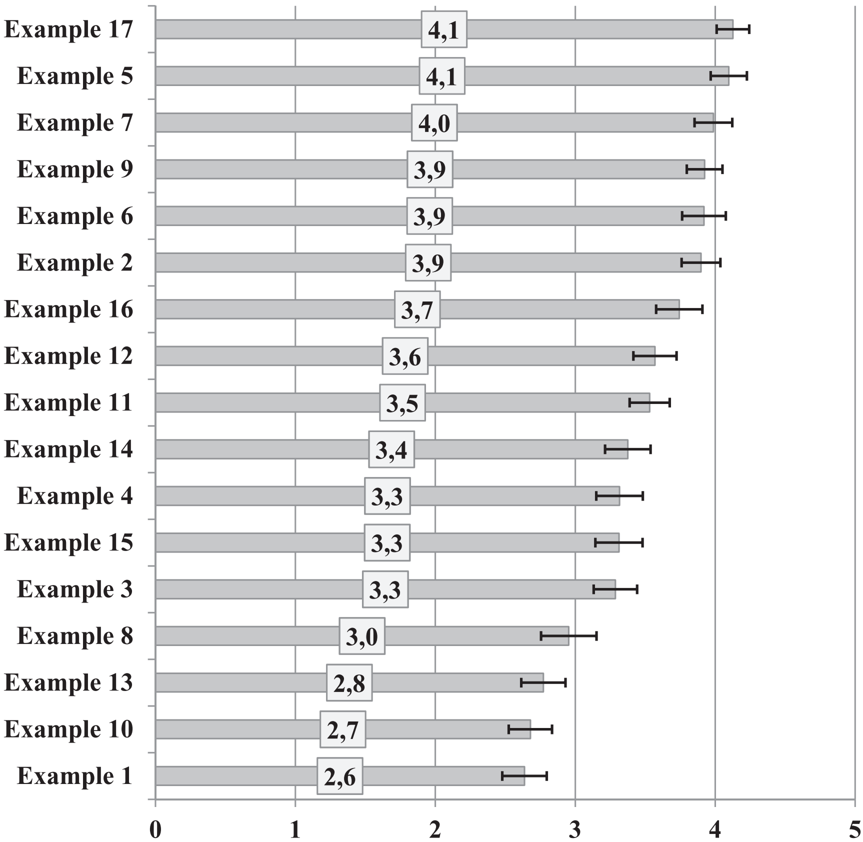

Figure 5.1 Average annoyance rating for each example behaviour, sorted in descending order with 95% confidence intervals. For a description of the behaviours see Table 5.3

All but four examples of annoying behaviour show a rating of above three on estimated annoyance. The annoyance level of the top six items lies on or above the 3rd quartile which cuts off the highest 25 percent of the data. The causes of annoyance among these six items concern examples of lane use or lane change behaviour (Statement 2, 5 and 7), gap size adjustment (Statement 6 and 9) and also speed adjustment (Statement 17).

5.3.3 Acceptability of CIVA

The later part of the questionnaire asked participants to give their attitude towards the proposed system. After reading the system description, participants filled in the semantic differential scale of acceptance related concepts. Figure 5.2 gives an overview of the mean ratings of the scale. Ratings are divided in categories of usefulness and satisfaction. It shows that the anticipated usefulness of the system was rated higher (M: 0.7, SD: 0.14) than the anticipated satisfaction (M: 0.26, SD: 0.14) with the system.

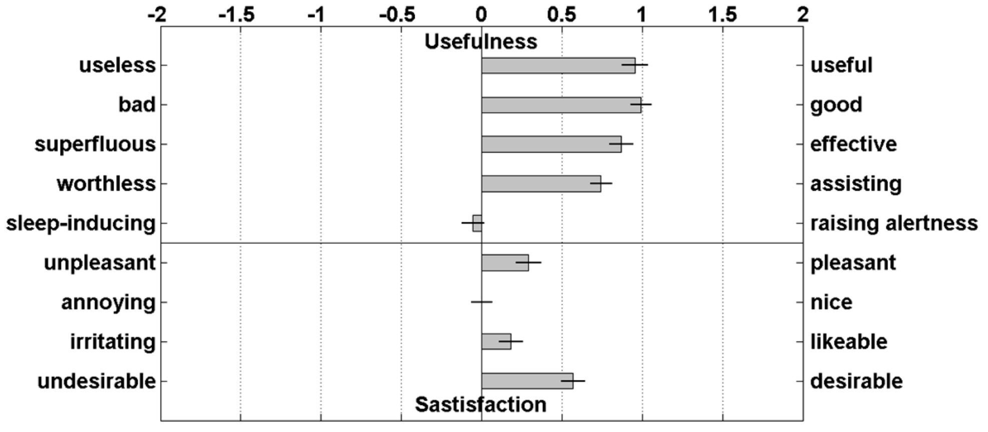

Figure 5.2 Anticipated usefulness and satisfaction with driver advice to improve traffic efficiency on motorways

5.3.4 Factors influencing adoption or rejection of CIVA

Factors that would influence participants' willingness to use the described system can be divided into two categories of conditional and contextual factors (Saad & Dionisio, 2007; Saad, 2004). Some participants were stating preconditions that would have to be met for them to use the system (conditional factors). Others were naming situations that would influence them to turn the system on or off during a trip (contextual factors). For both categories the answers were grouped by similarity. Participants stating conditional factors were concerned with the following:

- *Cost/benefit relation.* Participants demanded a beneficial effect from the system. The most frequently stated beneficial effect was saving time. On the other hand, a loss of autonomy, expensiveness and social deviance were the most frequent reasons to not use the system.
- *Penetration rate.* Drivers requested that there should be enough other drivers using the system. With regard to this, participants frequently requested that using the system should be made mandatory in order to use it themselves.
- *Agreement with instructions.* Participants requested that the system should be transparent in giving its instructions. However, they remarked that disagreement with the advice would be a reason not to use the system.
- *Interaction with the system.* The fewest of the given responses were made in context to the human-machine interaction. Those remarks were mostly safety concerns related to fear of distraction and overload.

These areas of user interest provide valuable points for future research on system acceptance. Furthermore, participants stating contextual factors were making their use dependent on:

- *Traffic demand.* High traffic demand was the reason to activate the system during a trip, whereas low traffic demand was seen as a reason to turn the system off.

- *Situation specific factors*. In bad weather the system would be switched on as well as on unfamiliar routes. However, several drivers remarked that they would turn the system off on familiar routes.

A detailed listing of the answers, grouped by similarity can be found in Appendix A.2.

5.4 Discussion

5.4.1 **Acceptability of CIVA**

The results of the scale indicate that the system is able to achieve positive usefulness as well as satisfaction ratings based on a general description. However, these results should be treated with caution and one should bear in mind the limits of this preliminary evaluation. The results are dependent on the description of the intended functionality of the system. The rating is based on the participant's imagination of the in-car advice rather than their experiences with a real prototype. Many factors that can influence the ultimate acceptance rating of the final system (e.g. driver system interaction, perceived penetration rate, amount of time saved using the system) cannot be considered in advance. Participants see value in a system that improves the distribution of cars on the motorway and that reduces the chance of congestion through tactical driver advice. In the following open questions, participants also put forward their demands from, as well as their concerns with such a system.

5.4.2 **Factors influencing adoption or rejection of CIVA**

The perceived benefit was the most prominent factor for using or rejecting the system. Saving time was the most often explicitly named benefit? Here a difference in benefit perception between the road operators and individual drivers can be observed. Although both focus on time saving as a measure of system benefit, road operators and traffic managers strive for a collective benefit (i.e. vehicle-loss-hours reduced by 30%, improved traffic flow and throughput), while individual driver strive for an individual benefit, that for them would justify the additional cost (that is increased effort, loss of autonomy) of using the system. Whether the beneficial effect on traffic flow created by the system is perceived by drivers as being sufficient to justify its use remains a topic for further investigation. Nevertheless, a difference in perceived benefit may result in situations where the system is deemed successful in improving traffic flow and reducing congestion from a road operator's standpoint (reducing overall travel time delay by a certain percentage); however for many drivers the individual travel time saving does not justify the use of the system. The analysis of the perceived cost/benefit relation can be challenging during the development of a system, especially when the systems beneficial effect is dependent on its penetration rate.

Furthermore, the monetary cost was a factor that would prevent the purchase of the system. A low willingness to pay for ADAS was observed in other survey studies (van Driel & van Arem, 2005), while higher prices would have negative consequences for their acceptability (Marchau, Penttinen, Wiethoff, & Molin, 2001).

Another influence factor for acceptance that was mentioned by participants stems from the interdependence between road users when it comes to traffic flow improvement. Many stated that they were only willing to participate in using the system under the conviction that enough other drivers would use the system as well. This is related to the dilemma between social and personal aims that have also been described in studies on the acceptance of pricing strategies for urban roads (Schade & Schlag, 2003; Vlassenroot et al., 2010). The present system represents a new direction among driver support systems. That is the creation of a collective benefit through promoting cooperative driving behaviour. This approach can have consequences for the acceptance of support systems that are yet to be understood. It can be argued that a dilemma between individual effort and collective benefit also plays a role in traffic flow improvement. How is collective benefit valued against (lack of) individual benefit? Also, the perceived penetration rate as well as the perceived compliance rate with the system's instructions become important variables that can determine the acceptance of the system. When drivers perceive the penetration rate as low, they may become discouraged to comply with the advice, feeling that their contribution does not make a difference. In the case of the presented system, the targeted collective benefit may also further reduce drivers' willingness to pay for the technology and installation.

A lack of agreement with the advice has been identified as a factor that in particular can influence the rejection of the system. Some participants indicated to reject a system whose instructions were in conflict with their own mental traffic model (i.e. the way they predict traffic development and determine the appropriate action). Some drivers intended not to use the system on familiar routes. In the introduction it was already mentioned that the system possesses information that the driver does not have, and that it could supply this information as a motivation for certain instructions. However, it may be questioned whether providing additional traffic information will lead to more congruence between the driver's view of the most appropriate action and the systems instruction. Besides the level of agreement with the advice, the individual driver's trust in the system may be an important variable that can determine acceptance of the advice.

An unexpected result was the low amount of concerns related to the user-interface and user-system interaction. Only a few drivers stated to be anxious about safety, distraction, and usability. However, not anticipating these and other problems that emerge from interacting with the system could also be a sign that participants did not have a sound understanding of what the interaction with the system would be like. Therefore, participants might just not be aware of problems related to the user-system interaction. Still such problems can be of great importance when they emerge while drivers experience the system in a real driving situation. Therefore it is too early to dismiss a poor quality of interaction as a significant influence factor to overall system acceptance.

Furthermore, some drivers indicated that they would prefer a system that integrates with their current support systems such as cruise control (CC) or adaptive cruise control (ACC). From the driver demographics it can be seen that CC is already used by half of the questionnaire population while the use of ACC can be expected to rise in coming years. Drivers may not be willing to abandon the comfort of these systems while following the advice. The compatibility of advisory systems with driver support systems already installed in a car can be seen as an option to improve system acceptance.

5.4.3 **Annoyance**

It is clear that the main objective of the presented system is the improvement of traffic efficiency and the reduction of congestion, not the reduction of annoying behaviour of road users. However, situations should be avoided where, in order to satisfy the system objective, an instruction is given that will cause extensive annoyance among other road users. Furthermore, targeting behaviours that are regarded as problematic may improve the acceptance of the system. The questionnaire results show that behaviours connected to merging and the choice of speed and following gap size were among those that road users see as problematic. This provides a first indication that the system will target behaviours that are relevant to road users.

Using the system and following advice should not cause additional annoyance among other road users. Whether or not compliance to an advice will cause annoyance is not only dependent on *what* driving manoeuvre is advised at a certain time. Attention must be drawn to *when* and *how* the advised manoeuvre will be carried out by the driver, which in turn is influenced by *when* and *how* the advice is provided by the system. This requires an analysis of the parameters that describe compliance behaviour and goes beyond the question whether an advice is being complied to or not. The change in driver behaviour parameters following the advice may be analysed for their potential to cause annoyance among other road users (in addition to an evaluation of their effect on driving safety). The examples of annoying behaviour that participants named in the questionnaire provide a starting point for the analysis. The following example shows how an understanding of annoying behaviour can support the development of a communication strategy for advisory systems.

In general, merging seems to be a major cause of annoyance (Positions 1, 5, 7 and 8 in Table 5.4). From a traffic management perspective the time of merging, the speed difference before merging and the accepted gap size are all possible access points for improvement. However, from the questionnaire we see that drivers sometimes have very divergent opinions about the optimal time of merging. While the majority of drivers are annoyed by late mergers (Position 1), early merging also appears in the list (Position 7). The results indicate that, even when a "system optimal" behaviour can be defined it may deviate from the "subjective optimal" behaviour for a certain group of drivers. Therefore it might be more promising to focus on generating the appropriate gap size for merging (Position 5) or the reduction of speed differences before merging (Position 8) instead. Also these two behaviours are less dependent on the correct timing in contrast to the choice of an optimal moment for a lane change.

Another cause of annoyance, that emerged in the questionnaire data, is that of a speed difference with the other traffic. For vehicles approaching a congested area, reducing their speed early can reduce the inflow into a congested area. Drivers may therefore receive an early advice to reduce their speed in anticipation of the upcoming situation. When enough drivers follow the advice, their behaviour could have an effect on unequipped vehicles that also reduce their speed. However, as the new recommended speed is not provided to all road users but only to a smaller number of equipped users, those are initially required to show socially deviant behaviour. Deviation from the general speed limit is seen as a nuisance (Position 10) and may be punished by fellow road users or even provoke dangerous behaviour such as tailgating. This example shows the importance of a minimum penetration rate. When the penetration rate is high, the number of equipped vehicles may reach a tipping point where the advised behaviour can create a new social norm that other, unequipped vehicles conform to. However, when the system's penetration is low, drivers who comply with its advice will deviate from the existing social norm which may lead to even more annoyance and traffic flow disturbance.

Furthermore, three forms of behaviour have been named both, with high frequency in the open question (Position 2, 3 and 4 in Table 5.4) while at the same time achieving high levels of annoyance. These are the perceived blocking of the left lane, tailgating and excessive lane changing in nearly congested traffic. While such behaviour can be identified as increasing the likelihood of shockwaves, the present system does not directly target their reduction. However, they may be reduced in as a side effect of using the system.

5.5 Conclusion

This chapter focussed on the acceptability of a preliminary advisory system with the goal of improving traffic flow and reducing congestion. Three concepts of acceptance were defined of which one (i.e. acceptability) was measured using a standard scale (van der Laan et al., 1997). Furthermore, factors influencing the acceptance of the system were identified. Finally, arguments were given for the importance of other road users' perception of driving behaviours that the system promotes.

Without having used the system, questionnaire participants regarded an advisory system that improves traffic flow while leaving the vehicle control to the driver as useful and moderately desirable. Yet, to get a better understanding of the acceptance of such a system, one needs to look at actual experience with the system in realistic situations.

Factors that influence adoption or rejection of the system have been identified. These factors show that potential users demand a benefit from using the system and that they are well aware of the interdependence between road users when it comes to traffic flow improvement and congestion reduction. Also, drivers may demand a system that behaves according to their understanding and expectations of what is considered the best behaviour in a given situation. A system that does not behave according to these expectations may fail to gain the trust of its users. Valid measurements of some of these concepts (i.e. perceived benefit, trust) depend on a functional prototype and may be difficult to analyse with a preliminary system.

Furthermore, the questionnaire results show that driver's notions of annoying traffic behaviour can diverge and that certain behaviours may be seen as beneficial or disturbing depending on the traffic situation (e.g. early vs. late merging). This has implications for the perceived usefulness of the instructions given by a system that aims to change this behaviour.

This questionnaire dealt with the acceptability of the proposed advisory system which shapes the initial attitude towards the technology. Future research will have to focus on assessing the change in driver behaviour as a reaction to the advice, but also on drivers' cognitive and affective response to the advice as they can greatly determine compliance rate as well as long term acceptance.

6 Driving simulator validation for instructed gap choice behaviour[2]

6.1 Introduction

In order to improve traffic efficiency, the CIVA system may advise drivers a certain speed, lane and gap size. There are different ways to communicate an advice to a driver. A straightforward method would be to provide a specific target value for speed or gap size or lane that should be attained. Such a specific target value would be the product of the advice algorithm, which is described in chapter 2.

However, providing a specific gap size target value may be more difficult than for lane or speed advice. When not hindered by other traffic, choosing a specific lane can be carried with relative ease by the driver. Furthermore, when choosing a specific speed, drivers may rely on the feedback of their speedometer. However, when attaining a specific gap size, drivers are usually not provided with feedback from their vehicle. This merits the question how good drivers are in following a specific gap advice. This question is studied in a driving simulator experiment, which is described in chapter 7.

[2] Parts of this chapter are based on the following publication:

Risto, M., & Martens, M. H. (2014). Driver headway choice: A comparison between driving simulator and real-road driving. *Transportation Research Part F: Traffic Psychology and Behaviour, 25*, 1–9.

To be able to generalize the results of a simulator study to real world driving, the simulator must elicit a driving behaviour that is similar to driving in the real world. The extent to which this is accomplished is denoted as the simulators behavioural validity. To gain confidence in the generalizability of the results provided in chapter 7, the driving simulator was validated for an instructed gap choice task. This chapter describes the validation of the driving simulator. First, some background on driving simulators is provided.

6.1.1 Background

Driving simulators provide a controllable, safe and cost-effective environment for gathering data, which makes them a valuable tool for research on driving behaviour (Kaptein, Theeuwes, & Van Der Horst, 1996). In a virtual environment, the safety of the driver is guaranteed even during dangerous driving manoeuvres, such as driving at short inter-vehicle distances. Furthermore, these environments provide researchers with an increased level of experimental control. This enables them to perform experiments on driver behaviour that would not be possible on real roads. For example, new forms of driver support can quickly be implemented and tested in a controlled environment without the need to conform to road safety regulations (Schieben, Heesen, Schindler, Kelsch, & Flemisch, 2009; van Waterschoot, 2013).

Driving simulators may vary in their physical appearance and their realism regarding the reproduction of the driving experience. Kaptein and colleagues (1996) differentiate between three broader categories of driving simulators: low-level, mid-level and high-level. Low-level simulators usually consist of desk-mounted computer monitors and gaming like vehicle control equipment (i.e. steering-wheel, gear shift and pedals). Mid-level simulators include a vehicle mock-up, placed in front of a larger projection screen with one or more projectors. High-level simulators usually provide a 180 to 360 degree field of view, often affording the use of side- and rear-view mirrors, and a vehicle mock-up on a moving base with several degrees of freedom.

In a driving simulator, driver behaviour is assessed in an artificial scenario, in a controlled environment and may not necessarily resemble driver behaviour that is displayed in a comparable real world situation (Carsten & Jamson, 2011; Loomis, Blascovich, & Beall, 1999). Simulator validation is important in order to be able to generalise the results obtained in a simulator to the real world. During simulator validation, several forms of validity may be assessed (for an overview see, for example, Blana, 1996; Mullen, Charlton, Devlin, & Bédard, 2011). Commonly simulators are being assessed with regard to their physical and behavioural validity. Physical validity refers to the correspondence of a simulator's physical components (e.g. appearance, visual display or vehicle dynamics) to the real world. Behavioural validity refers to the correspondence between driving behaviour elicited during driving in a simulator and driving in the real world (Allen, Rosenthal, & Cook, 2011; Engen, 2008; Kaptein et al., 1996; Mullen et al., 2011). An important distinction here is made between absolute- and relative behavioural validity. Absolute validity is obtained when measures of driver behaviour in a simulated environment produce the same numerical values as driving on a real road (Blaauw, 1982). If that is not the case, measures can still have a relative validity when numerical values (in response to an experimental manipulation) point in the same direction (Törnros, 1998). These definitions of validity make it impossible to refer to the overall validity of a driving simulator. Driving simulator validity has to be defined in relation to a specific research question (Kaptein et al. 1996). For example, several studies investigated whether driving simulators are suitable for research on speed behaviour specifically (Bella, 2008; Godley, Triggs, & Fildes, 2002; Shinar & Ronen, 2007). For a more comprehensive overview of driving simulator validation studies see Mullen et al. (2011).

6.1.2 Gap choice

The choice of an appropriate following distance is an essential skill in driving. Short distances have been identified as a major contributor to rear-end collisions (e.g. Knipling, 1993). Another term that has gained popularity in this context is headway. However, (Green, 2013) points out that in the literature the term headway is often inappropriately referred to as a measure for all forms of longitudinal separation. More accurately, headway is defined as either the time or the distance between the front bumper of a lead vehicle and the front bumper of a following vehicle. In turn, the distance or time between the rear-most surface of a lead vehicle and the forward-most surface of a following vehicle is accurately referred to as gap. In the present study the focus will be on the gap between the participant's vehicle and a lead vehicle. Figure 6.1 illustrates the difference between gap and headway.

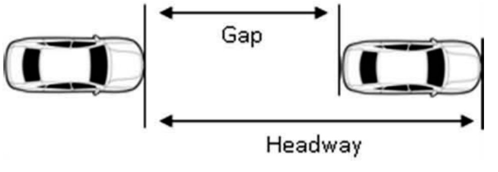

Figure 6.1 The difference between gap and headway

A distinction is made between distance gap, which describes the space between two vehicles in units of space (equal to following distance) and time gap, which describes the time difference between a vehicle arriving at a point on the road and the following vehicle arriving at that same point. Time gap is an established measure for driving safety. The Netherlands, Sweden and France stand as examples for jurisdictions where drivers are taught that a time gap of 2 s is considered to be safe.

For distance gaps it can be argued that a driver's choice of a specific gap size involves an estimation of the egocentric, absolute distance to the vehicle in front. In contrast to distance gap, the choice of a specific time gap involves the estimation of the time interval between the lead vehicle passing a particular point in space and the following vehicle passing that same point. This implies that the estimation of distance gap involves a judgement about space and the estimation of time gap involves a judgement about time.

Few studies have compared gap size estimation or gap choice between the two environments. Staplin (1995) observed that with oncoming traffic at an intersection the minimum gap that was still considered safe for a left turn was estimated larger in a simulator setting compared to the real world. Another study, using a truck-driving simulator, showed that, in verbal estimations, drivers underestimated distance gaps in the stimulator compared to real driving (Panerai et al., 2001). Duncan (1998) found that keeping a constant gap size was regarded as more difficult by participants driving in a simulator. These studies provide some direct comparisons regarding gap size estimation and gap size maintenance in a simulator and the real world. However, they may be considered dated taking into account the technological development that has taken place in driving simulator technology.

A common criticism of driving simulators is the reduced level of realism of the simulation compared to the real world. The estimation of the egocentric, absolute distance is guided by an evaluation of the same visual cues that provide information about the position of objects in space (Jamson & Jamson, 2010; Kemeny & Panerai, 2003), such as optic flow (Bremmer & Lappe, 1999), binocular disparity (Cutting & Vishton, 1995) and motion parallax (Rogers & Graham, 1979). In comparison to real world driving, simulated environments provide only a limited set of these visual cues, at a lower quality (Kemeny & Panerai, 2003). While it may be argued that this reduces a simulator's physical correspondence to the real world, it is not well understood to what extent it has an effect on the behavioural validity of the results. The evidence for the necessity of specific visual cues to correctly estimate egocentric distance (and with it distance gaps) is often contradictory. For example, a lack of visual complex imagery (e.g. natural texture, lighting) has been linked to less accurate perceptions of egocentric distance in virtual environments (Loomis & Knapp, 2003). Yet, according to a study by Thompson and colleauges (2004) using a directed-action task (that is, physically approaching a particular location in space), distance in photorealistic virtual environments was estimated with a similar accuracy as in more artificial appearing environments. According to the Known-Size-Apparent-Distance hypothesis "discrete changes in the size of the retinal image of an object, whose known size remains constant, will be perceived as corresponding changes in the apparent distance of that object" (Epstein, 1961, p. 333). However, Haber and Levin (2001) argue that distance perception is independent of the perceived size of an object. In earlier experiments it was found that egocentric distance perception was affected by binocular compared to monocular presentation (Levine & Rosinski, 1976). However, Creem-Regehr and colleagues (2003) found no effect of monocular viewing compared to binocular viewing on egocentric distance perception. Also it is commonly accepted that binocular disparity as a cue loses importance for egocentric distance perception with increasing distance between the observer and the object (Gibson, 1982; Wickens & Hollands, 1999). These studies demonstrate an inconsistency in the research on the importance of specific visual cues in the estimation of absolute, egocentric distance. Furthermore, the choice of time gaps may be affected less by a lack of visual cues. A lack of certain visual cues is therefore not sufficient to deem driving simulators un-suited for research on driver gap choice.

Studies comparing distance estimation in real and virtual environments outside the driving context describe virtual environments as compressed, leading egocentric distance estimates that underestimate the actual distance (Thompson et al., 2004; Willemsen & Gooch, 2002). However, these and similar studies, examining distance estimation outside the driving context, often use distance estimation methods such as directed walking (i.e. walking towards a point in space) or triangulated walking (i.e. walking in a different direction than the objects direction while pointing at the object) with participants occasionally being blindfolded. Whether these studies have a predictive value for comparisons of gap choice between a simulator and the real world may be questioned.

6.1.3 The present experiment

The aim of the present study is to investigate whether gap choice differs between a driving simulator and the real world. For this reason, gap choice following a gap instruction in a simulator is compared to following the same instructions in the real world. Considering the apparent difference between distance and time gap estimation, the present study includes a comparison between distance gap choice and time gap choice. Also, it has been argued that natural gap size adjustment is guided primarily by a non-verbal, visual representation of gap size, rather than an estimation of a specific gap size value that is derived from a verbal formulation (Lewis-Evans, De Waard, & Brookhuis, 2010; Taieb-Maimon & Shinar, 2001). For this reason, not only gap choice following a specific verbal instruction, but also unguided gap choice needs to be included in a comparison of driver behaviour between driving simulator and the real world. Results of this study can provide indicators of how a particular method for choosing gaps can vary between real and virtual environments.

Several studies have pointed out an underestimation of distance in virtual environments compared to real environments. Therefore, it is hypothesized that (1) gap choice in a simulator, following distance gap instructions, leads to gap sizes that are larger than in the real world. On the other hand gap choice following time gap instructions should not be influenced by the same visual cues as the choice of distance gaps. Therefore, it is hypothesized that (2) gap choice in a simulator, following time gap instruction, leads to gap sizes that do not differ significantly from gap sizes following time gap instructions in the real world. Lastly, similarly to distance gaps, self-chosen gaps should be affected by the same visual cues that affect distance estimation. Therefore, it is hypothesized that (3) self-chosen gaps in a simulator will lead to gap sizes that are larger that self-chosen gap sizes in the real world.

6.2 Method

6.2.1 Experimental design

The study used a 2 × 2 × 3 × 3 within subjects design with repeated measures. Vehicle Type (instrumented vehicle vs. driving simulator), Instruction Method (seconds vs. metres), Lead Vehicle Speed (80 vs. 100 vs. 120 km/h) and Target Gap (1 vs. 1.5 vs. 2 second(s)) were independent variables. This design was extended by adding three trials, one for each level of Lead Vehicle Speed. In these trials, participants were instructed to choose their own preferred gap size at the respective speed. The chosen gap size following a gap instruction was chosen as the dependent variable. Half of the participants began the experiment in the driving simulator the other half in the instrumented vehicle. The trials that participants encountered in both vehicles are given in Table 6.1.

Table 6.1 Overview of trials used in the experiment

	Instruction Method	Lead Vehicle Speed (km/h)	Target Gap (seconds)	Target Gap (metres)
Specific instructions	Seconds	80	1	-
		80	1.5	-
		80	2	-
		100	1	-
		100	1.5	-
		100	2	-
		120	1	-
		120	1.5	-
		120	2	-
	Meters	80	1	22
		80	1.5	33
		80	2	44
		100	1	28
		100	1.5	42
		100	2	56
		120	1	33
		120	1.5	50
		120	2	67
Self-chosen	-	80	-	-
		100	-	-
		120	-	-

Note. All trials were presented in the simulator and the instrumented vehicle

6.2.2 **Participants**

Twenty-two participants (18 men, 4 women), aged 27-64 years (M: 48.6, SD: 10.3) completed the experimental procedure. All participants were recruited from the pool of employees of the University of Twente and had no prior knowledge of the study. All participants were in possession of a driver's license for at least five years (M: 28.7, SD: 10.2) and drove at least 10.000 kilometres by car annually. Participation was completely voluntary and participants received a compensation of 50 euros. Participants reported to have normal or corrected to normal vision. One participant got sick due to simulator illness, while his instrumented vehicle data was already recorded. The trials from the simulator session were filled per trial by the average values of the remaining participants. Applying this method of mean imputation did not lead to a difference in the significance of the results compared to excluding the data from that participant.

6.2.3 **Driving simulator setup**

The driving simulator consisted of a car mock-up placed in front of a visual screen with 180° field of view. The virtual environment was generated using Lumo Drive v2.5 developed by Re-lion. The car-model that was used had an automatic gearbox. Mirrors and vehicle speed were projected onto the outside screen. Vehicle speed and following gap were recorded at 10 Hz. According to the classification of Kaptein and colleagues (1996) this constitutes a mid-level driving simulator.

The simulated road was a two lane motorway. A simulated lead vehicle, for which the vehicle model of a Renault Megane was used, was placed in the right lane. Behind the lead vehicle, the participant's vehicle was placed. Other vehicles were placed on the road. Vehicles on the right lane drove the same speed as the leading vehicle. To add realism, vehicles on the left lane drove the speed of the lead vehicle plus 5%. All simulated vehicles kept their own lane, and the participant was instructed to stay behind the lead vehicle. Figure 6.2 gives an impression of the used simulator setup.

Figure 6.2 The simulator setup used in the experiment

6.2.4 **Instrumented vehicle setup**

The instrumented vehicle was a Toyota Prius with automatic gearbox. Vehicle speed and following gap were recorded at 10 Hz. During the experiment, the current gap size was visible to the experimenter but not the participant. The lead vehicle was a Renault Megane driven by a research assistant that communicated by walkie-talkie. During the experiment, the lead vehicle's cruise control was used to keep the experimental speed. The test drives were done on a straight piece of German motorway.

6.2.5 **Procedure**

Before each driving sessions in the simulator as well as in the instrumented vehicle participants read instructions (see Appendix B.1) and signed an informed consent. After that, in the simulator, participants completed a test trial to get accustomed to the task and the simulator. In the instrumented vehicle, participants drove themselves to the motorway to familiarize themselves with the handling of the instrumented vehicle.

Both sessions were divided into three blocks with the lead vehicle driving 80, 100 or 120 km/h. Within each of these blocks, seven trials were held, while in each trial the participant was given one gap assignment. In three of the seven trials the participant was asked to attain a gap in seconds (i.e. 1, 1.5, or 2s), in three trials the participant was asked to attain a gap in metres (i.e. the equivalent of 1, 1.5 or 2s for that speed in metres) and in one trial the participant was asked to attain a gap size as they would normally do themselves. The order of the three blocks was randomized, as well as the order of the seven trials within each block.

The initial gap size to the lead vehicle in each trial was equivalent to a time gap of 3 seconds at the respective speed. In the simulator, before each trial, the participant's distance was set to the initial gap size. On the motorway, before each trial, the experimenter asked the participant to increase the distance to the lead vehicle to the initial gap size. At the initial gap size, the participant was instructed to attain one of the predefined gap sizes to the lead vehicle. In both vehicles, participants were given infinite time to attain the instructed gap. To finish a trial, participants confirmed their gap choice by telling the experimenter at the moment that they thought they had reached a stable gap size. In the instrumented vehicle, the experimenter restarted a trial whenever the lead vehicle had to brake, or when another car cut in between the instrumented vehicle and the lead vehicle.

6.2.6 **Treatment of missing values**

The radar of the instrumented vehicle had a range of 150 metres. When the distance from the participant's vehicle to the lead vehicle was greater than 150 metres, no distance data to the lead vehicle was recorded. In 18 of 462 instrumented vehicle trials this led to missing data. In these cases, distance values of 150 metres were used as a substitute for the analysis. To ensure comparability the same cut-off point was applied for distance data obtained in the driving simulator. As a result data was clipped in 17 simulator trials at a cut-off point of 150 metres. To obtain the dependent variable, distance gaps from the simulator and the instrumented vehicle were converted to time gaps using the participant's speed at the moment of their gap choice.

6.3 Results

6.3.1 **Gap choice: Instructed**

A repeated measures ANOVA was carried out with vehicle (Instrumented car vs. driving simulator), Instruction Method (seconds vs. metres), Target Gap (1 vs. 1.5 vs. 2 seconds) and Lead Vehicle Speed (80 km/h vs. 100 km/h vs. 120 km/h) as within subjects variables and time gap as the dependent variable. As measure of effect size generalized eta squared (η_G^2) are provided (Olejnik & Algina, 2003). Bakeman (2005) recommends using the following limits of 0.02 for small, 0.13 for medium, and 0.26 for denoting a large effect size.

Mauchly's test indicated that the assumption of sphericity had been violated for the interaction between Target Gap and Instruction Method W = 0.57, $p < .05$. Therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .70$). A significant main effect of Target Gap was found, $F(2,42) = 87.41$, $p < .05$, $\eta_G^2 = 0.096$, furthermore a significant main effect of Instruction Method was found, $F(1,21) = 7.78$, $p < .05$, $\eta_G^2 = 0.127$. However, a two-way interaction between Target Gap and Instruction Method was also found to be significant, $F(1.48,30.98) = 4.88$, $p < .05$, $\eta_G^2 = 0.008$. Figure 6.3 shows this interaction.

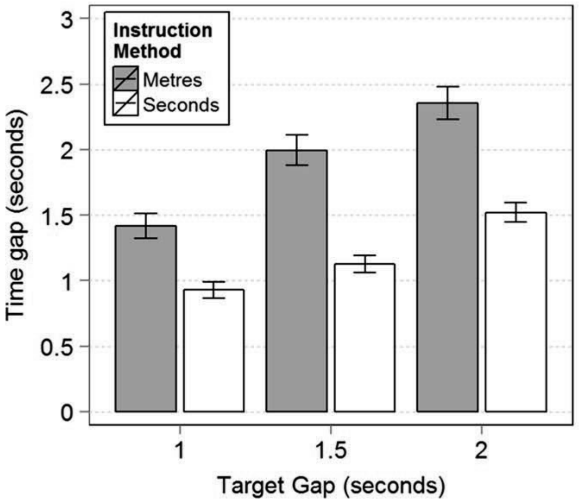

Figure 6.3 Interaction between Instruction Method and Target Gap on the chosen time gap. Error bars indicate the standard error

To break down this interaction effect it was tested whether the magnitude of the difference between levels of Instruction Method varied between levels of Target Gap. To achieve this, first, two separate ANOVA were carried out, one for each level of Instruction Method, with Target Gap as within participants variable. Both ANOVA were significant, indicating that for both levels of Instruction Method there were significant differences between levels of Target Gap. To locate which levels of Target Gap were different from another, each of the two ANOVA was followed up with three paired-samples t-tests (i.e. 1 vs. 1.5, 1.5 vs. 2 and 1 vs. 2), with Bonferroni correction. All resulting t-tests (three for unit-type time and three for unit-type distance) indicated significant differences between the means ($p < .05$).

Furthermore, a significant three-way interaction was found between Vehicle Type, Lead Vehicle Speed and Target Gap, $F(4,84) = 4.17$, $p < .05$, $\eta_G^2 = 0.003$. This three-way interaction is shown in Figure 6.4.

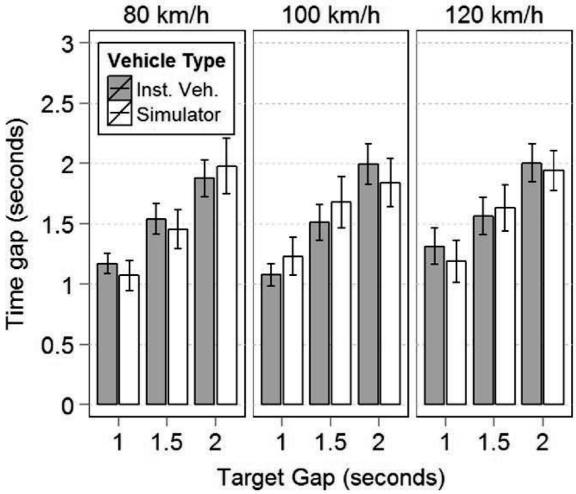

Figure 6.4 Three-way interaction between Vehicle Type, Lead Vehicle Speed and Target Gap on the chosen time gap. Error bars indicate the standard error

To break down the significant three-way interaction, three separate repeated measures ANOVA were carried out, one for every level of Lead Vehicle Speed, with vehicle (Instrumented vehicle vs. driving simulator) and Target Gap (1 vs. 1.5 vs. 2 seconds) as within participants factors and chosen time gap as dependent variable.

At 80 km/h a significant main effect of Target Gap was found $F(2,42) = 68.00$, $p < .05$, $\eta_G^2 = 0.241$. At 100 km/h Mauchly's test indicated that the assumption of sphericity had been violated for the interaction effect of Target Gap and Vehicle Type, $W = 0.43$, $p < .05$, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .64$). A significant main effect of Target Gap was found, $F(2,42) = 51.37$, $p < .05$, $\eta_G^2 = 0.174$, in addition an interaction effect of Target Gap and Vehicle Type was found, $F(1.28,26.78) = 4.24$, $p < .05$, $\eta_G^2 = 0.012$. At 120 km/h only a main effect of Target Gap was found, $F(2,42) = 40.02$, $p < .05$, $\eta_G^2 = 0.159$.

The significant two-way interaction of Target Gap and Vehicle Type at 100 km/h was broken down to three paired samples t-tests (with Bonferroni correction) at each level of Target Gap. These tests revealed that none of the means differed significantly from the other ($p > .05$, two-tailed).

The results of this analysis indicate an effect of the Type of Vehicle on chosen gaps when following gap instructions although subsequent pairwise comparisons provided no evidence that any mean was significantly different from the other.

6.3.2 Gap choice: Self-chosen

A repeated measures ANOVA was carried out with vehicle (Instrumented car vs. driving simulator) and Lead Vehicle Speed (80 km/h vs. 100 km/h vs. 120 km/h) as within subjects variables and time gap as the dependent variable.

No effect was found to be significant ($p > .05$). Self-chosen gaps did not differ significantly over all three levels of Lead Vehicle Speed for the simulator (M: 1.71, SD: 0.65) as well as the instrumented vehicle (M: 1.82, SD: 0.80). These results indicate that freely chosen gaps do not differ between the instrumented car and the simulator.

6.4 Discussion

Results indicate that for three different methods of gap instructions, gap choice in a driving simulator leads to similar results when compared to gap choice behaviour on a real road. An effect of Target Gap and an interaction with Instruction Method was found for chosen gaps when following specific gap instructions. Gap sizes following time based instructions were smaller than gap sizes following distance based instructions. This difference replicates earlier studies on gap size estimation (Taieb-Maimon & Shinar, 2001; Taieb-Maimon, 2007). The results support the notion that the type of a gap instruction will have an effect on the size of the chosen gap. This influence needs to be considered when providing specific gap advice to drivers and could be used to influence the drivers to drive at safer gap sizes. There was no significant difference in the simulator compared to the real world related to gap choice for both type of instructions.

The type of vehicle was part of a three-way interaction effect with Lead Vehicle Speed and Target Gap on gap choice when following specific gap instructions. However, subsequent pairwise comparisons did not reveal any significant difference in the average chosen gaps between simulator and real world at any combination of Lead Vehicle Speed and Target Gap. Based on these results the first hypotheses is rejected, that distance gap instructions lead to different gap choices in the simulator compared to the real world. On the other hand the results are not in stride with our second hypotheses, which time gap instructions lead to similar gap sizes in the simulator and the real world. Based on the lack of an effect of Vehicle Type on instructed gaps it can be concluded that, with regard to instructed gaps, behavioural validity of this simulator is high and generalizations from results obtained in the simulator to experiments on a real road can be made.

The type of vehicle had no effect on self-chosen gaps, failing to support our third hypotheses. The lack of an effect of Lead Vehicle Speed on self-chosen gaps in the simulator as well as in the real world supports earlier studies by Van Winsum and Heino (1996) where driver's time gap during car following in a driving simulator remained consistent over a range of speeds. Also in real world driving Taieb-Maimon and Shinar (2001) found that drivers adjusted their distance gaps in relation to speed so that a constant time gap emerged at all speeds. Based on the lack of an effect of the type of vehicle on self-chosen gaps it can be concluded that, with regard to self-chosen gaps, generalizations from results obtained in the simulator to experiments on a real road can be made. In general, these results provide evidence that absolute validity of gap choice behaviour can be obtained with mid-level driving simulators.

A limitation of this study lies within the decision to instruct the choice of a natural gap size in the present study. Following instructions in an experimental context, even those that ask for natural driving behaviour, may change the nature of the resulting behaviour. For experienced drivers gap choice may be considered an overlearned behaviour that can be carried with a certain degree of automation. The instruction to attain a self-chosen gap size will require the driver to make a conscious choice of a preferred gap size. The generalisation to natural gap choice outside the experimental context may therefore remain difficult due to the conscious execution of the instructed task.

In conclusion, the results provide evidence for the suitability of using mid-level driving simulators for the study of driver gap choice. However, a generalisation of the results to other simulator setups (even mid-level simulators) should be done with precaution. While the present results indicate that mid-level driving simulators can be used to study driver gap choice, each type of mid-level simulator should be validated separately including all relevant aspects of the specific research question. For example, in respect to gap choice, mid-level simulator setups may still differ in their presentation of certain visual cues. These differences may affect the validity of gap choice data in other simulators.

7 Driver ability to follow specific gap instructions[3]

7.1 Introduction

In order to improve traffic efficiency on motorways the CIVA system calculates an efficient gap size and advises drivers to use this gap size until advised otherwise. In the most straightforward way, the target gap size may be presented in metres or seconds. This form promises the ability to advise even small changes in target gap size (e.g. several metres or tenths of a second). However, to comply with the advice, drivers have to be able to accurately estimate their gap size, in order to compare their estimates to the advised gap size. Furthermore, in order to attain the advised gap size, drivers have to accurately position their vehicle with respect to the vehicle in front.

The goal of the studies presented in this chapter was (1) to assess whether time gap instructions lead to more accurate gap choice compared to distance gap instructions, and

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[3] Parts of this chapter are based on the following publications:

Risto, M., & Martens, M. H. (2013). Time and space: The difference between following time headway and distance headway instructions. *Transportation Research Part F: Traffic Psychology and Behaviour, 17,* 45–51.

Risto, M., & Martens, M. H. (2014). Supporting driver headway choice: The effects of discrete support when following headway instructions. *Applied ergonomics, 45(4),* 1167–1173.

whether this depends on vehicle speed and target gap size; (2) to assess the effect of discrete gap size feedback on gap choice accuracy for drivers carrying out time gap instructions.

In past research, several influence factors have been found regarding individual gap choice in driving (for an overview see Brackstone, Waterson, and McDonald (2009)). However it is not clear yet how these factors (e.g. driving speed) influence the driver's behavioural reaction to gap instructions. Furthermore, additional factors regarding the instruction itself can influence the chosen gap size.

7.1.1 **Time gap vs. Distance gap estimation**

As discussed in the previous chapter, a difference has to be made between time gap (i.e. seconds) and distance gap (i.e. metres) instructions. Experiments on natural gap choice have shown that gap choice in seconds remains constant across different driving speeds (Taieb-Maimon & Shinar, 2001; van Winsum & Heino, 1996). However, when drivers are required to estimate a specific gap size different results are found. For example, Taieb-Maimon and Shinar (2001) instructed drivers to choose the smallest gap size that was still considered save by drivers and to give an estimate of the chosen gap size in seconds, metres or car-lengths. The authors found that drivers' verbal estimates of time gap (in seconds) increased with speed while the actual chosen time gap remained constant. Verbal estimates in meters and car-lengths showed no effect of speed. With regard to the direction of deviation of the estimated from the chosen gap, estimates of time gaps yielded an overestimation which was greater than the observed underestimation of distance gap estimates. In another study, Taieb-Maimon (2007) instructed drivers to attain gaps of one or two seconds or the respective distance in meters. Here, the chosen gaps, following time based instructions, were smaller than the instructed gaps (reflecting an overestimation), while chosen gaps, following distance based instructions, were larger than the instructed gaps (reflecting an underestimation). Speed had no significant effect on attaining the instructed distance- as well as time gap. This illustrates the importance of a choice for an appropriate representation of gap size when instructing specific gaps. Furthermore, a comparison of both studies suggests that the verbal estimation of a chosen gap is affected differently by external factors (e.g. speed) than attaining a specific gap size.

To assess gap choice accuracy the above mentioned studies use different measures; the relative estimation error (Taieb-Maimon, 2007) and the absolute estimation error (Taieb-Maimon & Shinar, 2001). These measures inherently provide different information. The absolute estimation error is better suited to describe gap choice accuracy. Only the relative estimation error can show the direction of deviation of a chosen gap from an instructed gap (under or overestimation). A comparison of both measures can illustrate the difference between the two; however such a comparison has not yet been performed with regard to driver performance when following specific gap size instructions.

One characteristic of time gap is that a single safe gap size value can be advised independently of speed. It may therefore be assumed that estimates of time gap should be unaffected by variations in speed, as long as the time value, that is to be estimated, remains constant. However, if time gap instructions are transposed into distance gap instructions changes in speed as well as changes in target gap change the size (magnitude) of the physical distance that has to be estimated. Cutting and Vishton (1995) argue that the effectiveness of various depth cues, which are used by drivers to infer distance judgements, is reduced when the physical distance to the lead vehicle becomes larger. This suggests that the perceived distance is sensitive to the size of the physical distance and that estimates of distance gap should be sensitive to variations in speed and target gap. As stated in the previous chapter, time gap estimation may not be affected by the actual space between vehicles but by the time between vehicles. Therefore, it may be argued that varying vehicle speed does not affect driver ability to estimate a time gap while it affects driver ability to estimate distance gap. Due to the required estimation of greater physical distances at higher speeds distance gap estimation accuracy is expected to become lower.

In the first part of the present study, the effect of vehicle speed and gap size on driver gap choice accuracy is compared between time or distance gap instructions. Our hypotheses are the following:

> H1a: When following distance gap instructions, the accuracy of the chosen gap will decrease with increasing vehicle speeds

> H1b: When following time gap instructions, there will be no effect on gap choice accuracy with increasing vehicle speeds.

Furthermore, it can be argued that when vehicle speed remains constant, larger values of target gap (in seconds) will increase the inter-vehicle distance, as well as the time interval that has to be estimated. Therefore, target gap has an effect on gap choice for both time gap as well as distance gap instructions. This leads to the following hypotheses:

> H2a: Increasing target gap size will lead to decreased accuracy of the chosen gap when following distance based instructions.

> H2b: Increasing target gap size will lead to a decreased accuracy of the chosen gap when following time based instructions.

Taieb-Maimon (2007) showed that instructions based on time gap can affect the direction of the deviation of the chosen gap from the instructed gap differently, compared to instructions based on distance gap. In the experiment, following time based instructions caused drivers to choose positions closer to the lead vehicle than instructed. Following distance based instructions caused drivers to choose positions further away from the lead vehicle than instructed). Based on these findings, the hypotheses in this study are that:

> H3a: Time based instructions lead to gaps that are smaller than instructed.

> H3b: Distance based instructions lead to gaps larger than instructed.

7.1.2 Gap size feedback

In addition to the gap advice the system may assist drivers in attaining the instructed gap size. The in-vehicle human-machine interface of the presented system affords assistance to be provided via the auditory or visual channel. However, the visual channel is already predominantly used in car driving. Additional visual load, due to gap size feedback, may lead to overload and distraction (Heijer & Oppe, 1996; Lansdown, 2000). Alternatively, discrete auditory gap size feedback may have a beneficial effect in supporting drivers to attain an instructed gap size. Discrete gap size feedback takes the form of a stimulus, issued at the moment that a driver has reached a predefined (in this case the instructed) gap size. Auditory gap size warnings have been used in collision avoidance systems to indicate when drivers surpass a minimum safe gap size (e.g. Graham, 1999; Gray, 2011; Horowitz & Dingus, 1992) with an auditory tone being a more effective form of presentation compared to spoken text (Hirst & Graham, 1997). It has also been shown that sound produces faster reaction times than visual stimuli (Bly, 1982; Colavita, 1974; Wickens & Hollands, 1999), although more recent studies suggest this difference in reaction time to be modest (Scott & Gray, 2008). Furthermore, sound signals can be perceived while the driver's gaze remains on the road in place of an in-vehicle system. This reduces the risk of an impaired detection ability of events outside the vehicle (Dingus et al., 2006; Simons-Morton, Guo, Klauer, Ehsani, & Pradhan, 2014; Summala, Lamble, & Laakso, 1998). Providing discrete auditory gap size feedback may improve the accuracy of the chosen gaps.

An important question is, whether this form of driver assistance is equally effective in improving gap choice accuracy while increasing or decreasing gap size. According to the taxonomy of Michon (1985) gap size adjustment may be considered a tactical manoeuvre. The execution of this tactical manoeuvre is in turn triggering an action pattern at the vehicle control level (i.e. applying and releasing gas, braking). On the vehicle control level there are different action patterns involved in increasing and decreasing gap size. To decrease their gap size drivers have to apply gas in order to gain speed. At the point when they decide that the intended gap size is reached they need to reduce speed until it matches the speed of the lead vehicle. On the other hand, to increase gap size drivers have to let go of the gas or even use the brake to reduce speed. When their gap size has increased to the intended distance, they have to gain speed until it matches the speed of the lead vehicle. This process description illustrates how both tasks are different in theory. It is important to investigate in practice whether these differences are equally affected by the proposed form of driver support. The hypotheses reading gap size feedback were as follows:

> H4: Discrete gap size feedback will increase the accuracy of the chosen gap size when carrying out gap instructions.
> H5: The direction of gap size adjustment will affect the accuracy of the chosen gap size when carrying out gap instructions.

7.2 Method

7.2.1 Experimental Design

This study used a 2 × 2 × 3 × 3 repeated measures design with Presence of Support (support vs. no support) and Instruction Method (seconds vs. metres) as a between participant factors and Lead Vehicle Speed (50 vs. 80 vs. 100 km/h) and Target Gap (1 vs. 1.5 vs. 2 second(s)) as within participants factors. The initial gap size in a trial was 3 seconds, requiring participants to decrease their gap size in order to attain the target gap size. At each level of Lead Vehicle Speed one trial was added to the trial list where the initial gap size was set to one second and Target Gap was set to 2 seconds. In these trials the direction of gap size adjustment was to increase instead of decrease gap size. The dependent variables were average estimation error and relative estimation error. The trial list for the experiment is given by Table 7.1.

Table 7.1 Overview of trials used in the experiment

Target variable	Lead Vehicle Speed (km/h)	Initial gap size in metres (seconds)	Target Gap	
			TG (seconds)[a]	DG (meters)[a]
Long initial gap size	50	42 (3)	2	28
			1.5	21
			1	14
	80	66 (3)	2	44
			1.5	33
			1	22
	100	84 (3)	2	56
			1.5	42
			1	28
Short initial gap size	50	14 (1)	2	28
	80	22 (1)	2	44
	100	28 (1)	2	56

[a]TG = Time gap, DG = Distance gap

7.2.2 Participants

Forty participants (30 men, 10 women), aged 20 to 57 years (M: 37.6, SD: 9.6) completed the experimental procedure. Participants were randomly assigned to one of the four between participants conditions with an even distribution of gender and age between the groups. All participants were recruited from the pool of employees of the University of Twente and had no prior knowledge of the study. All participants were in possession of a driver's license for at least one year (M: 16.8, SD: 9.1) and drove at least 10.000 annual kilometres by car.

Participants reported to have normal or corrected to normal vision. Participation was completely voluntary and participants received no payment.

7.2.3 **Instructions**

The task for drivers was to adjust their gap size to the lead vehicle to represent the instructed gap size as closely as possible. Auditory speech gap instructions requested drivers to decrease or increase their gap size to a specific value. In the time gap (TG) condition participants were instructed to decrease their time gap to 1, 1.5 or 2 seconds. In the distance gap (DG) condition participants were instructed to decrease their gap size to a value in meters, corresponding to a time gap of 1, 1.5 or 2 seconds at the given level of Lead Vehicle Speed. As an example, the instruction a participant received would be: “Decrease your time gap to two seconds”. For the experiment, the auditory modality was chosen to present the instructions to the participant. Although the system may also make use of the visual modality, for this experiment it was chosen to make the human-machine interface as simple as possible, thereby avoiding the influence of additional interface elements.

7.2.4 **Discrete gap size feedback**

The form of gap choice support that was used in the experiment was discrete gap size feedback. It had the form of a tone (the note G played on a metal Xylophone) indicating the moment when the current time gap of the participant’s vehicle to the lead vehicle matched the instructed time gap. The sound was played once at the crossing of the instructed gap size. Any subsequent crossing in either direction would produce no further tone.

7.2.5 **Driving Simulator setup**

The simulator consisted of a car mock-up placed in front of a visual screen with 180° field of view. The virtual environment was generated using Lumo Drive v2.5. The car-model that was used had an automatic gearbox. Mirrors and dashboard were projected onto the outside screen. The pre-recorded gap instruction, as well as the discrete gap size feedback, were played via desktop speakers, placed on the dashboard. The vehicle speed and frontal gap size were recorded at 10 Hz.

The simulated road was a two lane motorway. The lead vehicle was placed in the right lane, driving at a constant speed of 50, 80 or 100 km/h depending on the current trial. Behind the lead vehicle, the participant’s vehicle was placed at an initial time gap size of 3 seconds in the ‘decrease’ scenarios and 1 second in the ‘increase’ scenarios. Other vehicles were placed on the road, those on the right lane driving at the same speed as the leading vehicle, those on the left lane driving the speed of the lead vehicle plus 5 per cent. All simulated vehicles kept their own lane, and the participant was instructed, to stay behind the lead vehicle. Figure 7.1 gives an impression of the used simulator setup.

Figure 7.1 The simulator setup used in the experiment

7.2.6 **Procedure**

After reading the instructions (see Appendix C.1) and finishing an informed consent, participants completed a test trial to get accustomed to the task and the simulator. The task for participants was to adjust their gap size to the lead vehicle so that it equalled the instructed gap size and to indicate their gap choice by pulling the leaver for the high beam. In addition, participants had to maintain the chosen gap size as close as possible until the end of the trial. Before the experiment participants had been randomly assigned to one of the four between participants groups (i.e. discrete gap size feedback vs. no feedback; time gap vs. distance gap). In each group ten participants completed twelve trials in randomized order. The trials were the result of combination of the within-participants factors and are given in Table 7.1.

At start of a trial the participants' vehicle was placed at the initial gap size of 3 seconds to the lead vehicle. In the instructions before the experiment, participants received suggestions on how to estimate the distance or time between their vehicle and the lead vehicle. Participants were asked to maintain the initial gap size as accurately as possible until the gap instruction was played. After the instruction was played drivers were given infinite time to attain the instructed gap size. To finish the trial, participants had to confirm the choice of their new gap size by pulling the lever for the high beam at the moment that they switched tasks from adjusting their gap size to maintaining a stable gap size. Participants receiving gap size feedback might have been tempted to confirm their gap choice as soon as the auditory feedback tone is played. To avoid these situations, participants in the feedback condition were instructed to use the auditory feedback as an orientation, but to make their final gap choice dependent on their own gap size estimation.

7.2.7 Estimation error

Distance gap was defined (and measured) as the distance from the back bumper of the lead vehicle to the front bumper of the participant's vehicle. Time gap was defined as distance gap divided by the speed of the participant's vehicle. The relative gap size estimation error was defined as the difference between an instructed gap size and the gap size chosen by a driver. Depending on the direction of the relative estimation error the difference value can either be positive (i.e. chosen gap size smaller than instructed gap size) or negative (i.e. chosen gap size larger than instructed gap size). Relative estimation errors that include positive as well as negative values can approach zero when averaged over multiple participants or sessions. This reduces their power to indicate gap choice accuracy (the average magnitude of the deviation from several instructed gaps, irrespective of the direction of deviation). To obtain a more correct representation of the average magnitude of deviation from an instructed gap size the absolute values of those estimation errors have to be used. The absolute estimation error (AEE) was defined as the absolute value of the relative estimation error.

7.3 Results

Table 7.2 gives an overview of the relative compared to the absolute estimation errors for every experimental trial separated by Instruction Method (i.e. seconds or metres).

Table 7.2 Relative and absolute estimation errors[a] (in seconds) per trial. Standard deviations in parentheses

Target Gap size	Distance gap estimation						Time gap estimation					
	50 km/h		80 km/h		100 km/h		50 km/h		80 km/h		100 km/h	
	REE[b]	AEE[b]	REE	AEE	REE	AEE	REE	AEE	REE	AEE	REE	AEE
1 sec	0.09 (0.17)	0.16 (0.10)	-0.12 (0.30)	0.25 (0.21)	-0.18 (0.39)	0.31 (0.30)	-0.05 (0.32)	0.21 (0.24)	-0.09 (0.44)	0.26 (0.37)	-0.05 (0.37)	0.22 (0.30)
1.5 sec	0.14 (0.25)	0.26 (0.12)	-0.07 (0.36)	0.31 (0.19)	-0.26 (0.54)	0.42 (0.42)	0.00 (0.34)	0.24 (0.24)	0.05 (0.42)	0.31 (0.29)	0.01 (0.46)	0.33 (0.32)
2 sec	0.16 (0.40)	0.35 (0.26)	-0.05 (0.43)	0.34 (0.27)	-0.07 (0.53)	0.43 (0.33)	-0.01 (0.45)	0.35 (0.28)	-0.16 (0.59)	0.43 (0.44)	-0.10 (0.51)	0.43 (0.29)

[a]Averaged over n = 10 respectively for distance gap and time gap estimation

[b]REE = Relative Estimation Error, AEE = Absolute Estimation Error

7.3.1 Effect of Instruction Method

7.3.1.1 Absolute estimation error (AEE)

Visual examination of frequency histograms and Q-Q plots of the data set showed that the sample of AEEs obtained in the experiment was positively skewed. Therefore it could not be assumed that it came from a normally distributed population. For this reason the Aligned

Rank Transform (ART) was applied to the AEEs before the data was analysed using ANOVA, as described in Wobbrock et al. (2011). ART is regarded as an accurate nonparametric procedure for both main and interaction effects (Higgins & Tashtoush, 1994; Salter & Fawcett, 1993).

After pre-processing of the data using ART, AEE were compared in a repeated measures ANOVA with Instruction Method (seconds vs. metres) as between participant factor and Lead Vehicle Speed (50 vs. 80 vs. 100 km/h) and Target Gap (1 vs. 1.5 vs. 2 second(s)) as within participant factors. As measure of effect size generalized eta squared (η_G^2) are provided as defined by Olejnik and Algina (2003). Bakeman (2005) recommends using the following limits of .02 for small, .13 for medium, and .26 for denoting a large effect size. Planned polynomial contrasts were used to test whether the effects of Lead Vehicle Speed or Target Gap size on estimation error follow a linear pattern.

Mauchly's test indicated that the assumption of sphericity had been violated for the main effect of Lead Vehicle Speed, W = 0.68, p < .001. Therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε = .76). There was a significant main effect of Lead Vehicle Speed on AEE, $F(1.52, 27.36) = 3.6$, $p = .03$. $\eta_G^2 = .02$. Polynomial contrasts revealed a significant linear trend for Lead Vehicle Speed, $F(1,19) = 4.59$, $p < .05$, indicating that AEE become larger with higher values for Lead Vehicle Speed.

The interaction effect between Lead Vehicle Speed and Instruction Method was not significant $F(2,36) = 0.97$, $p = .39$, $\eta_G^2 < .01$. These results confirm the first hypotheses (H1a), that the accuracy of the gap choice following distance based instructions becomes lower at higher values for Lead Vehicle Speed, leading to larger estimation errors. The missing interaction between Lead Vehicle Speed and Instruction Method indicates that estimation errors for time gap estimations also become larger with higher values for Lead Vehicle Speed. Therefore the second hypothesis (H1b) could not be confirmed.

There was also a significant main effect of Target Gap on AEE, $F(2,36) = 9.09$, $p < .001$, $\eta_G^2 = .04$. Polynomial contrasts also revealed a significant linear trend for Target Gap, $F(1,19) = 14.27$, $p = .001$, indicating that AEE become larger with larger instructed target gaps. The interaction between Target Gap and Instruction Method was not significant, $F(2,36) = 0.56$, $p = .57$, $\eta_G^2 < .01$. The significant main effect of Target Gap and the missing interaction with Instruction Method are in support of hypothesis H2a and H2b, that the accuracy of the chosen gap size following distance based as well as time based instructions becomes lower for larger instructed target gaps. Figure 7.2 illustrates both, the main effects of Lead Vehicle Speed (left) and Target Gap (right).

No significant main effect of Instruction Method was found, $F(1,18) = 0.01$, $p = .95$, $\eta_G^2 < .01$. Also no other interactions were significant at the $p > .05$ level.

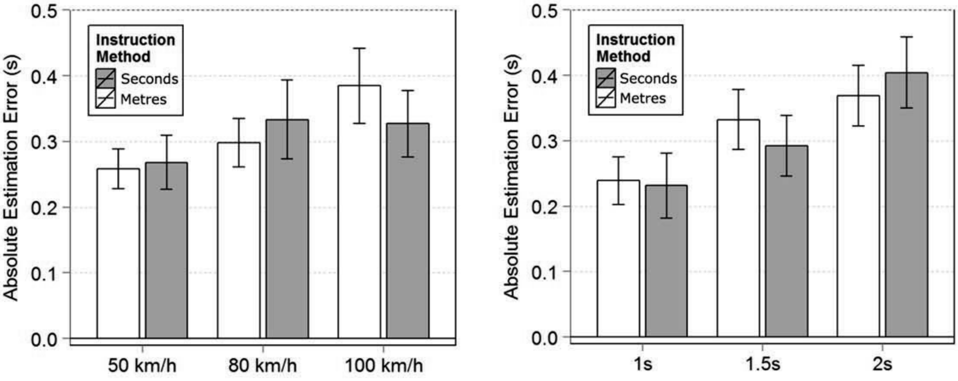

Figure 7.2 AEEs show a significant main effect for Lead Vehicle Speed (left) as well as Target Gap (right). Error bars indicate the standard error

7.3.1.2 Relative estimation errors (REE)

REE were compared in a repeated measures ANOVA with Instruction Method (seconds vs. metres) as between participant factor and Lead Vehicle Speed (50 vs. 80 vs. 100 km/h) and Target Gap (1 vs. 1.5 vs. 2 second(s)) as within participant factors. Again, planned polynomial contrasts were used to test whether the effects of Lead Vehicle Speed or Target Gap size on estimation error follow a linear pattern.

There was a significant main effect of Lead Vehicle Speed on REE, $F(2,36) = 8.55$, $p < .001$, $\eta_G^2 = .03$. Furthermore, a significant interaction effect was found between Lead Vehicle Speed and Instruction Method, $F(2,36) = 5.61$, $p < .01$, $\eta_G^2 = .02$. This indicates that Lead Vehicle Speed affected REE depending on the Instruction Method that was used. To break down this interaction polynomial contrasts were performed separately for the distance gap and the time gap group. A linear trend for Lead Vehicle Speed was found for participants in the distance gap group, $F(1,19) = 14.53$, $p = .001$, indicating that REE became smaller at higher values for Lead Vehicle Speed. For the time gap group no significant linear trend was found, $F(1,19) = 0.65$, $p > .05$. Figure 7.3 (left) illustrates this interaction effect.

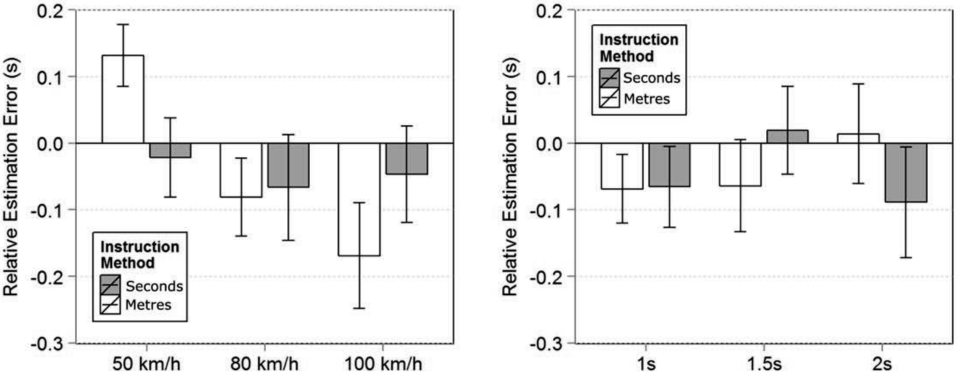

Figure 7.3 REEs for the time based and distance based instructions for the different speeds (left) and different target headways (right). Error bars indicate the standard error

The REEs in Figure 7.3 show that Lead Vehicle Speed had an effect on following distance based instructions, while REEs following time based instructions remain unaffected (left). REEs show some variation in response to changing levels of Target Gap, however, these did not lead to significant main effects or an interaction effect with Instruction Method (right).

There was no main effect of Instruction Method, F(1,18) = 0.01, p > .05, $\eta_G^2 < .01$. Therefore, hypothesis H3a, that following time based instructions would produce gaps that are smaller than instructed and hypothesis H3b, that following distance based instructions would produce gaps larger than instructed, had to be rejected.

No other effects and interactions were significant at the *p* < .05 level.

7.3.2 Effect of Presence of Support

Table 7.3 gives an overview of the absolute estimation errors for trials where participants increased or decreased their gap size to a Target Gap of 2 seconds.

Again, the Aligned Rank Transform (ART) was applied to the AEEs before the data was analysed using ANOVA (Wobbrock et al., 2011). After pre-processing of the data using ART, AEE were compared in a repeated measures ANOVA with Presence of Support (support vs. no support) as between participant factors and Direction of Gap Adjustment (increase vs. decrease) and Lead Vehicle Speed (50 vs. 80 vs. 100 km/h) as within participants factors.

A significant main effect of Direction of Gap Adjustment was found $F(1,18) = 9.95$, p = .006, $\eta_G^2 = .083$. However, also a significant two-way interaction was found between Presence of Support and the Direction of Gap Adjustment, $F(1,18) = 19.31$, p < .001, $\eta_G^2 = .15$. No other effects and interactions were significant at the p < .05 level. The interaction effect is shown in Figure 7.4.

Table 7.3 Absolute estimation errors[a] (in seconds) for attaining a time gap of 2 seconds from an initial gap size of either 3 seconds (decrease) or 1 second (increase). Standard deviations in parentheses

Lead Vehicle Speed	Support		No Support	
	Decrease	Increase	Decrease	Increase
50 km/h	0.23 (0.13)	0.43 (0.79)	0.28 (0.19)	0.26 (0.18)
80 km/h	0.20 (0.2)	0.27 (0.24)	0.20 (0.15)	0.42 (0.44)
100 km/h	0.17 (0.22)	0.47 (0.84)	0,36 (0,28)	0.24 (0.22)

[a]Averaged over n = 10 respectively for supported and unsupported trials.

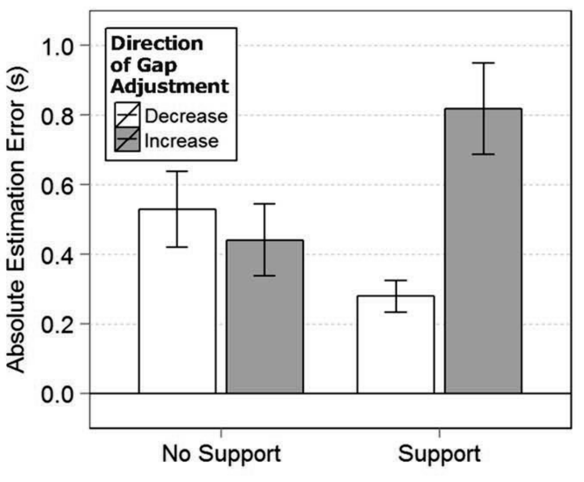

Figure 7.4 The interaction effect of Presence of Support and the Direction of Gap Adjustment on the absolute estimation error. Error bars indicate the standard error

To break down the interaction effect it was first checked, per support level, whether the average AEE for increasing and decreasing gap size were significantly different. Two Wilcoxon signed rank tests were carried out, one for each support condition. For adjusting alpha for multiple testing, Holm's sequentially rejective Bonferroni method was applied (Holm, 1979). As nonparametric measure of effect size Cliff's delta (δ) was used (Cliff, 1996). The magnitude of Cliffs delta is assessed using the following thresholds: $\delta < .15$ = negligible, $\delta < .33$ = small, $\delta \leq .47$ = medium, and $\delta > .47$ = large (Romano, Kromrey, Coraggio, & Skowronek, 2006).

The results show that without gap size feedback there is no significant difference in AEE between decreasing (M: 0.53, SE: 0.11) and increasing (M: 0.44, SE: 0.10) gap size, Z = -4.79, p = .52, δ = -.12 (two-tailed). With gap size feedback a significant difference in AEE was found between decreasing (M: 0.28, SE: 0.05) and increasing (M: 0.82, SE: 0.13) gap size, Z = -6.44, p < .001, δ = .64 (two-tailed). Subsequently, it was checked whether Presence of Support influenced the accuracy of the chosen gap size, that is, whether AEE was different in the support condition compared to the no support condition. For this reason two Wilcoxon rank sum tests were carried out, one for each level of Direction of Gap Adjustment. Again, alpha was adjusted using the Holm-Bonferroni method. The results show that when decreasing gap sizes, the AEE was significantly reduced by gap size feedback, Z = -4.75, p = .03, δ = -.32 (two-tailed). However, when increasing gap size, the AEE was significantly greater with gap size feedback, Z = -9.89, p = .002, δ = .45 (two-tailed).

These results indicate that discrete gap size feedback improved driver performance when drivers were instructed to reduce their gap size. However when drivers were instructed to increase their gap size, discrete gap size feedback lead to worse performance than if they had received no support. The AEE indicates the accuracy when carrying out gap instructions, showing the absolute deviation of a chosen gap size from the instructed gap size. Information on the direction of the deviation (i.e. over or underestimation) can be obtained by looking at the relative estimation error (REE). In Figure 7.5 it can be seen that on average participants in the no-support condition chose gap size that were larger than the instructed gap size (M: -0.27, SE: 0.16 and M: -0.20, SE: 0.15), while participants in the support condition, on average, chose slightly smaller than instructed gap size when decreasing gap size (M: 0.09, SE: 0.08) and chose larger than instructed gap size when increasing gap size (M: -0.79, SE: 0.14). Both outcomes indicate an overshoot of the instructed gap size.

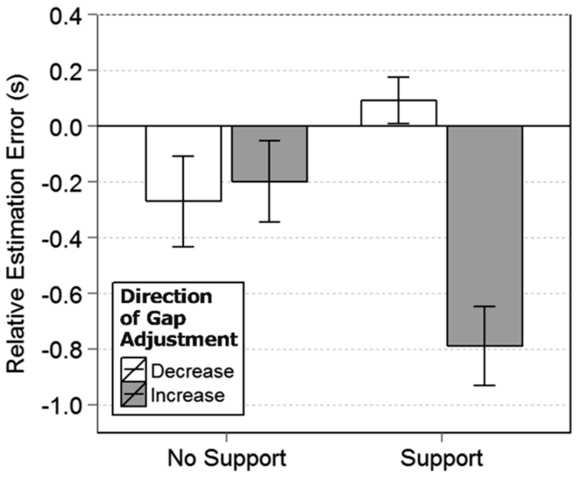

Figure 7.5 The interaction effect of Presence of Support and the Direction of Gap Adjustment on the relative estimation error. Error bars indicate the standard error

In contrast to the improved gap choice accuracy when decreasing gap size, the lowered accuracy when increasing gap size was unexpected. Relative estimation errors show that drivers chose larger gaps than instructed. To explore the reasons for this finding the development of relative speed in the progression of a trial was investigated. Figure 7.6 shows the change in average relative speed to the vehicle in front following the gap instruction.

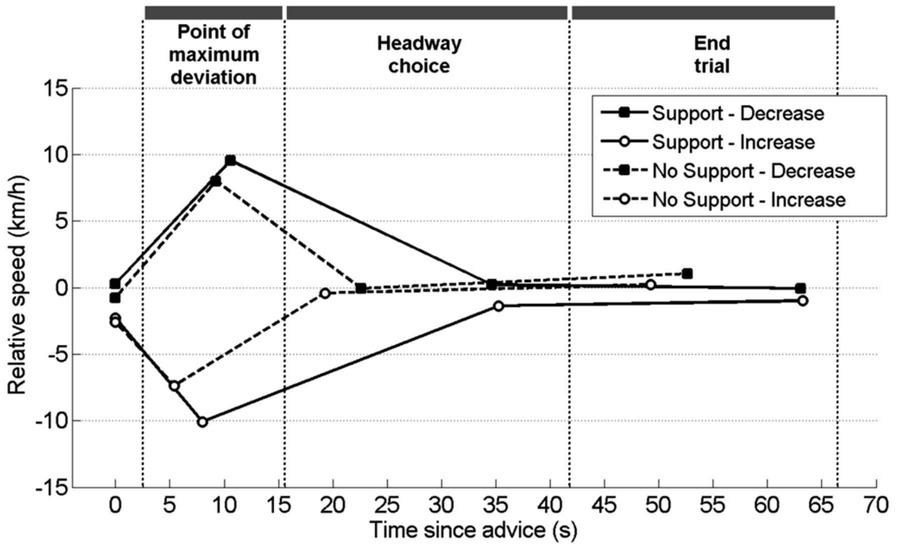

Figure 7.6 Average development of the participant's relative speed to the vehicle in front over the time of a trial. Positive values indicate that the participant's vehicle is faster that the vehicle in front, Negative values indicate that the participant's vehicle is slower than the vehicle in front. The instruction was given at t = 0

It can be seen from Figure 6 that at the time of the instruction (t = 0), relative speed is already negative for vehicles in the "increase" condition that were starting at a short gap (i.e. 1 second). In all trials, vehicles started at an equal relative speed to the vehicle in front. This shows that on average drivers had already reduced their speed directly after a trial had started, before the instruction was given. Furthermore, at the moment of gap choice, average relative speed is almost zero for all but the "Support – Increase" condition. From this figure it appears that participants in the "Support – Increase" condition failed to accelerate to the speed of the lead vehicle after having received gap size feedback thereby further increasing their gap size to the vehicle in front.

In addition to a point measure for gap choice accuracy, the absolute deviation from the chosen gap size over a period of 30 seconds was examined. Figure 7.7 shows the absolute deviation from the chosen gap size after the gap choice.

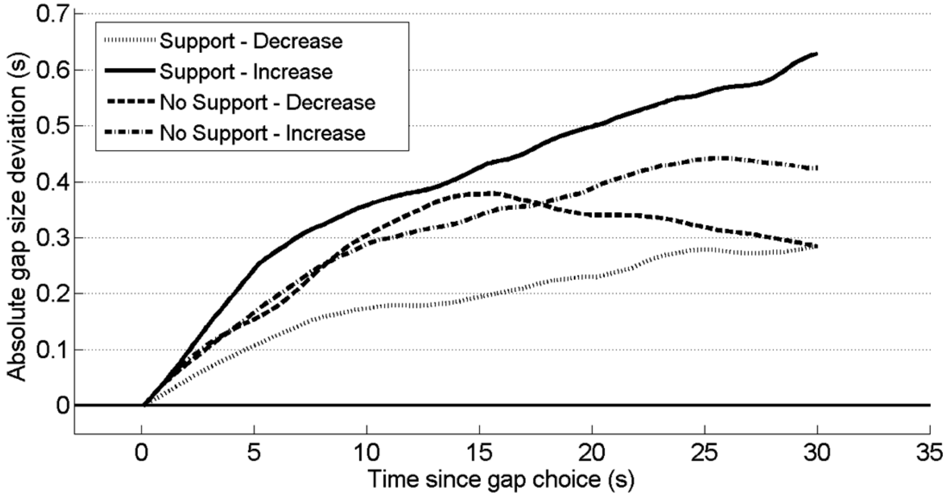

Figure 7.7 Absolute gap size deviation from the chosen gap size over a time interval of 30 seconds from the gap choice (t = 0)

From Figure 7 it appears that compared to no support, gap size feedback leads to a smaller absolute gap size deviation when decreasing gap sizes and a larger absolute gap size deviation when increasing gap sizes. This corresponds with the negative relative speed in the "Support – Increase" condition leading to a stronger absolute gap size deviation. It was tested whether the deviation from the chosen gap size showed a different development between conditions in the following 30 seconds of a trial. Therefore, the average absolute gap size deviation (AAGD, from t = 0s to t = 30s) was computed. Again, visual examination of frequency histograms of the data set showed that the obtained sample of AAGD was positively skewed. For this reason the Aligned Rank Transform (ART) was applied to the AAGD before the data was analysed using ANOVA. A repeated measures ANOVA was carried out, with Presence of Support (support vs. no support) as between participant factors and Direction of Gap Adjustment (increase vs. decrease) within participants factors. No effect was found at the $p < .05$ level.

7.4 Discussion

7.4.1 Time gap vs. distance gap estimation

7.4.1.1 Absolute estimation error

The results support hypothesis H1a, that higher vehicle speeds lead to larger AEE when following distance gap instructions. However hypothesis H1b, that higher vehicle speeds have no effect on following time gap instructions, is not supported by the data. Following distance gap instructions, a higher error rate in the perceived gap size due to larger physical gap size is reflected in larger AEE. However, when the same distance is instructed in units of time instead of distance, the error rate increases as well. Although the time to be estimated stays constant at different speeds, the perceived time gap varies under changing vehicle speeds.

This is also reflected in a large AEE. This suggests that following both time and distance gap instructions becomes more difficult at higher speeds.

A possible explanation for the low accuracy of chosen gaps following time based instructions at higher vehicle speeds may be the reduced perceivability of the distance between the lead vehicle and roadside objects at large inter-vehicle distances. According to the Weber-Fechner law, as the magnitude of a stimulus becomes larger, it becomes harder to accurately perceive the differences between stimuli of similar magnitude (Fechner, 1860; Stevens, 1961). In the simulated road environment, drivers had several possible orientation points on the side of the road (i.e. street lights, mileposts) as they would have in the real world. At greater distance between the participant's vehicle and the lead vehicle, it may become harder to determine the distance of the lead vehicle to a road side orientation point. Therefore, the exact moment when a lead vehicle passes a certain orientation point may be less accurately determined by the participant at greater distances. In the validation study no difference was found between chosen gap sizes in the simulator and in the instrumented vehicle at greater inter-vehicle distances. Therefore, it can be argued that the effect is not due to a lower perceiveability of the orientation points in the driving simulator, compared to the real world.

The larger AEE at larger values for Target Gap is in support of hypotheses H2a and H2b. The accuracy of gap choice when following time as well as distance gap instructions is reduced when target gaps become larger. In the case of distance based instructions larger values for Target Gap lead to a greater physical distance that has to be estimated. In the case of time based instructions a larger target gap means a larger time interval that has to be estimated. A systematic difference between different levels of Instruction Method, where one would produce more accurate gap choice in all studied situations, was not found.

7.4.1.2 Relative estimation error

Regarding hypotheses H3a and H3b there was no support in the data that, in general, time based instructions lead to gaps smaller than instructed while following a distance based method lead to gaps larger than instructed. Therefore the results of earlier studies (Taieb-Maimon & Shinar, 2001; Taieb-Maimon, 2007) could not be reproduced. However, the interaction effect of Lead Vehicle Speed and Instruction Method is surprising. It shows that relative estimation errors following time based instructions were less affected by vehicle speed than estimation errors following distance based instructions. Note that this was the proposed effect in hypotheses H1b with regard to absolute estimation errors. These results illustrate that for accuracy (AEE), following either one of the instruction methods is not affected by vehicle speed. However, when looking at the direction of the deviation from the instructed gap size (REE), following distance based instructions is affected by vehicle speed, while following time based instructions is not.

7.4.2 **Gap choice accuracy with discrete auditory feedback**

Regarding the second part of the experiment, the results indicate that the effect of gap size feedback on accuracy differs, depending on the direction of the gap adjustment. Compared to no support, discrete feedback led to greater gap choice accuracy when decreasing gap sizes.

However, discrete feedback also led to lower accuracy when increasing gap size. Regarding this effect, in contrast to hypotheses H4, discrete gap size feedback did not uniformly improve driver performance when carrying out gap instructions. After having received gap size feedback, drivers overshot their target gap. The overshoot was small when the instruction was to decrease gap size. However the overshoot was large following increase gap size instructions. Although a difference in the effect of discrete gap size feedback was hypothesised (H5), the observed magnitude of the effect of direction was unexpected.

In order to increase their gap size to 2 seconds, drivers started at a time gap of 1 second. When decreasing gap sizes they started at 3 seconds. Before the experiment started, drivers received the instructions to keep their speed and their gap size constant until the gap instructions was played. Still, relative speed profiles indicate (Figure 6) that even before an instruction had been given, participants in "increase gap size" trials were on average driving at lower speeds compared to "decrease gap size" trials. However, more important, after the gap instruction had been carried out, drivers in the "Support – Increase" condition failed to increase their speed to match that of the vehicle in front. This led to a negative relative speed at the moment of gap choice. It is assumed that the negative relative speed over a prolonged time contributed to the low gap choice accuracy at the time of the gap choice. Furthermore, an inability to detect the negative relative speed led to a continuous increase of gap size over time (shown in Figure 7). An explanation for why drivers did not accurately equalize their speed in the "Support – Increase" condition may stem from the already increased gap size to the lead vehicle. It appears that the ability to perceive the relative speed was impaired at the large gap sizes chosen by participants. This corresponds with earlier findings where it was observed that the accuracy of judgements of relative speed by drives decreased as gap sizes increased (Hoffmann & Mortimer, 1994; Olson, Wachsler, & Bauer, 1961).

The question remains why the large overshoot of the instructed gap size was not detected and corrected by drivers before their final gap choice. Several explanations are discussed of how discrete gap size feedback may produce the observed gap choice.

The correct gap size is observed at the moment the feedback sound is played. The initial idea behind the discrete gap size feedback was that the feedback could help drivers to gain a more accurate visual representation of the correct gap size. A corrected visual representation would enable drivers to make a more accurate gap size choice. This interpretation would be in line with the earlier mentioned assumption, that gap size adjustment is primarily visually guided (Taieb-Maimon, 2007). Here drivers' performance would depend on their ability to match the visual representation of the target gap size to their current gap size. However, the inconsistent data from the increase gap size trials does not support this assumption. If it would be the case, drivers would have recognized the discrepancy between their visual representation and the longer gap size they ended up choosing. Therefore, the data speaks against an update of a visual representation of the correct gap size.

Another possibility is that the discrete gap size feedback triggers a behavioural response to abort gap size adjustment and to choose the resulting gap without further checking its accuracy. Following this explanation the accuracy of the chosen gap size is mainly dependent on the correct timing of the feedback signal for increasing and decreasing gap size. Recall that feedback was given at the moment when the instructed gap size was reached. At that point drivers still had a higher speed (when decreasing gap size) or a lower speed (when increasing gap size) than the lead vehicle. Therefore, from the moment that the drivers received gap size feedback they were already overshooting the target gap size, until they readjusted their speed to that of the lead vehicle. Based on the level of Direction of Gap Adjustment, the required adjustment in speed involved a different action pattern on the vehicle control level. Upon hearing the support sound drivers decreasing their gap size had to let go of the gas pedal and decelerate, while drivers increasing their gap size had to apply gas and accelerate to match the speed of the lead vehicle. Differences in the time it takes drivers to adjust their speed to match that of the lead vehicle would have produced the observed differences in chosen gap size. This explanation recognizes the difference between the task of increasing or decreasing the gap size on the vehicle control level. Gap choice accuracy may then be improved by adjusting the timing of the gap size feedback. The optimal feedback timing would consider the difference in the time it takes to adjust the relative speed, respectively for increasing and decreasing gap size. Furthermore, this interpretation would imply a certain amount of complacency by the driver regarding the use of driver support. It has been shown that when the trust in automation exceeds the operator's confidence in their own ability, they are more likely to rely on automation (Lee & Moray, 1994; Parasuraman & Manzey, 2010; Parasuraman & Riley, 1997). A lack of confidence, among participants, in their ability to correctly estimate gap sizes might have led them to rely more on the automatic gap size estimation (even though they failed to make adequate use of this form of support). Although both, the supported and unsupported group, received the instruction to base their final gap choice on their own estimations of gap size, a form of complacency or overconfidence in the support system might have kept supported drivers from questioning and re-examining the gap size that they ended up choosing.

A third explanation would be that the greater inter-vehicle distance resulting from the stronger overshoot reduced the supported drivers' ability to estimate time gaps. However, this would imply that estimation errors were also affected by Lead Vehicle Speed. A time gap of two seconds results in greater inter-vehicle distance at higher speeds. Estimation errors did not show an effect of Lead Vehicle Speed in this study, therefore there is no reason to assume that a stronger overshoot in the process of increasing gap size would impair participant's ability to estimate time gaps. The absence of an effect of speed on instructed gap choice was also found in a previous real world study (Taieb-Maimon, 2007). In that study the same values for speed were used (i.e. 50, 80 and 100 km/h), while no effect of speed on the ability to attain instructed time- and distance gaps of trained drivers was found. However, in another real world study, speed affected estimates of time gap for female participants (Taieb-Maimon & Shinar, 2001). In estimates of self-chosen gaps, female participants showed higher estimation errors with increasing speeds.

One of the discussed interpretations of the results suggests that an adjustment of the timing of the sound signal used as gap size feedback could prove sufficient to reduce the overshoot in the chosen gap size observed in this experiment. However, the adjusted timing might not affect the negative relative speed that lead to a steady increase in the average absolute gap size deviation. The inability to further support gap size maintenance after the support sound has been issued is a shortcoming of a single, discrete sound signal to support gap choice. Also in this study, the speed of the lead vehicle varied between trials but was held constant within each trial. Vehicles in real traffic are expected to show more variations in their speed behaviour. These changes in relative speed also have implications for the design of gap choice support systems. Repeated discrete feedback or even continuous gap size feedback may be needed to support drivers in readjusting their gap size after a gap choice has been made.

7.4.3 **General discussion**

The study assessed drivers' ability to follow specific gap instructions given in either metres (distance gap) or seconds (time gap). As an indicator of driver performance the absolute estimation error was larger with higher values for Lead Vehicle Speed and larger values for Target Gap when following time gap as well as distance gap instructions.

As indicated by the relative estimation error in this study, distance gap estimates may lead to an underestimation of gap size. Drivers therefore could end up driving at gaps smaller than the ones advised. For this reason distance gap instructions may be a less safe choice, compared to time gap instructions, when small gap sizes are being advised. Overall the results indicate an inability of drivers to follow specific gap size instruction with great accuracy. Furthermore, in its current form discrete gap size feedback is not sufficient to improve the overall accuracy of chosen gap sizes when carrying out gap instructions.

Alternatively to advising a specific gap size and supporting drivers in attaining that gap size a different approach would be to define a margin around the system optimal gap size and support drivers in keeping their gap size within that margin. In this approach the support sound would not inform drivers at the time when the instructed gap size is reached but at the time when the margin around the instructed gap size is exceeded or surpassed. This would eliminate the need for drivers to continuously estimate their gap size. However, in case that driver's gap size would oscillate around such a boundary value on one side of the margin, the driver would hear the support sound every time the boundary is crossed and might lead to annoyance. Furthermore, two separate support sounds would be needed, one indicating when the gap size is larger than the margin and the other indicating when the gap size is smaller than the margin.

A similar alternative would be to provide gap instructions in less specific terms. For instance, drivers may be instructed to keep a short but safe gap, to close the gap to the vehicle in front or to make room for another vehicle. In this approach the gap instruction would be provided in the form of driving manoeuvres already familiar to drivers.

8 Behavioural response to tactical driver advice

8.1 Introduction

To improve traffic flow and throughput in anticipation of a bottleneck, the CIVA system aims to optimize the distribution of vehicles on a road by influencing driving behaviour. Therefore, the system provides drivers with an advice on their speed, gap size and lane use.

The advice that an individual driver receives depends on the current traffic situation, the physical road layout of the location where a bottleneck is predicted (e.g. lane drop, on-ramp, straight motorway) and parameters related the drivers own situation at the time that an advice is given (e.g. speed, gap size and lane position).

The formulation of an advice message can have an influence on drivers' ability to carry out the advice. The ability of drivers to carry out specific gap advice on a straight motorway with restricted movement of other vehicles has been studied in a driving simulator experiment, described in the previous chapter.

Furthermore, with regard to a driver's behavioural response to advice messages, the way an advised action is carried out may be different depending on a given traffic scenario. Specifically, the road layout of a particular location and the behaviour of other vehicles at these locations can influence a driver's behavioural response.

In the experiment, described in the present chapter, advice messages on all three levels (e.g. speed, gap size and lane) were presented in different physical road layouts (i.e. a lane drop, an on-ramp, and weaving section) and with realistic driving behaviour of other vehicles. The presented advice messages were tailored to these road layout so that they would generate a beneficial effect on traffic flow (Schakel, 2014).

8.1.1 **Separate and combined advice**

As discussed in chapter 2, for the development of the system it was chosen to present the advice in unambiguous auditory text messages. The advantage is that minimal training is required for the driver comprehend and act upon auditory text messages (Burrows, 1962; Edworthy & Hellier, 2006; van Winsum, Martens, & Herland, 1999). Furthermore, spoken text does not require drivers to take their eyes off the road therefore reducing the visual distraction by the message.

In some situations the system may combine two related advice messages, where one advice prompts an action that should be carried out before the other action (e.g. adjust speed before a lane change manoeuvre). Instead of waiting for the first advice to be carried out before the second advice is being issued, both advice messages may be given consequently as one longer advice. This requires the second part of the advice to be stored in the driver's working memory, until the first part of the advice has been carried out. It may be argued that this increases working memory load (Wickens & Hollands, 1999), or that drivers remember the first part of the advice message (primacy) or the last part of the advice message (recency) while the middle of the message is forgotten (Cao, Castronovo, Mahr, & Müller, 2009; Flemming, Green, & Katz, 1998). It has been argued that audio messages, that require the full attention of the driver, should not be longer that 5 seconds (Verwey, 1996). In this study the effect of two related advice messages given separately or in combination on driving behaviour and mental effort is assessed. It is hypothesised that following advice leads to higher ratings of perceived workload compared to regular driving.

8.1.2 **Traffic density**

The system will operate in flowing but nearly congested traffic. As traffic density increases, driving changes gradually from self-paced, where actions are initiated by the driver, to forced-paced, where the actions of other vehicles increasingly dictate a driver's behaviour (Ranney, 1999). As traffic becomes more congested, the influence of individual preferences on speed choice, gap choice and lane choice decreases. Similarly, high traffic density may have an effect on the drivers' ability to comply with an advice by reducing opportunities to carry out the advised manoeuvre. For instance, when traffic density is high the driver might not be able to switch to another lane immediately or to keep a larger time gap. In some cases, drivers may have to accept smaller gaps between vehicles on the target lane when changing lanes. In this experiment advice messages will be provided to drivers in low and high traffic density conditions. It is assessed whether the difference in traffic density has an effect on drivers' behavioural response behaviour as well as perceived mental effort when carrying out the advice. It is hypothesised that higher traffic density leads to higher levels of mental effort when carrying out the advice. Also it is hypothesised that it takes drivers longer to follow a lane change advice in dense traffic, compared to regular traffic. At last it is hypothesised that drivers accept smaller gaps when changing lanes in dense traffic conditions.

8.1.3 Other road users response to compliance behaviour

Following an advice may result in driving manoeuvres that are experienced as annoying by other drivers. Results from the survey, presented in chapter 5, show that several of the top ten annoyances, observed in Dutch traffic, were related to merging of vehicles. The following causes of annoyance are discussed in greater detail:

- Late, aggressive merging at a lane drop, motorway entrance or exit
- Early merging at a lane drop, motorway entrance or exit
- Merging with speed differences at a lane drop, motorway entrance or exit
- Hindrance with merging at a lane drop, motorway entrance or exit

Aggressive merging can be characterised as accepting very small gaps on the target lane. In the user survey this behaviour has been related to merging manoeuvres into a dense traffic stream at lane drops and motorway exits or entrances. For example, in an experiment on lane change behaviour when merging into heavy motorway traffic, the smallest accepted gaps varied between 0.75 and 1 second (Daamen et al., 2010). However, an advice may also trigger aggressive merging behaviour independent of the location of where a driver merges. In that case, a lane change advice would induce a sense of urgency with the driver making him/her accept small gaps, in order to timely comply with a request of the system. Therefore, in the experiment it is assessed how lane change advice (compared to receiving no advice) affects the size of the accepted gap on the target lane at the time of the lane change. It is hypothesised that lane change advice leads to smaller accepted gaps compared to no advice.

Changing lanes too early, but also too late, in case of an emerging lane drop, on- or off-ramp causes annoyance among other road users. It may therefore be unlikely that a single optimal (i.e. accepted by all road users) moment for a lane change can be determined experimentally. In traffic simulations a system optimal moment for a lane change (i.e. from the standpoint of traffic efficiency) may be determined for a specific road layout and traffic situation. Assuming an optimal moment for a lane change can be determined, the advice must be given so that the average duration from the presentation of a lane change advice until the actual lane change is accounted for. This average duration may be determined empirically and be integrated in the optimal timing of a lane change advice.

Merging with speed difference concerns an elevated relative speed between the merging vehicle and the vehicles on the target lane. With regard to the relative speed, two causes of annoyance can be characterized. In the first case, a driver merges into a traffic stream that is driving at a lower speed. In this case the merging driver has to reduce speed to avoid collision with the car in front on the target lane. In the second case, a driver merges to a traffic stream that drives at a higher speed. In that case, the driver is required to increase speed in order to adjust to the overall speed on that stream. Otherwise, the driver forces following vehicles on the target lane to reduce their speed in order to avoid collision. In both cases the abrupt reduction of speed can disturb traffic flow and cause shockwaves in dense traffic. To avoid merging manoeuvres with larger speed differences, a lane change advice is preceded by the instruction to adapt one's own speed to the speed of the cars on the target lane. In the experiment it is assessed how accurate drivers have adapted their speed to the speed of the target lane at the time of line crossing. It is hypothesised that absolute speed differences to the vehicles on the target lane, at the time of line crossing, are lower following a speed advice, compared to unadvised lane changes.

Increasing one's gap size to a distance that facilitates merging can reduce the chance of traffic disturbances at several locations. However, results from a previous experiment on gap choice (chapter 7) suggest that drivers have difficulties to attain a specific following gap with great accuracy. Maintaining a constant gap to allow for merging vehicles means driving at a distance that may be larger than the distance that is preferred by drivers. Van Winsum and Heino (1996) found that drivers preferred time gap was at 1 second at a speed range of 40-70 km/h. Ayres, Li, Schleuning, et al. (2002) observed that, in rush hour traffic, driver preferred time gaps of 1-2 seconds. In an experiment Taieb-Maimon and Shinar (2001) found that the average comfortable gap size of drivers at speeds between 50 and 100 km/h was between 0.9 and 1 second. Advising gap sizes that substantially exceed 2 seconds may seem too long to drivers. Furthermore, in the previous experiment it was observed that gap choice accuracy decreased at larger values for Target Gap. For this reasons a 2 second time gap is chosen as target gap for facilitating merging.

In this experiment the behaviour of other vehicles followed a more dynamic speed profile compared to the previous experiment, which may influence drives ability to attain and maintain a target gap. Therefore, it was assessed how accurate drivers adjust their gap size when instructed to attain a time gap of 2 seconds, and how accurate they maintain the advised gap.

8.1.4 Modelling of compliance behaviour based on behavioural response parameters

As discussed in chapter 3, drivers' ability to carry out the advice is largely determined by the improvement of traffic flow and throughput that the behavioural response to CIVA produces. However, this can only be determined at higher penetration rates. During the development of the system, the effect of different penetration and compliance rates may be determined by using traffic simulations. In these simulations the behavioural response of individual drivers is modelled. To be able to model the behavioural response of drivers, their behavioural response to an advice has to be measured in a set of behavioural parameters that can be used to refine the models. The present experiment provided the behavioural response parameters that can be integrated into driver models for large scale traffic simulations. A list of driving behaviour parameters that are provided by the experiment are presented in Table 8.4.

8.2 Method

8.2.1 Participants

Thirty-five participants (30 men, 5 women), aged 23 to 64 years (M: 46.9, SD: 12.1) completed the experimental procedure. Two more participated but had to abort the experiment due to simulator sickness. All participants were recruited from the pool of participants registered by TNO and had no prior knowledge of the study. All participants were in possession of a driver's license for at least four years (M: 27.4, SD: 12.9) and drove at least 10.000 annual kilometres by car. Participants reported to have normal or corrected to normal vision. Participants received €50 for their participation. The demographics of the participants are shown in Table 8.1.

Table 8.1 Demographics of the sample population

Category	Count	%
Gender		
Women	5	14.3
Men	30	85.7
Age (in years)		
18 - 24	2	5.7
25 - 39	6	17.1
40 - 65	27	77.1
> 65	0	0
Lowest value	23	
Mean (SD)	46.9 (12.1)	
Highest value	64	
Possession of driver's license (in years)		
< 3	0	0
3 - 7	4	11.4
> 7	31	88.6
Lowest value	4	
Mean (SD)	27.3 (12.7)	
Highest value	45	
Annual mileage (in km)		
10.000 - 20.000	15	42.9
20.001 - 30.000	12	34.3
> 30.000	8	22.9
Lowest value	10000	
Mean (SD)	21371 (11149)	
Highest value	55000	

8.2.2 Experimental design

The experiment had a 3 × 3 × 2 within-participant design with repeated measures. Independent variables were Location (lane drop vs. on-ramp vs. weaving section), Advice (no advice vs. separate advice (1 kilometre distance between first and second advice) vs. combined advice (two advice messages given in short succession)) and Traffic Density (low density vs. high density). The exact traffic density values that were used are described in paragraph 'Traffic Density'.

8.2.3 **Locations**

The road layout as well as the starting and presumed ending lane (where drivers end up after following the advice) are shown in Appendix D.5.

8.2.4 **Advice messages**

Two advice variations were developed for each location (Table 8.2). The content and timing of the advice messages was chosen based on the timing that was discussed during the development of the advice strategy (also see Klunder, Jonkers, and Schakel (2011)).

Table 8.2 Advice messages given to participants

Location	Separate advice	Combined advice
Lane drop	2 km before beginning lane drop: *"Adapt your speed to the speed of the traffic on the right"* 1 km before beginning lane drop: *"Change lane to the right"*	2 km before beginning lane drop: *"Adapt your speed to the speed of the traffic on the right and change lane to the right"*
On-ramp	3 km before beginning on-ramp: *"Adapt your speed to the speed of the traffic on the left"* 2 km before beginning on-ramp: *"Change lane to the left"*	3 km before beginning on-ramp: *"Adapt your speed to the speed of the traffic on the left and change lane to the left"*
Weaving	3 km before beginning weaving: *"Increase your gap size tot two seconds"* 1 km before beginning weaving: *"For Ridderkerk change lane to the right"*	3 km before beginning weaving: *"Increase your gap size tot two seconds. For Ridderkerk change lane to the right"*

Note. Ridderkerk was the name of the city that participants were instructed to drive to.

The advice strategy includes several scenarios in which advice will be given to improve traffic efficiency. For each scenario a general advice is presented that should lead to a desired traffic state in that scenario. The general advice is sent to all equipped vehicles and is transformed to individual advice messages that are communicated via the human-machine interface (HMI). The advice messages are given up to three kilometres before a specific location to allow participants enough time to carry out the advice before unadvised road users change their behaviour in reaction to the approaching location.

Eventually, if the CIVA system would be implemented in real life traffic the advice that drivers would receive, would dynamically adapt to their current lane, the chosen route as well as the current positions and route choices of the other traffic. However the decision algorithms that would produce the advice were not yet available in this experiment. Therefore, in the present experiment it was chosen for static (no adapting to external variables) advice messages. This advice would not adapt to the chosen lane and would not change due to changes in the behaviour of other traffic. The given advice was based on the starting lane of the participant (that was pre-determined by the experimental set-up) and in case of a weaving section the participant got the instruction to drive to a certain destination (i.e. Ridderkerk) that would require them to change lanes to enter the other motorway. To account for the static advice, participants were instructed to stay on the lane on which they started and keep their gap size and speed constant until an advice would be given.

As stated above the advice messages were presented as a spoken text via the car loudspeaker. Participants were asked to comply to the advice as much as they could. The reason for this was that in this experiment the focus was entirely on participants' ability to comply to the advice and the parameters that describe the behavioural response.

8.2.5 **Traffic density**

A high density condition would represent traffic conditions on the verge of congestion, while a low density condition describes a traffic condition where traffic is flowing freely. Table 8.3 gives an overview of the traffic densities per lane at the beginning of a trial at each location.

8.2.6 **Dependent variables**

The dependent variables were driver behaviour parameters that describe a driver's behavioural response to the provided advice messages. The goal of the study was to assess driver performance to carry out the advice as well as the potential of compliant behaviour to cause annoyance among other road users based on the most annoying situations presented chapter 5. Therefore, the time from a lane change advice to the actual lane change was assessed as well as the position where a lane change took place. The accepted gap size could indicate whether participants accept smaller gaps when changing lanes due to a lane change advice. Also the difference in speed with the target lane was assed to indicate the difference in relative speed between advised and unadvised lane changes. At last the change in time gap between the participant's vehicle and the lead vehicle was assessed in scenarios were a gap advice was given. Therefore, time gap during the gap advice, 15 seconds and 30 seconds after the advice was compared. Table 8.4 gives an overview of the dependent variables per location.

Table 8.3 Traffic density at the beginning of a trial at each location, per lane

	Lane drop			On-ramp			Weaving					
Lane	3a	2a	1a	2a	1a	1b	3a	2a	1a	2b	1b	
Km/h	120	110	85	110	85	85	100	90	85	85	85	
% trucks	0	0	33	0	27	10	0	0	30	0	20	
Density (v/km)	12,5	21,8	20	20	15,3	5,9	20	20	22,4	21,2	21,2	Low Density
Distance headway (m)	80	45,8	50	50	65,4	170	50	50	44,7	47,2	47,2	
Time headway (s)	2,4	1,5	2,1	1,6	2,8	7,2	1,8	2	1,9	2	2	
Flow (v/h)	1500	2400	1700	2200	1300	500	2000	1800	1900	1800	1800	
Density (v/km)	25	43,6	40	40	30,6	11,8	40	40	45,9	42,4	42,4	High Density
Distance headway (m)	40	22,9	25	25	32,7	85	25	25	21,8	23,6	23,6	
Time headway (s)	1,2	0,8	1,1	0,8	1,4	3,6	0,9	1	0,9	1	1	
Flow (v/h)	3000	4800	3400	4400	2600	1000	4000	3600	3800	3600	3600	

Note: v = number of vehicles; km = kilometre; m = metre; h = hours; s = seconds

Table 8.4 Dependent variables

Advice	Lane drop	On-ramp	Weaving
Lane change	- Position of lane change - Lane change advice execution time - Accepted time gap size on target lane		
Speed	- Speed development after speed advice - Speed difference to vehicles on the target lane during lane change		[no speed advice]
Gap	[no gap advice]	[no gap advice]	- Time gap development after gap advice

At the lane drop and the on-ramp locations, execution time was measured from the moment the lane change advice had stopped playing until the moment of the crossing of the line between lanes. In trials with a weaving section execution times were measured from the moment a participant had reached the end of the uninterrupted road marking until the crossing of the line between lanes.

Speed difference to the target lane was defined as the absolute difference value between the speed of the participant's vehicle and the mean of the speeds of the two vehicles (one in front and one in the back) on the target lane at the time of line crossing.

Time gap was measured from the back-bumper of the lead vehicle to the front-bumper of the following vehicle.

Accepted time gap between vehicles driving on the target lane was the gap size of the two vehicles on the adjacent lane at the time of line crossing (see Figure 8.1)

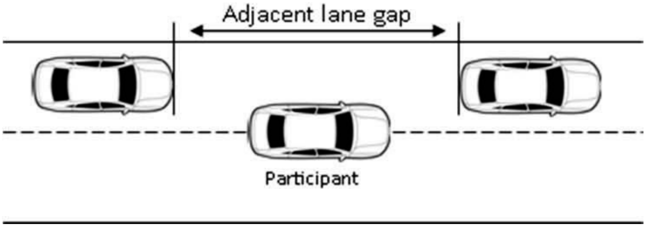

Figure 8.1 Accepted gap size on the target lane at the time of line crossing

8.2.7 **Trials**

As a result of the three within-participants factors a total of 18 trials were presented to each individual participant in randomized order (see Table 8.5).

Table 8.5 Trial list

Trial	Location	Advice	Traffic density
1	Lane drop	no advice	low
2	Lane drop	no advice	high
3	Lane drop	separate	low
4	Lane drop	separate	high
5	Lane drop	combined	low
6	Lane drop	combined	high
7	On-ramp	no advice	low
8	On-ramp	no advice	high
9	On-ramp	separate	low
10	On-ramp	separate	high
11	On-ramp	combined	low
12	On-ramp	combined	high
13	Weaving	no advice	low
14	Weaving	no advice	high
15	Weaving	separate	low
16	Weaving	separate	high
17	Weaving	combined	low
18	Weaving	combined	high

note. For an extended list see Appendix D.6

8.2.8 **Driving simulator setup**

The experiment was conducted in the advanced driving simulator at TNO (Figure 8.2). It consisted of a BMW 318I mock-up that is mounted on a moving base with six degrees of freedom. Only the mock-up was mounted on the platform; the video projectors and the projection screens were stationary. Feedback of steering forces was given to the driver by means of an electrical torque engine. In front of the simulator a radial screen (180 degree) was present on which the road and the traffic environment were projected with a refresh frequency of 60 Hz. Images for the rear-view mirror were projected on a screen on the backseat. Images for the side mirrors were projected on separate screens behind the car. Motor sound as well as the sound of other traffic was presented via loud speakers. The simulation was controlled from a separate room adjacent to the simulator room. Driver behaviour could be monitored via screen sharing and video cameras inside the mock-up.

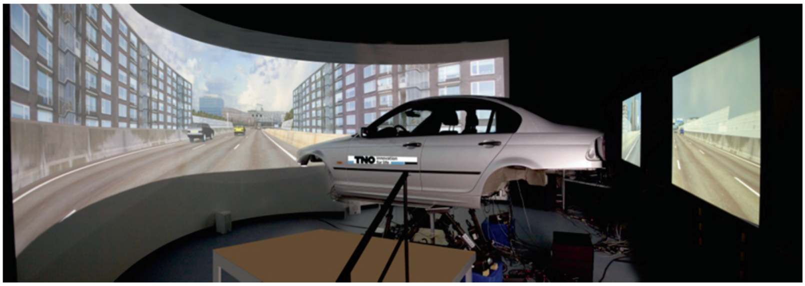

Figure 8.2 Moving-base BMW 318I driving simulator at TNO

8.2.9 **Procedure**

Participants were welcomed and asked to read the experiment instructions (Appendix D.1) and sign the informed consent. Then they filled in the pre-experimental questionnaire (for a copy of the used questionnaires see Appendix D.3 and D.4). Before starting the actual experiment, participants drove a practice trial to get accustomed to the task and to driving in the simulator.

Per location drivers were instructed to adhere to certain trip goals, shown in Table 8.6. These were necessary to avoid changes in lane, speed or gap size prior to the advice and to produce comparable driver behaviour in trials were no advice was given.

Table 8.6 Trip goals per location that were given as instructions to participants

	Lane drop	On-ramp	Weaving
ADVICE	Drive as usual Adhere to the advice Stay on your lane until the advice	Drive as usual Adhere to the advice Stay on your lane until the advice	Drive as usual Go to: [Destination 2] Adhere to the advice Stay on your lane until the advice
NO ADVICE	Drive as usual	Drive as usual	Drive as usual Go to: [Destination 2]

Participants then completed each of the 18 experimental trials in randomized order in three blocks of six trials with a break in between blocks. After every trial participants filled in a version of the RSME (a standardized scale to assess mental work load). After all experimental trials had been completed, participants filled in the post-experimental questionnaire.

8.2.10 **Data collection**

8.2.10.1 Behavioural response parameters

The driving simulator stored the data with a frequency of 10 Hz. The data that was used to produce the dependent variables is shown in Table 8.7.

Table 8.7 Data used to produce the dependent variables

Dependent variable	Recorded data					
	Lane	Travelled distance	Elapsed time	Time gap	Speed	Acceleration
Position of lane change	●	●				
Lane change advice execution time	●		●			
Accepted time gap size on target lane	●			●		
Speed difference to vehicles on the target lane during lane change	●				●	
Time gap development after gap advice			○	●	○	○

Note. Time gap data was computed by the driving simulator. The elapsed time, speed and acceleration was used in figures to illustrate the development over time.

Aside from the participant's vehicle, the simulator stored the data of the six surrounding vehicles closest to the participant at any moment in time. Figure 8.3 depicts the positions of slots (relative to the participant's vehicle) for which data was stored. In the experiment the slots were occupied by varying vehicles depending on the behaviour of the driver as well as the surrounding traffic. When the participant was driving on the left or the right lane only the data of the four surrounding vehicles (i.e. in the front / back and two on the adjacent lane) was logged.

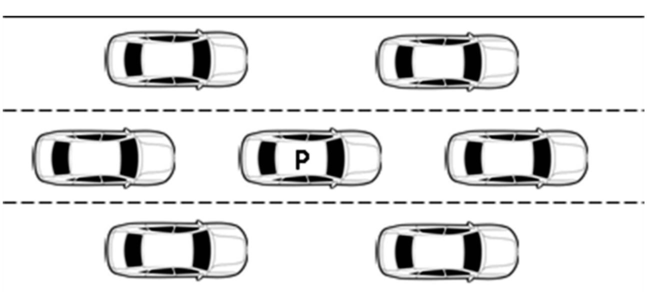

Figure 8.3. Six slots around the participant's vehicle for which data was stored. The vehicle marked with a P is the participant's vehicle

8.2.10.2 Measures for workload

Workload was measured using a self-administered questionnaire, the Rating Scale Mental Effort (RSME, Zijlstra, 1993)(see Appendix D.2). The RSME is a one-dimensional scale where ratings of invested effort are indicated by a cross on a continuous line. After each experimental trial, the participants marked the point on the scale that represented their perceived effort in relation to carrying out the advice. The range of the scale is 0 "absolutely no effort" to 150 "extreme effort". The scale is scored by the measurement of the distance from the origin of the scale to the mark in mm. The RSME is suitable for measuring subjective workload and has shown to be more sensitive to workload changes than the NASA-TLX (Veltman & Gaillard, 1998).

8.2.10.3 Measures for acceptance

A standardised checklist of the acceptance of transport telematics was used to measure the participant's acceptance of the system (van der Laan et al., 1997). The checklist consists of nine 5-point rating-scale items. These items load on two scales: (1) a usefulness scale and (2) a satisfaction scale. Individual item scores run from -2 to 2. Item numbers 3, 6 and 8 are mirrored compared to the other items.

The participants had to fill in this checklist at two moments in time during the experiments: (1) after having received a written description of the system (before having experienced the advice while driving) and (2) after driving with the advice in the simulator. Usefulness scores were computed as the average of the items 1, 3, 5, 7 and 9; whereas the satisfaction scores were computed as the average of the items 2, 4, 6 and 8 (An example of the checklist is shown in Appendix D.3, Question 1).

8.2.11 **Definition and choice of lane changes for further analysis**

A lane change was defined as the middle of the participant's vehicle crossing the line between two lanes.

After an advice had been given and during trials without any advice, participants would often carry out several lane changes until the end of the experimental trial. Per participant one lane change was chosen per trial, following a set of choice criteria. This would result in a total of 630 chosen lane changes (35 participants times 18 trials) to be used in the analysis. For each of the chosen lane changes the dependent variables (i.e. duration from advice to lane change, accepted gap for lane change, speed difference during lane change) were obtained. To obtain unbiased estimates, the duration of the advice message was subtracted from the duration from the advice till the lane change. The criteria based on which the lane changes were chosen were the following:

In trials from the *separate* advice condition (i.e. one minute between adjust speed and lane change advice), the first lane change that (1) followed the lane change advice and (2) originated on the starting lane and ended on the target lane was chosen.

In trials from the *combined* advice condition (i.e. no pause between adjust speed and lane change advice), the first lane change that (1) followed the combined advice and (2) originated on the starting lane and ended on the target lane was chosen.

In trials from the *no advice* condition an end point was defined as a distance at which the physical location ended (i.e. end lane drop, end on-ramp, end weaving section). Then, the last lane change (1) before the end point (2) originating on the starting lane and ending on the target lane was chosen.

8.2.12 **Treatment of missing data**

8.2.12.1 Missing lane changes

In seventeen trials no lane change could be identified that matched the criteria described in the previous section. Table 8.8 gives an overview of the reasons of why in these trials no lane change could be identified.

Table 8.8 Reason for missing lane changes

PP	Trial	Location	Advice	Reason
33	4	Lane drop	Separate	Premature lane change after speed advice
4	7	On-ramp	No	Nothing advised, no lane change as trip goal
18	8	On-ramp	No	Nothing advised, no lane change as trip goal
30	9	On-ramp	Separate	Premature lane change after speed advice
5	9	On-ramp	Separate	Premature lane change after speed advice
21	9	On-ramp	Separate	Premature lane change after speed advice
5	10	On-ramp	Separate	Premature lane change after speed advice
11	10	On-ramp	Separate	Premature lane change after speed advice
13	10	On-ramp	Separate	Premature lane change after speed advice
16	10	On-ramp	Separate	Premature lane change after speed advice
21	10	On-ramp	Separate	Premature lane change after speed advice
33	10	On-ramp	Separate	Premature lane change after speed advice
13	11	On-ramp	Combined	Premature change before combined advice
13	12	On-ramp	Combined	Premature change before combined advice
31	13	Weaving	No	Missed trip goal
37	13	Weaving	No	Missed trip goal
25	14	Weaving	No	Missed trip goal

In further analyses observations for these lane changes were treated as missing data. Data from participants with missing lane changes were excluded during analysis (list wise exclusion).

8.2.12.2 Missing accepted gap size data

Vehicles in the simulator environment were simulated within a spatial frame of 250 metres in front and behind the participant's vehicle. Vehicles that moved out of that region were removed from the simulated environment. As a result of that, one of the six slots around the participant's vehicle was occasionally empty due to a lack of vehicles. During that time no data was logged in that slot.

During 11 lane changes one of two vehicles on the target lane (in front or behind) was positioned further than 250 meters away from the participant's vehicle at the time of line crossing. Due to the missing vehicle no gap size could be computed. In these occasions the gap size on the target lane was regarded as an infinite gap size and replaced by a cut-off score. The cut-off score was defined as the largest of the non-infinite scores in that trial.

8.2.12.3 Missing speed difference data

Recall that speed difference to the target lane was defined as the absolute difference values between the speed of the participant's vehicle and the mean of the speeds of the two vehicles (one in front and one in the back) on the target lane at the time of line crossing. Therefore, the missing of one vehicle on the target lane also led to missing speed difference data at the time of lane change. In these cases, instead of a mean value of the front and back vehicle, data from the remaining vehicle was used in the analysis.

8.3 Results

8.3.1 Lane change position

In general, compared to regular driving, lane change advice led to a lane change taking place in a smaller region just after the advice was given (see Appendix D.8). In the lane drop location, the majority of drivers without lane change advice, changed lanes after the road sign that indicates the lane drop in a distance of 1 kilometre. The lane change advice was given 2 (separate) or 3 (combined) kilometres before the lane drop. It can be seen that drivers did not wait until they saw traffic signs for the lane drop approaching, but changed lanes shortly after the advice. In the on-ramp location, unadvised lane changes were distributed over the whole distance of the test track. In advised trials the lane changes took place within a smaller area. However, for the weaving section no difference was visible between lane changes with or without a lane change advice. This was due to the fact that even without the advice, road users had the tendency to change lanes as soon as the uninterrupted road marking ended. For the cumulative percentage of lane changes as a function of distance see Appendix D.9.

8.3.2 Lane change advice execution time

An overview of the lane change advice execution times is shown in Table 8.9.

Table 8.9. Time from lane change advice until the line crossing

Location	Traffic Density	Advice	
		Separate	Combined
Lane drop	Low	6.3 (0.6)	10.7 (1.2)
	High	7.4 (0.6)	13.1 (1.7)
On-ramp	Low	6.4 (0.9)	8.5 (1.1)
	High	7.9 (0.8)	11.4 (1.6)
Weaving	Low	5.1 (0.9)	7.7 (1.1)
	High	6.2 (0.9)	5.9 (9.4)

Note. In the weaving section the time was measured from the ending of the uninterrupted road marking till line crossing. Standard error in parentheses.

A repeated measures ANOVA with Location (lane drop vs. on-ramp vs. weaving section), Advice (separate vs. combined – in the control condition there was no advice so it was not possible to measure advice execution time) and Traffic Density (low vs. high) as within participant factors and lane change advice execution time as dependent variable was carried out. It was hypothesized that traffic density would show a significant main effect on execution time. High densities were also hypothesised to increase execution times.

As measure of effect size of the ANOVA generalized eta squared (η_G^2) are provided (Olejnik & Algina, 2003). Bakeman (2005) recommends to use the limits of 0.02 for small, 0.13 for medium, and 0.26 for denoting a large effect size. To control the family wise error rate with subsequent pairwise comparisons p-values were adjusted using the Holm-Bonferroni method as recommended by Holm (1979).

There was a significant main effect of Location on lane change duration, $F(2,54) = 10.5$, $p < .001$, $\eta_G^2 = .06$. Post-hoc pair-wise comparisons (two-tailed) with Holm-Bonferroni correction (k = 3) showed that duration was significantly lower in the weaving section (M: 6.2, SE: 0.5) compared to the lane drop (M: 9.4, SE: 0.6), $t(111) = 4.2$, $p < .001$, $r = .37$ and to the on-ramp (M: 8.6, SE: 0.6) , $t(111) = 3.09$, $p = .005$, $r = .28$. There was no significant difference between the lane drop and the on-ramp, $t(111) = 1.13$, $p = .26$, $r = .11$.

There was a significant main effect of Advice on lane change duration, $F(1,27) = 19.6$, $p < .001$, $\eta_G^2 = .07$. Following a combined advice took participant significantly longer (M: 9.6, SE: 0.6) than following a separate lane change advice (M: 6.6, SE: 0.3).

There was a significant main effect of Traffic Density on lane change duration, $F(1,27) = 4.6$, $p = .04$, $\eta_G^2 = .01$. A lane change took participants significantly longer in high density traffic (M: 8.7, SE: 0.5) compared to low density traffic (M: 7.5, SE: 0.4).

No other effect was significant at α = .05.

8.3.3 **Accepted gaps on the target lane**

An overview of the gap sizes between the front and the back vehicle on the target lane at the time of line crossing is shown in Table 8.10.

Table 8.10 Accepted gap size on the target lane

Location	Density	Advice		
		No	Separate	Combined
Lane drop	Low	2.1 (0.1)	2.7 (0.3)	1.8 (0.1)
	High	1.5 (0.1)	1.5 (0.1)	1.6 (0.1)
On-ramp	Low	3.0 (0.4)	4.5 (0.6)	3.2 (0.3)
	High	4.6 (0.6)	7.7 (1.4)	4.1 (0.6)
Weaving	Low	3.4 (0.6)	8.2 (1.4)	5.9 (1.3)
	High	5.0 (1.0)	5.5 (1.1)	6.4 (1.1)

Note. Standard error in parentheses.

A repeated measures ANOVA with Location (lane drop vs. on-ramp vs. weaving section), Advice (separate vs. combined) and Traffic Density (low vs. high) as within participants factors and accepted gap size as dependent variable was carried out. It was hypothesized that accepted gap size would show a significant main effect of Advice. Following lane change advice would lead to smaller accepted gaps. Also a main effect of Traffic Density was hypothesized. High densities were expected to reduce accepted gap sizes.

Mauchly's test indicated that the assumption of sphericity had been violated for the main effect of Location, W = 0.46, $p < .001$ and Advice W = 0.59, p = .004, as well as the interaction effect of Location and Advice W = 0.2, $p < .001$ and the interaction effect of Location and Traffic Density W = 0.59, p = .004. For these effects the degrees of freedom were adjusted using Greenhouse-Geisser estimates of sphericity (ε = 0.65, 0.71, 0.61, 0.71, respectively).

The main effect of Location on accepted gap size was found to be significant, F(1.36, 28.56) = 22.04 , $p < .001$, η_G^2 = .17. Also, the main effect of Advice on accepted gap size was found to be significant, F(1.42,31.24) = 6.33 , p = .004, η_G^2 = .04. However also the interaction effect between Location and Advice was significant, F(2.45,53.89) = 3.05 , p = .021, η_G^2 = .02. The interaction is shown in Figure 8.4.

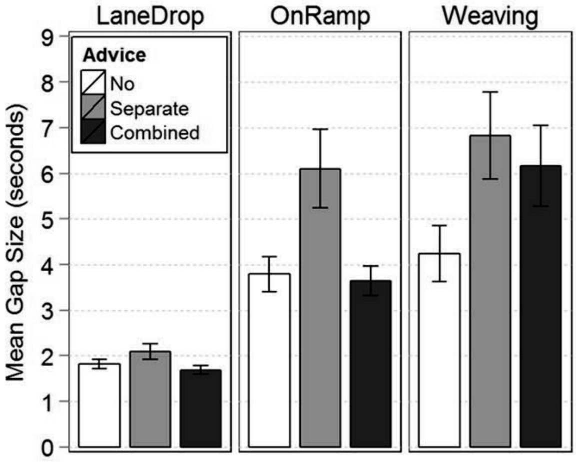

Figure 8.4 Interaction of Location and Advice on accepted gap size. No = No advice; Sep = Separate advice; Comb = Combined advice

This interaction effect was further analysed by doing three separate ANOVA, one for each Location (i.e. lane drop, on-ramp and weaving section), with Advice (no advice vs. separate vs. combined) as the within factor and gap size as dependent variable.

For the Lane Drop, a main effect of Advice on accepted gap size was found to be significant, F(2,44) = 3.72 , p = .03, η_G^2 = .11. However subsequent pairwise comparisons with Holm-Bonferroni correction (k = 3) revealed that gap sizes without advice (M: 1.8, SE: 0.1) were not significantly larger that gap size following separate advice (M: 2.1, SE: 0.2), t(45) = 1.52, p = .93, r = .22 (one-tailed) as well as gap sizes following combined advice (M: 1.7, SE: 0.1), t(45) = -1.09, p = .28, r = .16 (one-tailed).

For the on-ramp, Mauchly's test indicated that the assumption of sphericity had been violated for the main effect of Advice, W = 0.57, p < .002. Therefore, degrees of freedom were adjusted using Greenhouse-Geisser estimates of sphericity (ε = .70). Also, a main effect of Advice on accepted gap size was found, F(1.39, 30.69) = 7.37, p < .006, η_G^2 = .16. Here as well, subsequent pairwise comparisons with Holm-Bonferroni correction (k = 3) revealed that gap sizes without advice (M: 3.8, SE: 0.4) were not significantly larger than gap sizes following separate (M: 6.1, SE: 0.8), t(45) = 2.99, p = .99, r = .41 (one-tailed), as well as gap sizes following combined advice (M: 3.6, SE: 0.3), t(45) = -0.33, p = .75, r = .05 (one-tailed).

For the weaving section, no effect was significant at α = .05.

Besides the interaction effect of Location and Advice, also an interaction effect between Location and Traffic Density was significant, F(1.42, 31.17) = 6.67, p = .008, η_G^2 = .002. To further analyse this interaction, three separate pairwise comparisons were carried out between low and high density (one for each level of Location). It was hypothesized earlier that accepted gap size would reduce at high traffic density therefore one-tailed (instead of two-tailed) pairwise comparisons were carried out.

Pairwise comparisons with Holm-Bonferroni correction (k = 3) revealed that only at the lane drop, gap size was significantly smaller at high traffic density (M: 1.5, SE: 0.1) compared to low traffic density (M: 2.2, SE: 0.1), t(68) = -4.97, p < .001, r = .52 (one-tailed). Both other pairwise comparisons were not significant at α = .05 (one-tailed). The interaction is shown in Figure 8.5.

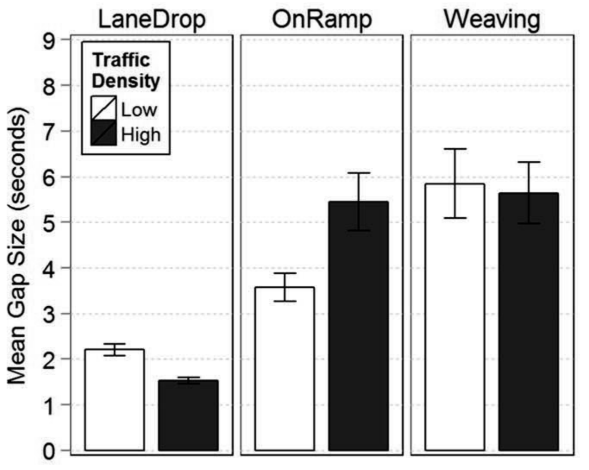

Figure 8.5 Interaction of Location and Advice on accepted gap size. Error bars indicate the standard error

Appendix D.10 shows the distribution of accepted gap sizes at the time of the lane change for each trial.

8.3.4 **Speed adjustment after speed advice**

An overview of the speed at the time of the advice and at the time of the lane change is shown in Table 8.11.

Table 8.11 Mean speeds (in km/h) at the time of advice and at the time of lane change

Location	Traffic Density	Advice	Time of Measurement: During Advice*	Time of Measurement: During lane change
Lane Drop	Low	No advice	114.7 (1.4)	105.9 (3.6)
		Separate	116.9 (1.2)	110.4 (2.3)
		Combined	117.5 (1.4)	109.0 (3.0)
	High	No advice	117.2 (1.5)	102.4 (3.0)
		Separate	116.4 (1.0)	108.6 (1.3)
		Combined	118.7 (1.4)	109.8 (1.3)
On-Ramp	Low	No advice	100.1 (2.6)	96.6 (1.9)
		Separate	85.0 (2.2)	90.4 (1.7)
		Combined	85.3 (2.3)	95.8 (1.7)
	High	No advice	84.8 (2.7)	89.7 (2.5)
		Separate	77.0 (1.7)	83.7 (1.8)
		Combined	76.7 (1.9)	85.6 (1.9)

Note. Standard error in parentheses
* The “No advice” condition was used as a control condition. In this condition the participants’ speed at the time that the advice would have played, if there had been one, was used for the analysis.

At the lane drop location participants had to slightly reduce their speed (10 km/h, see Appendix D.5) while adjusting to the speed on the right target lane. At the on-ramp location participants were required to increase their speed, by about 25 km/h, in order to adjust to the faster left lane.

To determine whether the adjust speed advise had led to an adjustment of speed to the target lane, participants’ speed at the time of the advice and at the time of line crossing were compared separately for the lane drop and the on-ramp location. Therefore, per level of Location, a repeated measures ANOVA with Time of Measurement (during advice vs. during lane change), Advice (no advice vs. separate vs. combined) and Traffic Density (low vs. high) as within participant factors and participant speed as dependent variable was carried out. The “no advice” condition was used as control condition. In this condition the participants’ speed at the time that the advice would have played, if there had been one, was used for the analysis.

For the lane drop a significant main effect of Time of Measurement was found, $F(1, 25) = 56.83$, $p < .001$, $\eta_G^2 = .174$. On average the speed at the time of the advice (M: 117.0, SE: 0.8) was higher than speed at the time of lane change (M: 107.6, SE: 1.5).

For the on-ramp significant main effect of Traffic Density was found, $F(1, 25) = 102.68$, $p < .001$, $\eta_G^2 = .167$. On average the speed at a low level of Traffic Density (M: 92.4, SE: 1.3) was higher than the speed at a high level of Traffic Density (M: 83.0, SE: 1.3). Furthermore, a significant main effect of Time of Measurement was found, $F(1, 25) = 15.71$, $p < .001$, $\eta_G^2 =$

.063, as well as a significant main effect of Advice, F(1, 50) = 17.38, p < .001, η_G^2 = .110. However, also a significant interaction between Time of Measurement and Advice was found, F(2, 50) = 5.72, p < .009, η_G^2 = .010. The interaction effect is shown in Figure 8.6.

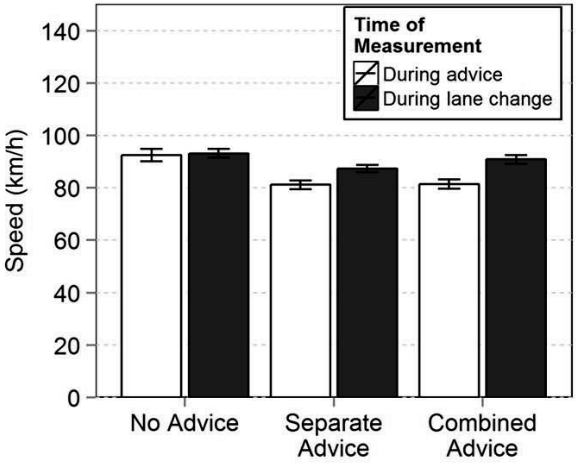

Figure 8.6 Interaction of Time of Measurement and Advice on speed in the on-ramp location. Error bars indicate the standard error

To further analyse this interaction, three separate pairwise comparisons were carried out between the two levels of Time of Measurement (one for each level of Advice). These pairwise comparisons with Holm-Bonferroni correction (k = 3) revealed that in the separate advice condition speed at the time of the advice (M: 81.1, SE: 1.6) was significantly lower than speed at the time of the lane change (M: 87.3, SE: 1.4), t(51) = -3.68, p = .003, r = .43. Also, in the combined advice condition speed at the time of advice (M: 81.4, SE: 1.8) was significantly lower than speed at the time of the lane change (M: 90.9, SE: 1.7), t(51) = -5.42, p < .001, r = .60. However for the no advice condition the speed at the time of advice (M: 92.4, SE: 2.3) was not significantly different from the speed at the time of the lane change (M: 93.1, SE: 1.7) at α = .05 (two-tailed).

The results show that participants adapted their speed following the advice. To achieve this participants increased (on-ramp) as well as decreased (lane drop) their speed. Speed development plots (in Appendix D.12) show that the speed adjustment after the advice is smooth. For the lane drop location this suggests that participants were not braking hard in order to follow the advice. These results also show that in the lane drop location, participants who had not received an advice were also reducing their speed before a lane change, while in the on-ramp location no change in speed could be observed.

8.3.5 **Speed difference to the target lane at the time of line crossing**

An overview of the absolute speed difference relative to the vehicles on the target lane at the time of line crossing is shown in Table 8.12.

Table 8.12 Absolute speed difference to the vehicles on the target lane (in km/h) at the time of line crossing

Location	Traffic Density	Advice		
		No advice	Separate	Combined
Lane drop	Low	7.0 (0.8)	6.6 (1.0)	7.2 (1.3)
	High	7.0 (1.4)	6.1 (0.8)	5.6 (1.0)
On-ramp	Low	13.8 (1.4)	15.3 (1.4)	13.8 (1.4)
	High	15.1 (1.7)	12.6 (1.8)	13.3 (1.6)
Weaving	Low	7.2 (1.2)	7.3 (0.8)	9.0 (1.7)
	High	7.7 (0.9)	5.9 (0.8)	10.3 (1.4)

Note. Standard error in parentheses

A repeated measures ANOVA with Location (lane drop vs. on-ramp vs. weaving section), Advice (no advice vs. separate vs. combined) and Traffic Density (low vs. high) as within participant factors and the absolute speed difference relative to the vehicles on the target lane as dependent variable was carried out. It was hypothesized that speed difference to the target lane would show a significant main effect of Advice. The hypothesis was that the condition without any advice would lead to greater absolute speed differences compared to separate as well as combined advice.

Mauchly's test indicated that the assumption of sphericity had been violated for the main effect of Location, W = 0.57, p = .04. Therefore, degrees of freedom were adjusted using Greenhouse-Geisser estimates of sphericity (ε = .79).

The main effect of Location on accepted gap size was found, F(1.58, 34.76) = 53.61, p < .001, η_G^2 = .22. Post-hoc pair-wise comparisons with Holm-Bonferroni correction (k = 3) showed that the speed difference at the time of line crossing was significantly higher in the on-ramp (M: 14.0, SE: 0.6) compared to the lane drop (M: 6.6, SE: 0.4), t(137) = -9.86, p < .001, r = .64 (two-tailed) and the weaving (M: 7.9, SE: 0.5), t(137) = 7.63, p < .001, r = .02 (two-tailed). Speed differences at the weaving section were also significantly higher compared to the lane drop, t(137) = -2.54, p = .036, r = .18 (two-tailed).

The relative speed difference shows the direction of the difference of participants' speed relative to the vehicles on the target lane at the time of line crossing (Table 8.13). It can be seen at the on-ramp location the participants did not accelerate enough to reach the average speed of the two vehicles on the target lane.

Table 8.13 Relative speed difference to the vehicles on the target lane (in km/h) at the time of line crossing

Location	Density	Advice		
		No advice	Separate	Combined
Lane drop	Low	-3.0 (1.5)	-0.3 (1.8)	-1.8 (2.0)
	High	-1.3 (2.0)	-3.5 (1.4)	-1.8 (1.5)
On-ramp	Low	-12.8 (1.8)	-9.2 (2.7)	-13.3 (1.4)
	High	-11.5 (2.3)	-8.5 (2.6)	-8.5 (2.0)
Weaving	Low	2.6 (1.9)	-1.9 (1.8)	1.4 (2.6)
	High	0.6 (1.8)	-0.3 (1.4)	-1.2 (2.2)

Note. Standard error in parentheses

No other effect was significant at $\alpha = .05$.

The frequency distribution plots in Appendix D.11 show the speed difference to the vehicles on the target lane at the time of line crossing. The speed development plots in Appendix D.12 show how driver speed changes after an advice has been given.

8.3.6 **Gap size adjustment**

The gap advice was given in order to increase participants' time gaps in anticipation of the weaving section. However the, advice was given at greater distance to the weaving section so that the development of gap size after the gap advice could be assessed before participants would change lanes to fulfil their trip goal.

To assess the development of time gap after a gap advice, time gap at the time of the advice was compared to time gap 15 seconds and 30 seconds after the advice. Therefore, a repeated measures ANOVA with Time of Measurement (at time of advice vs. 15 seconds after advice vs. 30 seconds after the advice), Advice (separate vs. combined) and Traffic Density (low vs. high) as within participants factors and time gap to the vehicle in front as dependent variable was carried out.

There was a significant main effect of Time of Measurement on gap size, $F(2,68) = 12.14$, $p < .001$, $\eta_G^2 = .04$. The main effect is shown in Figure 8.7.

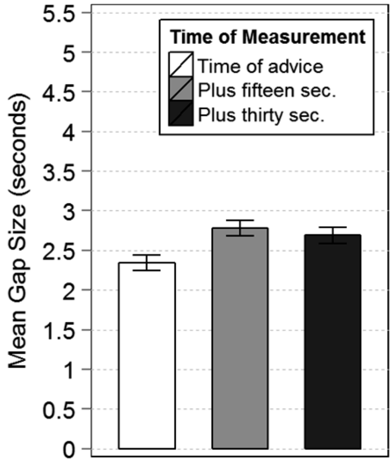

Figure 8.7 Main effect of Time of Measurement on gap size

Pairwise comparisons with Holm-Bonferroni correction (k = 3) showed that gap size at the time of the advice (M: 2.3, SE: 0.1) was significantly smaller than gap size 15 seconds after the advice (M: 2.8, SE: 0.1), t(139) = -5.34, p< .001, r = .41 (two-tailed), as well as gap size 30 seconds after the advice (M: 2.7, SE: 0.1), p < .05, t(139) = -4.22, p < .001, r = .34 (two-tailed). The difference between the gap size after 15 seconds was not significantly different from that after 30 seconds, t(139) = 1.26, p = .21, r = .11 (two-tailed).

The gap size development plots in Appendix D.13 also show how gap size changes in the time between advice and second measurement. It can be seen that participants reduce their speed as a reaction to the gap advice leading to the increase in gap size. The advice is given on a straight piece of motorway before the actual weaving section. At this point only few vehicles merge to the participant's lane from adjacent lanes. This results in a smooth gap size graph with few sudden gap size reductions.

8.3.7 **Acceptance**

Wilcoxon signed rank tests were carried out on perceived usefulness and satisfaction scores to compare acceptance before and after exposure to the system. Compared to acceptance before use, the results show a decline in acceptance of the system after use. Perceived usefulness was significantly lower after exposure to the system (M: 0.6, SE: 0.2) than before exposure (M: 1.2, SE: 0.1), Z = -4.75, p < .001, δ = -.40 (two-tailed). Also, perceived satisfaction was significantly lower after exposure to the system (M: 0.1, SE: 0.2) than before exposure (M: 0.6, SE: 0.2), Z = -1.72, p = .042, δ = -.26 (two-tailed). The data of the van der Laan scale are shown in Figure 8.8.

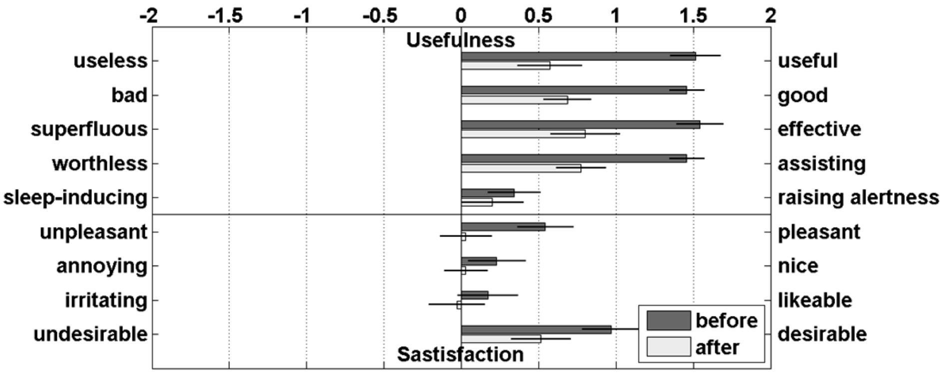

Figure 8.8 Ratings of usefulness and satisfaction assessed through the Van der Laan scale, both before and after experience with the advice

8.3.8 Mental effort

The data of the RSME are shown in Figure 8.9. A score of 25 corresponds with "*little effort*" and 38 with "*some effort*". A repeated measures ANOVA with Location (lane drop vs. on-ramp vs. weaving section), Advice (no advice vs. separate vs. combined) and Density (low vs. high) as within participant factors and mental effort scores from the RSME as dependent variable was carried out. It was hypothesized that perceived workload would increase in high density conditions. Also carrying out advice was hypothesised to increase workload ratings. No effect was significant at $\alpha = .05$.

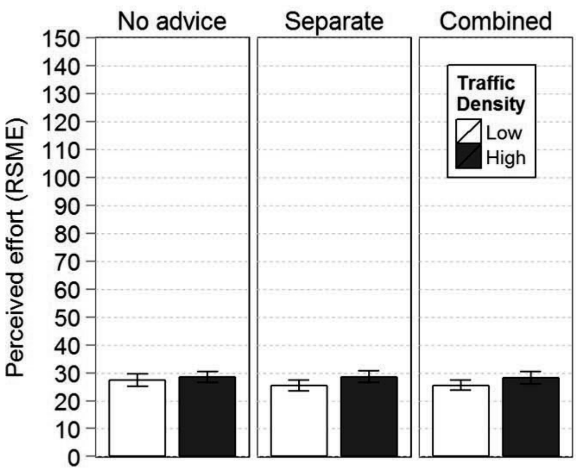

Figure 8.9. Subjective Ratings of mental effort on the RSME. Scores between 20 and 30 correspond to "little effort". Error bars indicate the standard error

8.4 Discussion

8.4.1 Lane change position

Lane change advice led to the lane changes occurring in a small region after the advice was given, with an exception for the weaving section. In the weaving section no difference can be seen between the positions of lane changes with and without an advice. This can be explained by the tendency of participants to change lanes in a weaving section as soon as the uninterrupted road marking ended, regardless of the lane change being advised or part of the participant's trip goal. The tendency of road users to change lanes early in a weaving section may be detrimental for smooth traffic flow at that location. A more optimal distribution of lane changes over the whole weaving area would result in a smoother weaving of vehicle streams and reduce disturbances. Changing lanes earlier is not an option. Alternatively, the system may advise drivers to delay their lane change in these situations.

8.4.2 Lane change advice execution times

The time that it took participants to carry out a lane change after an advice varied in relation to the location. At the lane drop as well as at the on-ramp location it took participants longer to carry out a lane change, compared to the weaving section. However, the execution times in the weaving section were measured not from the time that the advice message ended, but from the point where the uninterrupted road markings ended. The shorter lane change times suggest that driver had prepared the lane change before the road markings disappeared, to be able to change as soon as weaving was formally allowed.

It took participants longer to execute a lane change advice when it was directly preceded by a speed advice. Recall that the duration of the advice message was not included in the final lane change duration, therefore the longer advice text did not cause the observed difference. Following a combined advice, it took participants on average three seconds longer to cross the line between lanes (indicating a lane change).

The hypothesis that execution times would be longer for high density compared to low density traffic, is supported by the data. On average it took participants 1.2 seconds longer to carry out a lane change in dense traffic. Although this effect was statistically significant, 1.2 seconds may be considered as a small effect size. From Table 8.11 it can be seen that the speed adjustment in the high and the low density conditions is similar. On average drivers reduced their speed 8.0 km/h at the lane drop and increased their speed 7.9 km/h at the on-ramp locations, irrespective of Traffic Density. This is an argument against a longer speed adjustment period as an explanation for a longer lane change duration in the high density traffic condition. An alternative explanation would be that drivers had to wait longer for an opportunity to carry out the lane change advice due to an increased number of vehicles on the target lane.

8.4.3 Accepted gaps on the target lane

It was hypothesized that participants would accept smaller gaps when following a lane change advice compared to regular driving. An interaction effect of Advice and Location on accepted gap size was found. However, further analysis of the interaction effect showed that accepted gaps following an advice were not smaller, compared to regular driving. Drivers, following a lane change advice, do not appear to force themselves onto the target lane. However, at the on-ramp and the weaving location overall accepted gaps were generally large (i.e. between 4 and 7 seconds). This might indicate, that distances between vehicles at these locations were not so small as to require a decision by participants whether a gap was acceptable or not. When the gaps were “large enough” they were always accepted.

Furthermore, it was hypothesized that accepted gap size would be affected by Traffic Density. The results show that Traffic Density significantly reduced accepted gap size only at the lane drop location, during merging from the left lane (that was about to end) to the middle lane. In the high density condition average gaps of 1.5 seconds (SE: 0.1) were accepted, compared to 2.2 (SE: 0.1) seconds in the low density. At the lane drop location all vehicles from the left lane had to eventually change lanes to the right. Due to the number of vehicles that had already changed, the middle lane was more crowded than a lane at one of the other locations would be in dense traffic conditions. In other studies it has been observed that accepted gaps in dense traffic can become even smaller than what was measured in the present experiment (Daamen et al., 2010).

The relatively large gap sizes that were measured at the lane drop and weaving location make it difficult to determine whether participants would also have accepted smaller gaps in these locations. Each trial started with a predefined traffic density (Appendix D.5) that determined the initial gap size between vehicles at the start of a trial. A visual examination of the vehicle positions in the six slots around the participant’s vehicle shows that the larger gap sizes on the target lanes developed over the course of a trial. At the on-ramp location vehicles drove faster on the left lane of the motorway compared to the right lane where the participants started. After a trial had started, vehicles on the left lane would pass the participant, driving on the right lane. In the beginning of the trial these passing vehicles would have a density that is the starting density in that trial. After a certain number of vehicles had passed a gap would appear on the left lane, before the next vehicle would overtake the participant on the left lane (see Figure 8.10). This gap was the result of new vehicles being spawned by the driving simulator behind the participant while the vehicles that had passed the participant and were driving at a certain distance, were taken out of the simulation. A delayed spawning of new vehicles on the left lane was the reason for the gap appearing on the left lane. This gap was often used by participants when changing lanes due to an advice.

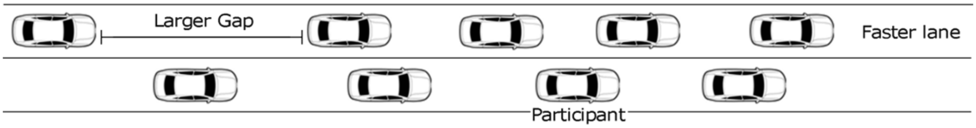

Figure 8.10 Gap appearing after some time on the faster left lane

An analysis of the time gaps between vehicles on the target lane showed that the gap size of passing vehicles was smaller than the gap that appeared on the left lane after some vehicles had passed. In the separate advice condition the lane change advice would be given shortly before the larger gap would appear to the left of the participant. Therefore few vehicles with smaller gaps would pass before a participant, having received an advice to change lanes, would choose this larger gap. In the combined advice condition the advice was given 1 km earlier than in the separate advice condition. Therefore participants would have to wait longer before they could change to the larger gap. In the low density condition, the gaps between the passing vehicles on the left lane were larger. Therefore, more participants would have changed to the left lane (choosing one of the smaller gaps) before the larger gap would appear on that lane. This would result in a smaller average accepted gap size for the low density conditions compared to the high density conditions. In the high density conditions the gaps of the passing vehicles on the left lane were so small that participants were waiting for an opportunity that would eventually appear in the form of the large gap. It is assumed that a combination of the gap size as well as the relative speed of vehicles passing the participant on the left lane were the reason for participants not changing lanes.

At the weaving location a trial would also start with the predefined conditions as shown in the Appendix D.5. However, traffic density would decrease over time. At this location the actual weaving area would start at 3 km from the starting position of the participant's vehicle. At the time that the participant had reached the weaving area, traffic density had often decreased, resulting in larger gap sizes between vehicles on the target lane at the time of line crossing. Additionally, at the end of the uninterrupted road marking other vehicles would weave to the participant's lane before the participant would weave to the target lane. This would lead to greater time gaps between vehicles on the target lane at the time that a participant would change lanes.

8.4.4 Speed difference to the target lane at the time of line crossing

The results show that drivers adapted their speed before a lane change in trials were an advice was given. At the lane drop location, where the speed adjustment required a speed reduction, the speed plots (Appendix D.12) indicate a smooth reduction of speed, rather than strong braking manoeuvres. This can be regarded as a desirable effect as it suggests that the speed advice will not lead to further disturbance due to sudden braking manoeuvres before a lane change.

As a response to the advice participants on average reduced their speed by 7.9 km/h at the lane drop location and also increased their speed by 7.9 km/h at the on-ramp location. No difference was found between speed adjustment after separate advice compared to combined advice.

It was hypothesized that the absolute speed difference to vehicles on the target lane during a lane change, would be lower as a result of the “adjust speed” advice, compared to unadvised driving. This was not supported by the data. Both, in the separate advice and in the combined advice conditions the speed differences during a lane change did not differ significantly from those in unadvised trials. An explanation may be that, while participants adjusted their speed before a lane change after an advice, unadvised participants did adjust their speed as well. This would explain the lack of a difference between advised and unadvised trials regarding speed relative to the target lane.

At the time of the lane change the absolute speed difference between the participant’s vehicle and the vehicles on the adjacent lane was larger at the on-ramp, compared to the lane drop and the weaving location. Recall that at the lane drop location participants had to reduce their speed (10 km/h), while at the on-ramp location participants were required to increase their speed, by about 25 km/h, in order to adjust to the faster left lane. Relative speed shows that at the time of the lane change participants were still driving more slowly than the vehicles on the target lane. In the weaving section the starting lane (the right lane on the left motorway) and the target lane (the left lane on the right motorway) had the same speed. Also, at this location participants received no advice to adapt their speed to the target lane. The absolute speed difference at the time on line crossing shows that drivers did not adapt exactly to the speed on the target lane. The relative speed values show no tendency for a positive or negative speed difference relative to the target lane. This suggests that the observed speed difference may be the normal deviation from the target lane during a lane change.

8.4.5 **Gap size adjustment**

The results show that participants increased their gap sizes as a response to the gap advice at the weaving location. Noteworthy is that that the time of the advice participants were, on average, already at a time gap above two seconds (2.3 seconds). This contradicts studies which indicated that the preferred gap size of drivers is below 2 seconds (Ayres et al., 2002; Taieb-Maimon & Shinar, 2001; van Winsum & Heino, 1996). Nevertheless, in the first fifteen seconds after the advice, time gaps increased to an average of 2.8 seconds and were at an average of 2.7 seconds, 30 seconds after the advice had been given. The large initial gap size may be explained by a generally low traffic density in the weaving scenario at the time of the advice. These results may be interpreted as further evidence that drivers have difficulties to estimate their time gap on a with great accuracy. Also this result supports the claim that when people’s confidence in their own ability is low, they are more likely to rely on automation (Lee & Moray, 1994). Other studies showed that recommendations of automated systems were followed even when contradicted other available sources of information (Parasuraman & Riley, 1997; Skitka, Mosier, & Burdick, 1999). While drivers failed to recognize the inaccuracy of the advice, as they were already driving at 2 seconds time gap, on average they further increased their gap size to demonstrate compliance with the system.

8.4.6 **Acceptance**

A reduction of acceptance after use of an advisory system was observed. However, it is too early to regard the system as a whole as not useful in the eyes of the participants. Rather this result may be seen as a sign that the system in its current form did not convey its usefulness in the experiment. This would be expected, given that the actual beneficial effects on traffic flow, that the system aims to create, were not visible for participants in the experiment. Recall that the beneficial effect is dependent on a minimum penetration and compliance rate. Here the system differs from other, conventional driver support systems such as cruise control, lane departure warning or navigation systems. While using these systems, the individual driver is able to observe a benefit from using the system, even in situations where (s)he might be the only one using the system.

Users may also have difficulties to see the usefulness of the system at all, judging only from observations of their own circumstances after compliance. A beneficial effect, as a result of their compliance behaviour, may only become visible to other drivers further upstream and not necessarily to the driver who is carrying out the advice. However, driver's perception of the outcome of compliance to an advice may determine their willingness comply to similar advice messages in the future. When drivers feel that compliance brings them in a situation that is perceived an disadvantageous, they may be discouraged to comply to similar advice messages. Therefore, drivers' perception of the outcome of compliance merit closer attention in future studies.

8.4.7 **Mental effort**

It had been hypothesized that driving with advice would lead to higher ratings for mental effort, compared to driving without advice. However, this was not supported by the data. Also Traffic Density showed no effect on drivers' perceived mental effort. These results indicate that receiving and following the advice was not taxing a driver's mental capacity to a level that would have been perceived as more effortful than regular driving. A reason for the low perceived effort may be the timing of the advice messages in the experiment. Advice messages were provided at least 1 kilometre before an action was required. This gave participants enough time to process and carry out the advice. Advice messages that require an immediate response by drivers may lead to more elevated levels of perceived mental effort. The result also suggests that a lack of mental capacity may not be the cause for the lack of accuracy in speed and gap size adjustment.

Also, the combination of two related advice messages was not perceived as more effortful than the advice given separately. It may be that the relatedness of the two advised actions turned out beneficial for the memorization of the advice message. Adjusting one's speed to an adjacent lane is usually followed by a lane change to that lane. Therefore, acting out the first part of the combined advice message may have acted as a cue for acting out the second part of the advice message. The results could be different with combinations of unrelated advice messages, where the required action from the second message cannot be deduced from the action requested in the first message.

8.4.8 Effect of separate speed and lane change advice

At the on-ramp location, people had to change from the slower right of two lanes to the faster left lane. When two related advice messages where given separately (i.e. a speed advice, followed by a lane change advice), sometimes the speed advice resulted in a lane change before the actual lane change advice had been given. Generally, drivers were instructed to refrain from proactively changing speed, gap size or lane until an advice to do so had been issued. However, following the first advice, drivers increased their speed in order to adapt to the vehicles on the faster, left lane. Before they received the advice to change lanes, some drivers were already closely approaching the vehicle in front of them. Rather than reducing their speed again, to avoid a collision with the vehicle in front, drivers usually chose to change lanes prematurely.

An explanation for the preference of the premature lane change may be given by Rasmussen's skill/rule/knowledge framework (1983). In this framework rule based behaviour is characterized as a certain response, that is chosen more or less consciously, according to a rule that, in the past, has proven to be successful. Through their driving experience, participants may have developed a rule that increasing one's speed and approaching the car in front is usually followed by a lane change. Therefore, compliance to the speed advice may have triggered this rule and led to the lane change over deceleration.

In addition, participants may had already experienced a similar scenario in an earlier experimental trial, where a speed advice was indeed followed by a lane change advice. Now, confronted with the choice, they would repeat the behaviour that had been right earlier, rather than disobeying the given speed advice. Arguing from this example, a combined speed and lane change advice would be preferable over two separated advice messages.

8.5 Conclusion

The present experiment assessed drivers' behavioural response to advice messages in a driving simulator. The 'adapt speed' advice led to an adaption of speed to the speed of the target lane. However, participants with and without speed advice showed similar absolute speed difference to the target lane at the time of line crossing, suggesting that unadvised drivers were also adapting their speed before a lane change. Lane change advice led to the intended behaviour. Similar to the previous experiment, following gap advice in dynamic traffic conditions led to changes in gap size that reflect an inability to estimate time gap. The results give no indication that compliance to the advice would lead to behaviour that might annoy or endanger other road users. A combined speed and lane change advice can avoid situations that lead to premature lane changes that are triggered by a single speed advice. Furthermore, combined advice has not increased drivers' perceived mental effort in the experiment, compared to separate advice. These results support the combination of related advice messages. Traffic Density did affect driver response parameters but there was no effect on perceived mental effort. Acceptance of the system reduced as a result of driving with advice. A better knowledge of the underlying advice strategy may improve drivers' perception of the system's usefulness.

9 The effect of information on estimated compliance rates[4]

9.1 Introduction

The survey, presented in chapter 5, investigated, among other things, the conditions under which drivers would potentially use an advisory driver support system that aims to improve overall traffic flow. It was found that one of the strongest incentives for drivers to use such a system would be an observable beneficial effect on traffic flow and throughput. In turn, whether the system has any effect on traffic flow is dependent on the percentage of vehicles on the road that are equipped with the system (i.e. the penetration rate of the system) and the number of drivers that adhere to the given advice (i.e. the compliance rate of drivers). Although these terms describe distinct concepts, the difference is of lesser importance in the presented experiment. If penetration rate is 10% but compliance is 100%, this has the same

[4] Parts of this chapter are based on the following publications:

Risto, M., & Martens, M. H. (2012). Improving traffic flow on motorways through individual driver advice: A social dilemma? *Proceedings of the TRAIL-Beta Congress*, Eindhoven, The Netherlands.

Risto, M., & Martens, M. H. (2013). Assessing driver's ability to estimate compliance rates to in-car, advisory driver support. *European Transport Research Review, 1-9.*

effect as a penetration rate of 100% but a compliance rate of 10%. For this reason, the terms penetration rate and compliance rate are used interchangeably.

Traffic flow improvement requires a collective effort of road users. While a single act of an individual driver can deteriorate traffic flow, a single driver following an advice is not enough to improve traffic flow. Rather, there is an interdependency between drivers, requiring a collective, coordinated action to create a beneficial effect of traffic flow. In the end of chapter 3 it has been discussed how this interdependence can lead to a social dilemma where a greater collective benefit would be created when everyone is using the system and following the advice, however, where drivers are tempted to improve their individual benefit and not follow the advice when it does not appear beneficial to them.

In order to improve traffic flow efficiency, drivers in the survey stated to be willing to cooperate under the condition that others cooperate as well. This refers to a phenomenon also known as conditional cooperation (Fischbacher, Gachter, & Fehr, 2001; Keser & van Winden, 2000). A similar idea has been introduced by Pruitt and Kimmel as part of the "goal/expectation theory" (Pruitt & Kimmel, 1977). The theory states that cooperative behaviour requires not only an individual's goal to achieve mutual cooperation, "It must be accompanied by an expectation that the other will cooperate […]." (p. 375). Therefore, in addition to having the goal to improve traffic flow by using the system, drivers need to be convinced that there is sufficient compliance among other drivers on the road in order to show cooperative (i.e. compliant) behaviour. If drivers are under the assumption that the compliance rate among other drivers is too low, they may guard themselves from exploitation by refusing to comply themselves. This makes drivers' ability to detect different levels of compliance, among other road users, an important factor in their own willingness to use the system. If drivers are able to distinguish between a high and a low compliance rate, they might be inclined to stop using the system in case of low compliance. Furthermore, if drivers are not able to tell the difference between compliance rates, acceptance of the system would benefit from an overestimation of the compliance rate, especially when the actual compliance rate is low.

In the present study it was investigated whether drivers are able to deduct the current (or the difference between a high and a low) compliance rates to CIVA, from observations of traffic around them. Furthermore, it was tested whether additional information about the advice strategy would improve drivers' ability to distinguish between different compliance rates.

9.1.1 **Additional information about the advice strategy**

When a bottleneck has been predicted by the back office system, the advice algorithm generates an advice to optimize the speed, gap size and lane use of drivers approaching the location where the bottleneck was predicted. Based on advice strategy, the back office system determines what advice drivers receive per lane. When different advice messages need to be given to drivers on the same lane (e.g. some driver need to change lanes, while other need to keep a larger gap), the system coordinates which driver will receive which advice.

Knowledge of the advice strategy may improve drivers' ability to perceive the current CIVA penetration rate. Drivers who have an understanding of the patterns that they may observe in traffic behaviour under high penetration rates may react to the presence or absence of these expected patterns.

This study assesses participants' ability to estimate the compliance rate to CIVA advice based on observations of traffic behaviour around them. Furthermore, the effect of information about the advice strategy on estimated compliance of other road users was assessed.

9.2 Method

9.2.1 **Participants**

Forty-two participants (33 men, 9 women), aged 26 to 66 years (M: 53.6, SD: 10.5) completed the experimental procedure. One other participated, but had to abort the experiment due to simulator sickness. All participants were recruited from the pool of participants registered by TNO and had no prior knowledge of the study. All participants were in possession of a driver's license for at least five years (M: 32.7, SD: 11.9) and drove at least 10.000 annual kilometres by car. Participants reported to have normal or corrected to normal vision. Participants received €50 for their participation. Table 9.1 shows additional demographics of the participants.

Table 9.1 Demographics of the sample population

Category	Count	%
Gender		
Women	9	21.4
Men	33	78.6
Age (in years)		
18 - 24	0	0
25 - 39	5	11.9
40 - 65	34	81
> 65	3	7.1
Lowest value	26	
Mean (SD)	53.6 (10.5)	
Highest value	66	
Possession of driver's license (in years)		
< 3	0	0
3 - 7	2	4.8
> 7	40	95.2
Lowest value	5	
Mean (SD)	32.7 (11.9)	

Highest value	48	
Annual mileage (in km)		
10.000 - 20.000	35	83.3
20.001 - 30.000	5	11.9
> 30.000	2	4.8
Lowest value	10000	
Mean (SD)	18905 (7525)	
Highest value	45000	

9.2.2 **Experimental design**

In this part of the experiment, the effect of additional information about the advice strategy on drivers' ability to distinguish between different rates of system penetration was assessed. The experiment had a 3 × 3 × 2 mixed factorial design with repeated measures. Within-participant variables were Location (lane drop vs. on-ramp vs. straight motorway) and Simulated Compliance Rate (10% vs. 50% vs. 90%). Between-participant variable was the Level of Information (low vs. high) about the advice strategy. The dependent variables were participants' estimated compliance rates and their confidence in their estimate.

9.2.3 **Locations**

In contrast to the previous experiment a straight motorway location was chosen instead of a weaving section. Due to the similarities in advised and unadvised driving behaviour in the weaving section, found in the previous experiment, it was argued that it would be too difficult for participants to notice any difference between compliance rates. The road layout of the three locations are shown in Appendix E.6.

9.2.4 **Information about the advice strategy**

Participants were randomly assigned to one of two groups. Both groups received information about the overall goal of the system and the driver-in-the-loop approach that the system takes. This information characterized the low information condition. In addition to that, the high information group received detailed information about the advice given by the system and the goal that is pursued with the advice at the three experimental locations. Furthermore, each of the three locations was shown in a top view, with vehicles on each lane and arrows indicating the driving paths of vehicles that follow a particular advice. The additional information that participants in the high information condition received are shown in Appendix E.10.

9.2.5 **Compliance behaviour of other vehicles**

To implement system compliant behaviour of the virtual vehicles, compliance zones were defined per lane for every location. In these zones, parameters in the driver model of the simulator were adjusted in a way that the vehicle would exert a behaviour as if following an advice. Figure 9.1 gives an overview of the specific compliance zones per location.

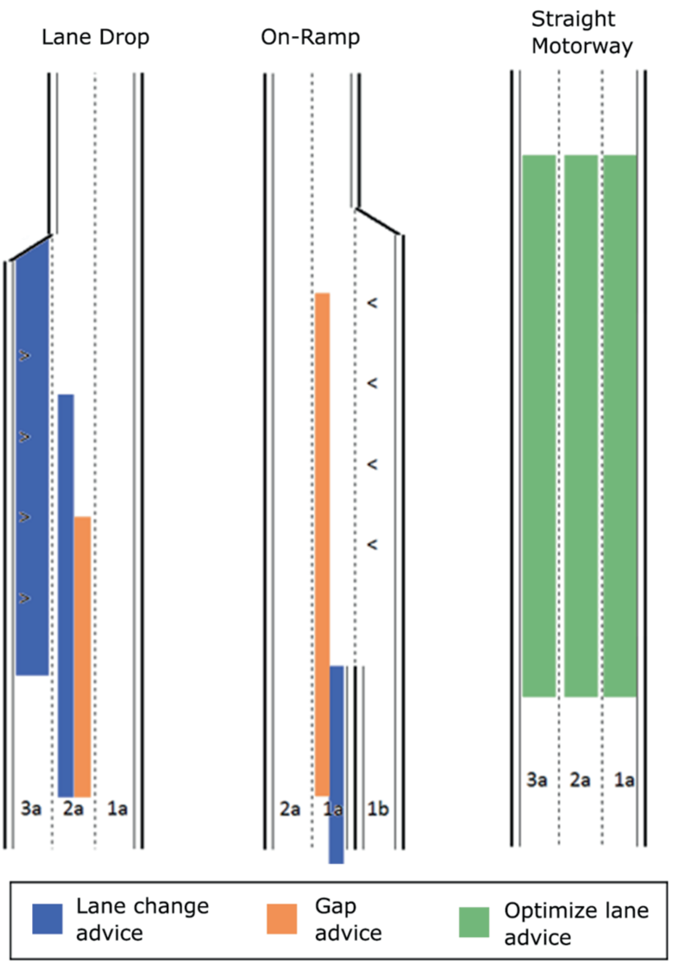

Figure 9.1 Compliance zones were used to start and stop the execution of compliance behaviour of the virtual traffic

A parameter in the driver model defined the vehicle's urge to carry out the advised behaviour. The urge parameter increased as a virtual vehicle approached the end of a compliance zone. The increased urge resulted in compliant behaviour even in traffic conditions were not optimal to carry out the advised behaviour. For example, in the case of a lane change advice, as the urge of a specific vehicle to change lanes increased, the vehicle accepted shorter gaps. As a result of this set up, every simulated vehicle that received an advice had carried out the advice at the end of the compliance zone, thereby simulating a compliance rate of 100%. For modelling the compliance behaviour of other vehicles in the experiment it did not matter whether the compliance rate was kept constant at 100% while the penetration rate varied between trials or the other way around.

In order to simulate compliance behaviour of equipped vehicles, the behaviour of those vehicles was adjusted as follows:

Lane compliance zone: Upon entry of the lane compliance zone a simulated driver had the urge to change lanes towards the target lane. This urge increased towards the end of the zone.

Gap compliance zone: Upon entry of the lane compliance zone a simulated driver had the urge to increase their gap size. An advice to increase gap size would not be given to vehicles driving at a gap size larger than 2 seconds, therefore only vehicles driving at a gap size at or below 2 seconds would be affected. The previous experiment has shown that drivers would also increase their gap size even if they were already driving close to the target gap size. This was simulated by multiplying the gap size by the factor 1.5 and setting it as the driver's desired gap size, to yield simulated gap sizes, similar to those measured in the previous experiment.

Optimize compliance zone: On the straight motorway, in the beginning, an artificial bottleneck was created by letting the trial start with an unequal distribution of vehicles over the lanes. The distribution in that trial was skewed towards the left lane as described by Schakel, Knoop and van Arem (2012). Upon entry of the optimize compliance zone, equipped vehicles received a lane change advice in order to equalize the distribution of vehicles over the lanes. The urge of the advised vehicles to change lanes would increase during driving in the compliance zone, so that at the end each advised vehicle had changed its lane. The number of vehicles that received a lane change advice was computed in such a way that as a result of compliance an equal distribution over the three lanes would be achieved.

9.2.6 **Penetration rate of other vehicles**

In part one of the experiment the penetration rate of the system was varied between 10%, 50% and 90% of equipped vehicles among other vehicles on the road. An overview of the penetration rate per trial is shown in Table 9.2. For the full overview of penetration rates see the Appendix E.8.

9.2.7 **Driving simulator setup**

The experiment was conducted in the same driving simulator, that was used in the previous experiment in chapter 8.

9.2.8 **Procedure**

Participants were welcomed and asked to read the experiment description (Appendix E.1) and sign the informed consent. Then they filled out the pre-experimental questionnaire (for a copy of the used questionnaires see Appendix E.2 – E.5). After the questionnaire participants in the high information condition received the additional information about the strategy behind any advice in different trials including the advice that they might expect from the system in a given trial. In the simulator, the participants drove a practice trial to get accustomed to the task and the simulator. Participants then completed the first part of the experiment (the first nine trials) in randomized order. The location and the penetration rate of the system varied between trials. After each trial participants gave an estimate of the penetration rate in that trial and indicated their confidence with that estimate. After finishing the first part, participants were given a break of about 45 minutes before the second part of the experiment started. The list of trials for the first part is shown in Table 9.2.

Table 9.2 Trial list for the first part of the experiment

Trial	Advice	Location	Starting lane	Penetration
1	No advice	Lane drop	Middle	10%
2				50%
3				90%
4		On-ramp	Right	10%
5				50%
6				90%
7		Straight	Middle	10%
8				50%
9				90%

note. For a more detailed view of the starting conditions of every trial see Appendix E.7.

9.2.9 **Data collection**

After every trial in the first part, participants were asked to estimate the penetration of CIVA-equipped vehicles in that trial on a scale from 0% to 100%, and to indicated their subjective confidence in that rating on a scale from 1 (not at all confident) to 5 (very confident).

In addition to the raw estimates of system compliance, absolute estimation errors of the compliance rate (AEEC) were computed per trial by the formula

$$AEEC = \sqrt{(C_{estimated} - C_{actual})^2} \tag{9.1}$$

where $C_{estimated}$ was the participant's estimated compliance rate in a trial and C_{actual} was the simulated compliance rate in that trial.

9.3 Results

9.3.1 Estimates of compliance rate

Figure 9.2 shows the average estimated compliance in the experiment.

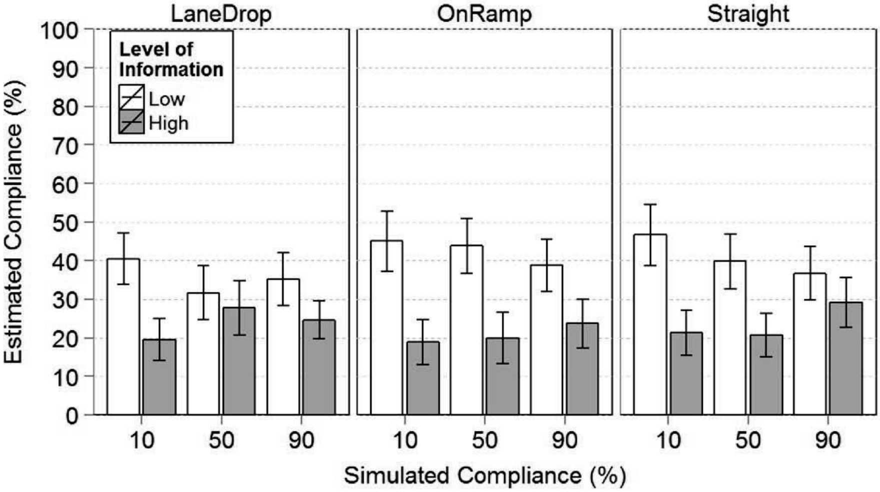

Figure 9.2 Average compliance estimates per trial. Error bars show the standard error

A repeated measures ANOVA was carried out on the estimated compliance scores with Location (lane drop vs. on-ramp vs. straight motorway) and Simulated Compliance Rate (10% vs. 50% vs. 90%) as within-participant factors and Level of Information (low vs. high) as between-participant factor.

No main effect of Simulated Compliance Rate on estimated compliance was found ($p < .05$). Furthermore, a significant main effect of Level of Information on estimated compliance was found, $F(1, 40) = 6.94$, $p = .01$, $\eta_G^2 = .084$. However, also the interaction effect between Level of Information and on estimated compliance was significant, $F(2,80) = 3.66$, $p = .03$, $\eta_G^2 = .009$. Figure 9.3 depicts this interaction.

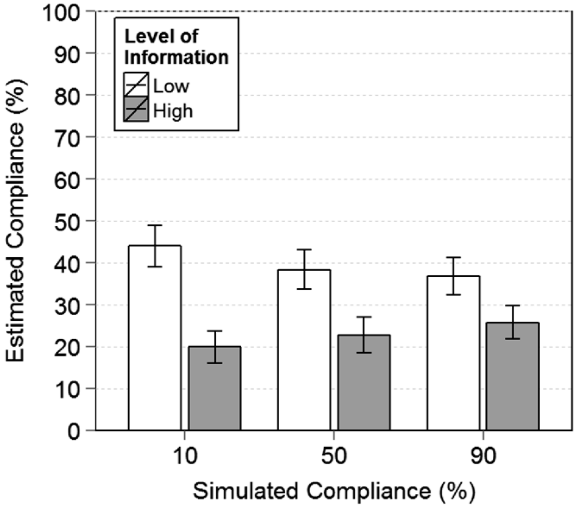

Figure 9.3. The interaction effect of Level of Information and Simulated Compliance Rate on the compliance estimate. Error bars show the standard error

To break down the interaction, post-hoc pairwise comparisons with Holm-Bonferroni correction were carried out. These are shown in Table 9.3a and 9.3b, depicted by the letter A-I.

Table 9.3a. Pairwise comparisons of mean estimated Compliance (in %)

		Simulated Compliance Rate				
		10 %		50 %		90 %
		↙		F		↘
Level of Information	Low	44.05 (4.94)	← D →	38.43 (4.71)	← E →	36.9 (4.49)
		↑ A ↓		↑ B ↓		↑ C ↓
	High	19.95 (3.77)	← G →	22.78 (4.31)	← H →	25.83 (3.92)
		↖		I		↗

note. Standard error in parenthesis.

Table 9.3b. Pairwise comparisons of mean estimated compliance

Contrast	df	t	p_{holm}	r
A	124	4.75	< .001*	.39
B	124	-3.00	.007*	.26
C	124	-2.28	.171	.20
D	62	1.40	.670	.18

E	62	0.55	1	.07
F	62	1.96	.325	.24
G	62	-0.70	1	.09
H	62	-0.91	1	.11
I	62	-1.67	.496	.21

note. * significant at α = 0.05

9.3.2 Absolute estimation error of the compliance rate

To obtain a measure of the estimation performance, for each compliance estimate the absolute estimation error of the compliance rate (AEEC) was computed according to equation (1). Average AEEC provides an indication of the estimation performance in each trial where lower scores denote a better estimation performance (see Figure 9.4).

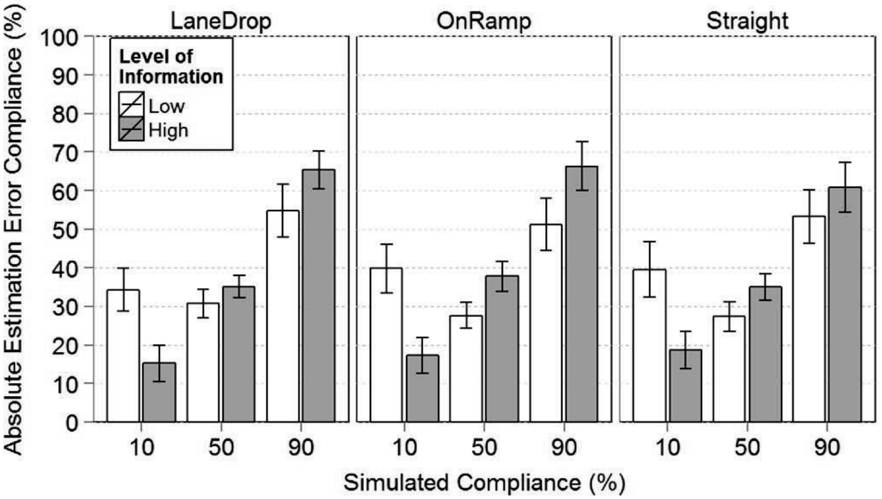

Figure 9.4 The absolute estimation error of the compliance rate per trial. Error bars show the standard error

A repeated measures ANOVA was carried out on the AEEC scores with Location (lane drop vs. on-ramp vs. straight motorway) and Simulated Compliance Rate (10% vs. 50% vs. 90%) as within-participant factors and Level of Information (low vs. high) as between-participant factor.

Mauchly's test indicated that the assumption of sphericity had been violated for the main effect of Simulated Compliance Rate, W = 0.34, p < .001, as well as the interaction effect of Simulated Compliance Rate and Level of Information W = 0.34, p < .001. For these effects the degrees of freedom were adjusted using Greenhouse-Geisser estimates of sphericity (ε = .60 and .60 respectively).

A significant main effect of Simulated Compliance Rate on AEEC was found, $F(1.2, 48) = 30.83$, $p < .001$, $\eta_G^2 = 0.271$. Also the interaction effect between Simulated Compliance Rate and Level of Information was significant, $F(1.2,48) = 8.33$, $p = .004$, $\eta_G^2 = 0.091$. Figure 7 depicts this interaction.

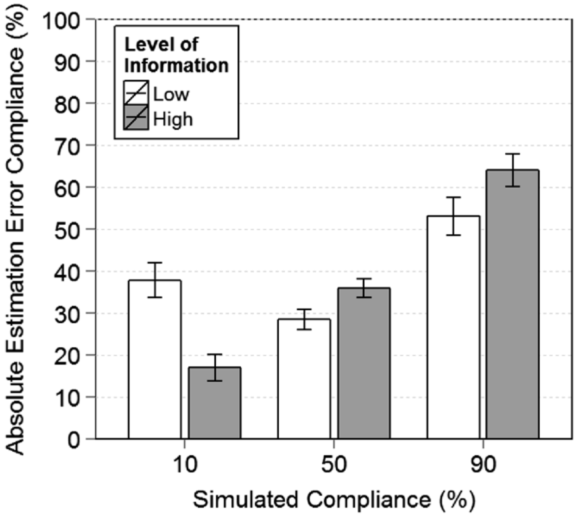

Figure 9.5 The interaction effect between compliance rate and Level of Information on the AEEC. Error bars show the standard error

To break down the interaction post-hoc pairwise comparisons with Holm-Bonferroni correction were carried out. These are shown in Table 9.4a and 9.4b, depicted by the letter A-I.

Table 9.4a Pairwise comparisons of mean AEEC (in %)

		Simulated Compliance Rate				
		10 %		50 %		90 %
		↙		F		↘
Level of Information	Low	37.86 (4.21)	← D →	28.56 (2.39)	← E →	53.10 (4.49)
		↑ A ↓		↑ B ↓		↑ C ↓
	High	17.03 (3.09)	← G →	35.95 (2.29)	← H →	64.18 (3.92)
		↖		I		↗

note. Standard error in parenthesis.

Table 9.4b Pairwise comparisons of mean AEEC

Contrast	df	t	p_{holm}	r
A	113.80	4.88	< .001*	.42
B	123.78	-2.74	.029*	.24
C	121.75	-2.28	.049*	.20
D	62	2.15	.036*	.26
E	62	-8.00	< .001*	.71
F	62	-2.47	.049*	.30
G	62	-5.71	< .001*	.59
H	62	-9.78	< .001*	.78
I	62	-10.17	< .001*	.79

note. * significant at α = 0.05

9.3.3 **Confidence with the compliance estimate**

Participants' confidence with their estimate per trial is shown in Figure 9.6 Recall that participants rated the confidence with their compliance estimate on a scale from 1 (not at all confident) to 5 (very confident).

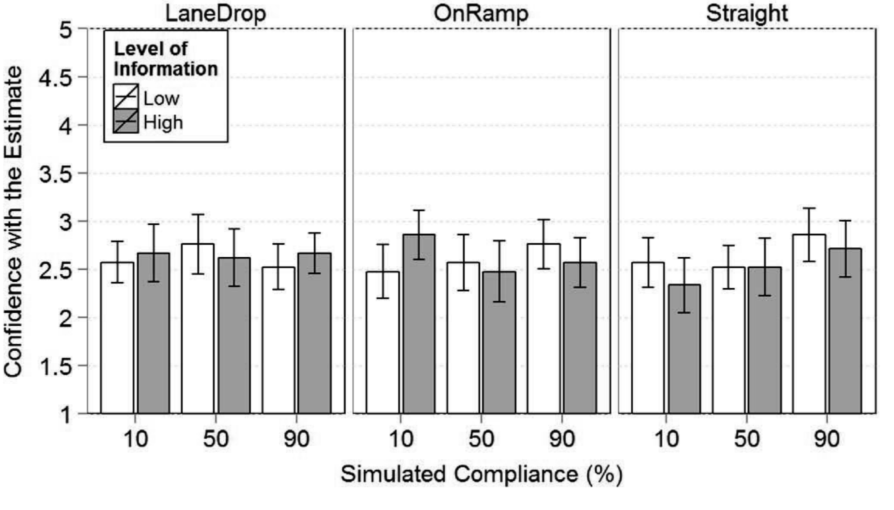

Figure 9.6 Confidence level with estimated compliance rates. Error bars show the standard error

A repeated measures ANOVA was carried out on the confidence scores with Location (lane drop vs. on-ramp vs. straight motorway) and Simulated Compliance Rate (10% vs. 50% vs. 90%) as within-participant factors and Level of Information (low vs. high) as between-participant factor.

No effect was significant at α = .05.

9.4 Discussion

This part of the experiment examined drivers' ability to distinguish between different compliance rates of other road users to the CIVA system. Furthermore, the effect of additional information on estimates of compliance rates and the confidence with these estimates was investigated. No effect of Simulated Compliance Rate on participants' estimate of compliance was found. However a significant effect of the Level of Information as well as an interaction effect between Level of Information and Simulated Compliance Rate was found. Participants in the high information condition estimated compliance to be lower than participants in the low information condition. This difference appears to decrease with rising levels of Simulated Compliance Rate. While the results show a difference between compliance estimates in the low compared to the high information condition, they do not necessarily indicate a better performance by the high information group (this is shown by the lack of effect of Level of Information on estimation performance that is indicated by the AEEC).

The difference in estimated compliance may stem from differences in how both groups looked for signs of compliance in the traffic scene. More informed participants had received explicit information about the advice that the system would give at a particular location as well as a bird's eye view of coordinated behaviour patterns that groups of equipped vehicles would show at higher compliance rates. Therefore it can be assumed that they had certain expectations about the behaviour that the traffic around them would exert at higher levels of actual compliance. In contrast, participants in the low information condition had merely received information about the system's general aim and that a driver-in-the-loop approach is used. As a result, drivers in the low information condition might have looked at traffic behaviour more generally, while drivers in the high information condition might have looked for particular indicators of compliance, that they had learned of in the additional information.

Traffic in general was flowing most of the time, regardless of the Simulated Compliance Rate. Occasionally traffic flow was disturbed near the end of lane drops, however, this did not lead to congestion. Traffic flow would recover from these disturbances so that drivers would not end up in congestion. Uninformed drivers may have credited the general lack of congestion to an elevated compliance rate and therefore gained a more optimistic view of compliance than informed drivers. It may be seen as advantageous for the acceptance of the system, that uninformed drivers overestimated others compliance to the advice when the Simulated Compliance Rate was low (i.e. 10%).

No main effect of the Level of Information on estimation performance (indicated by the AEEC) was found. There was an effect of Simulated Compliance Rate on AEEC. For higher levels of Simulated Compliance Rate the difference scores with estimated compliance increased as well. This is led to the higher AEEC. It suggests that estimation performance decreased (higher AEECs) with rising levels of Simulated Compliance Rate. Also, an interaction effect of Simulated Compliance Rate and Level of Information on AEEC was found. This interaction effect stems from the elevated AEEC of the low information group at 10% Simulated Compliance Rate compared to the low AEEC of the high information group.

Participants' ratings of confidence with their compliance estimates showed no effect of Simulated Compliance Rate, Level of Information or Location. Participants were neither extremely confident nor extremely unconfident about their estimates. These results suggest that the additional information did not help to improve participants' average levels of confidence in their estimates. Still, the average confidence ratings appear high, given the low estimation performances. This level of confidence paired with low actual performance hints at the difficulty of the task of estimating compliance rate, where even estimates given with high levels of confidence turned out to be wrong.

The present results imply that, when implementing systems whose beneficial effect depends on perceived compliance rate, drivers should not be provided with more detailed information about the advice strategy of the system. Additional information leads to lower compliance estimates, while having no effect on drivers' estimation performance or confidence with the estimate. Informed drivers may be less likely to comply to an advisory system as they are more likely to perceive the compliance of other road users as low. Furthermore, for uninformed drivers, compliance estimates are equally high over different simulated compliance levels, even in the condition where the simulated compliance is low (10%). This can be beneficial for the acceptance of the CIVA system where the interdependence between drivers plays an important role for the successful implementation.

10 The effect of information on system acceptance

10.1 Introduction

To extend the time at which traffic is flowing on a nearly congested road, the system aims to optimize the distribution over the lanes and behaviour of drivers currently on that road. Therefore the development of traffic is modelled using up-to-date traffic loop and floating car data in order to make predictions about the state of traffic in the near future. If a bottleneck is predicted, the advice algorithm determines the optimal behaviour for equipped vehicles in order to increase traffic flow efficiency and reduce the chance of disturbances in traffic flow.

The system's "perceptual horizon" and as a result the available bulk of situational information exceeds that of the human driver. Yet, even if drivers were able to perceive all that information they would still lack the knowledge and processing capacity to make predictions similar to those made by the system. This inequality of knowledge and insight can make it difficult for drivers to understand the motivation behind any given advice and may lower the perceived usefulness of the advice and the acceptance of the system as a whole.

The effectiveness and the benefit of the system depends on the coordination of a larger group of equipped vehicles, while each driver receives an individual advice. However, from the advice itself it may not be evident how the advice fits in the larger advice strategy. Without further information about the collective approach that is applied by the system, any advice that a driver receives can only be evaluated from the driver's individual point of view. Yet, in itself the advice may not convey its beneficial effect on the traffic situation to the individual driver.

It can be argued that the problem may be one of an incomplete or inaccurate mental model of the system's advice strategy. When trying to deduct the reason for a given advice, drivers rely on their mental model of how the system may operate. An incomplete or inaccurate mental model of the system may lead to unrealistic expectations, incomprehension of the advice and result is low perceived usefulness and effectiveness. However, providing drivers with a more correct model of the system's advice strategy may not in itself increase perceived usefulness. Drivers need to agree that the presented approach is effective in improving traffic efficiency when followed.

This study assesses participants' evaluation of the systems advice strategy. Furthermore the effect of information about the advice strategy on perceived comprehension of the advice messages, perceived compliance of other road users and the overall acceptance of the system is assessed.

10.1.1 **Behavioural response parameters at medium penetration**

The advisory system relies on a large scale implementation in order to have the desired effect on traffic flow and throughput. However, during the development process, constraints of time and production cost only allow for small amounts of test units. Therefore, it is difficult to measure, through field operational tests, the effect that the system will have on traffic flow. Modelling of compliance behaviour at different penetration rates plays an essential role in estimating the effect of driver advice on traffic flow. In order to model compliance behaviour it is important to determine behavioural response parameters such as execution time of certain advices, accepted gaps on the target lane, chosen gaps, speed adaptation. In the previous experiment, described in chapter 8, response parameters have already been assessed . In the present experiment behavioural response parameters to driver advice are assessed under moderate, simulated penetration rates.

Since the experiment presented in chapter 8, the advice messages CIVA have evolved. Earlier experiments showed that drivers have difficulties to accurately estimate and attain specific gap sizes (Chapter 7 and 8). Therefore, specific gap advice has been replaced by less specific gap advice in terms of an advised manoeuvre (i.e. leave room for merging vehicles) instead of a fixed target gap in seconds. It is argued that in merging situations this advice will have an effect similar to advising a time gap of two seconds, without requiring an explicit estimation of time gap.

10.2 Method

10.2.1 **Participants**

The same participants that had completed the first part of the experiment (chapter 9) also participated in the second part.

10.2.2 **Experimental design**

The second part of the experiment had a between participant design with the level of information about the advice strategy (Low vs. High) as independent variable. Perceived comprehension of the advice, the evaluation of the drivers own situation following compliance and acceptance of the system were the dependent variables. Participants encountered six different scenarios that were a combination of one of three locations (i.e. lane drop, on-ramp or straight motorway) and one of two advice messages (i.e. combined speed and lane advice or combined gap and lane advice). Self-reported comprehension of the advice and participant's impression of the effect that compliance to an advice had on their own situation, were assessed after every trial and aggregated to frequency scores. Acceptance was measured at two times, once before and once after exposure to the system in the simulator. Participants in the high information condition received the additional information after the first measurement of acceptance. Table 10.1 depicts the design in a schematic representation.

Table 10.1 Design of the second part of the experiment

Random assignment to conditions	→	First acceptance measure	→	Additional information	→	Exposure to CIVA system	→	Second Acceptance measure
Low Info		●		○		●		●
High Info		●		●		●		●

Note. Self-reported comprehension and perceived outcome of compliance were assessed after each trial

10.2.3 **Driver behaviour parameters**

During the second part of the experiment, behavioural response parameters were measured at three different locations (lane drop, on-ramp and straight motorway) and with two different advice messages (combined speed and lane change advice and combined lane and gap advice).

Each of the six trials was presented to participants a second time to provide information about the intra-driver variability when carrying out the same advice at the same location. Table 10.2 gives an overview of the measured driver behaviour parameters per advice.

Table 10.2 Behavioural response parameters

Advice	Parameter
Combined Speed & Lane change	• Distance to end of physical location • Lane change advice execution time • Accepted gap size on target lane • Speed difference to target lane during lane change
Gap	• Time-gap to lead vehicle before/after advice

At the straight motorway location there was no physical location, instead the distance to the end of the compliance zone was measured.

Lane change advice execution time was measured from the moment that the lane change advice had stopped playing until the moment that the participant's vehicle crossed the line between lanes.

The speed difference to the target lane was defined as the absolute difference value between the speed of the participant's vehicle and the mean of the speed of the two vehicles (one in front and one in the back of the participant's vehicle) on the target lane.

Time gap was measured at three times. (1) At the time the advice was given, (2) 15 seconds later, (3) 30 seconds later.

10.2.4 **Locations**

The road layout of the three locations, as well as the starting and presumed ending position of the driver were the same as in the first part of the experiment (shown in Appendix E.6).

10.2.5 **Information about the advice strategy**

The additional information that participants in the high information condition received was the same as in the first part of the experiment (shown in Appendix E.10).

10.2.6 **Compliance behaviour of other vehicles**

The compliance behaviour of other vehicles was simulated in the same way as in part one of the experiment.

10.2.7 **Penetration rate of other vehicles**

In part two, the penetration rate was kept at a medium level (50%) in all trials. For the full overview of penetration rates see the Appendix I.

10.2.8 **Advice messages**

Based on the chosen start positions of the participant's car, a lane change advice and a gap advice were developed (Table 10.3). These were designed based on the most recent advice strategy at that time.

Table 10.3 Advice messages given to participants

	Lane change advice	Gap advice
Lane drop	At 2 km before beginning lane drop: *"Adapt your speed to the speed of the traffic on the right and change to the right lane"*	At 2 km before beginning lane drop: *"Stay on your lane and make room for merging traffic from the left"*
On-ramp	At 1 km before beginning on-ramp: *"Adapt your speed to the speed of the traffic on the left and change to the left lane"*	At 400 m before beginning on-ramp: *"Stay on your lane and make room for merging traffic from the right"*
Straight Motorway	At 1 km into the trial: *"Adapt your speed to the speed of the traffic on the right and change to the right lane"*	At 1 km into the trial: *"Stay on your lane and make room for merging traffic from the left"*

In the final system the advice that drivers will receive, will be dynamically determined by a decision algorithm and adapted to the drivers current lane, speed, gap size, the chosen route as well as the current positions and route choices of the other traffic. However, the decision algorithms that would produce the advice were not available at this stage in the project. Therefore, in the present experiment it was chosen for static (not adapting to driver and external variables) advice messages. This advice was static in the way that it would not adapt to the chosen lane, speed or gap size, and would not change due to changes in the behaviour of other traffic. The given advice was based on the starting lane of the participant. To account for the static advice, participants were instructed to stay in the lane in which they started and keep their gap size and speed constant until given an advice.

Furthermore, participants were asked to always comply to the advice, regardless of their opinion about it. The reason for this was that in this experiment we were interested in participants' impression of their own situation after they had complied with the advice and behavioural response parameters.

10.2.9 **Traffic density**

Compared to the previous experiment the density was chosen in such a way that it was at a medium level, not low or high. Table 10.4 gives an overview of the traffic densities per lane at the beginning of a trial at each location.

Table 10.4 Traffic density at the beginning of a trial at each location, per lane

	Lane drop			On-ramp			Weaving		
Lane	3a	2a	1a	2a	1a	1b	3a	2a	1a
Km/h	120	110	85	110	85	85	100	90	85
% trucks	0	0	33	0	27	10	0	0	30
Density (v/km)	18,8	32,7	30,0	30,0	22,9	11,8	45,0	30,0	23,5
Distance headway (m)	53,3	30,6	33,3	33,3	43,6	85,0	22,2	33,3	42,5
Time headway (s)	1,6	1,0	1,4	1,1	1,8	3,6	0,8	1,3	1,8
Flow (v/h)	2250	3600	2550	3300	1950	1000	4500	2700	2000

Note: v = number of vehicles; km = kilometre; m = metre; h = hours; s = seconds

10.2.10 **Driving simulator setup**

The experiment was conducted in the same driving simulator, that was used in the previous experiment in chapter 8.

10.2.11 **Procedure**

Participants that had completed the first part of the experiment were given a break of about 45 minutes. After the break the second part (twelve trials) were completed in randomized order. In these trials system penetration was kept at 50% while the location and the advice messages varied. After all experimental trials had been completed, participants filled in the post-experimental questionnaire and were debriefed. The list of trials for the second part is shown in Table 10.5.

Table 10.5 Trial list

Trial	Advice	Location	Starting lane	Penetration
10, 11	Lane change Advice	Lane drop	Middle	50%
12, 13	Lane change Advice	On-ramp	Right	50%
14, 15	Lane change Advice	Straight	Middle	50%
16, 17	Gap Advice	Lane drop	Middle	50%
18, 19	Gap Advice	On-ramp	Right	50%
20, 21	Gap Advice	Straight	Middle	50%

note. For a more detailed view of the starting conditions of every trial see Appendix E.7.

10.2.12 **Data collection**

10.2.12.1 Acceptance of the advice strategy

Participants, who had received additional information about the advice strategy at different locations, were asked, per location, whether they thought the used strategy would have a beneficial effect on traffic flow if the advice was compiled to by a sufficient amount of drivers. Possible answer where: “Yes”; “I don’t know”; “No”.

10.2.12.2 Perceived comprehension of the advice

After each trial, participants were asked to indicate whether they had the feeling that they understood why the advice had been given to them in that trial (‘yes’ or ‘no’).

10.2.12.3 Perceived outcome of compliance

After each, participants were asked to state their perception whether compliance to the advice had advantageous or disadvantageous consequences (or no remarkable consequence) for them personally.

10.2.12.4 Acceptance

To measure acceptance the same standardized checklist of the acceptance of transport telematics was used as in the previous experiment in chapter 8 (van der Laan et al., 1997).

10.2.12.5 Purchase propensity

As another measure of acceptance purchase propensity was assessed before and after the experiment. The question was “Based on what you know over the system, are you apt to acquire one for you?” Possible answers were: “Yes and I would pay __ for it”; “Only if I do not have to pay for it”; “I don’t know”; “No”.

10.2.12.6 Behavioural response parameters

During the experiment, the driving simulator recorded the same data behavioural response parameters that were already recorded in the previous experiment in chapter 8.

Lane changes at the lane drop and on-ramp location were selected according to the procedure already described in chapter 8. In straight motorway trials where an advice was given, the first lane change that (1) followed the combined advice and (2) originated on the starting lane and ended on the target lane was chosen. In trials where no advice was given the first lane change in that trial originating on the starting lane and ending on the target lane was chosen.

10.3 Results

10.3.1 Agreement with the advice strategy

Participants who had received additional information (n=21), were asked whether they thought that the system's advice strategy would have a beneficial effect on traffic flow if the advice was followed by a sufficient amount of drivers. The frequencies of the answers per location are shown in Table 10.6.

Table 10.6 Agreement with advice strategy

Location	Response		
	Yes	Don't know	No
Lane drop	18	3	0
On-ramp	15	4	2
Straight motorway	14	7	0

Generally, drivers considered the advice strategy effective in improving traffic flow at the presented locations.

10.3.2 Perceived comprehension of the advice

The frequencies of trials, where participants claimed to understand the reason behind a given advice, are shown in Table 10.7.

Table 10.7 Comprehension of a given advice

Level of information	Understand the reason behind the advice	
	Yes	No
Low	147	105
High	170	82

The association between Level of Information (low vs. high) and the frequency of reported comprehension of an advice ('yes' or 'no') was tested with a chi-squared test. There was a significant association between the level of information and whether or not a person had the impression to comprehend the reason behind a given advice $\chi^2 = 4.50$, $p = .034$ (two-tailed). Based on the odds ratio, participants with a high level of information were 1.48 times more likely to report that they understand the reason behind a given advice.

10.3.3 Perceived outcome of compliance

The frequencies of trials, where participants perceived the outcome of their compliance to an advice as either 'advantageous', 'disadvantageous' or 'nothing noticed', are shown in Table 10.8.

Table 10.8 Outcome perception of compliance

Level of information	Outcome was perceived as…		
	Advantageous	Disadvantageous	Nothing noticed
Low	78	111	63
High	80	91	81

The association between level of information (low vs. high) and the frequency of a certain view of the outcome of compliance to an advice (‘advantageous’, ‘disadvantageous’, ‘nothing’) was tested with a chi-squared test. There was no significant association between the level of information and outcome perception $\chi^2 = 4.26$, $p = .12$ (two-tailed).

10.3.4 **Acceptance**

Perceived usefulness and satisfaction scores before and after exposure to the system were analysed with Wilcoxon signed rank tests. P-values were corrected with the Holm-Bonferroni method. For the group with a low level of information, perceived usefulness of the system before exposure to the advice in the simulator was significantly higher (M: 0.95, SE: 0.14) than after exposure (M: 0.53, SE: 0.14), Z = -1.78, p = .031, δ = -.35 (two-tailed). Also, perceived satisfaction was significantly higher before exposure (M: 0.49, SE: 0.15) compared to after exposure (M: 0.08, SE: 0.18), Z = -1.94, p = .026, δ = -.33 (two-tailed). Usefulness and satisfaction scores for the low information condition per item are shown in Figure 10.1.

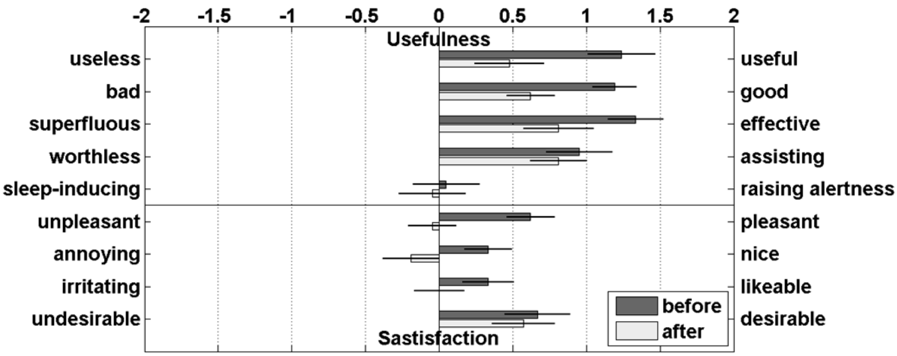

Figure 10.1 In the low information condition, perceived usefulness and satisfaction with the system reduced significantly after exposure to the advice in the driving simulator. Error bars show the standard deviation

For the group with the high level of information no effect of exposure to the system was found for perceived usefulness, Z = -0.67, p = .25, δ = -.18 (two-tailed), as well as for perceived satisfaction, Z = -0.77, p = .22, δ = -.19 (two-tailed). Usefulness and satisfaction scores for the high information condition per item are shown in Figure 10.2.

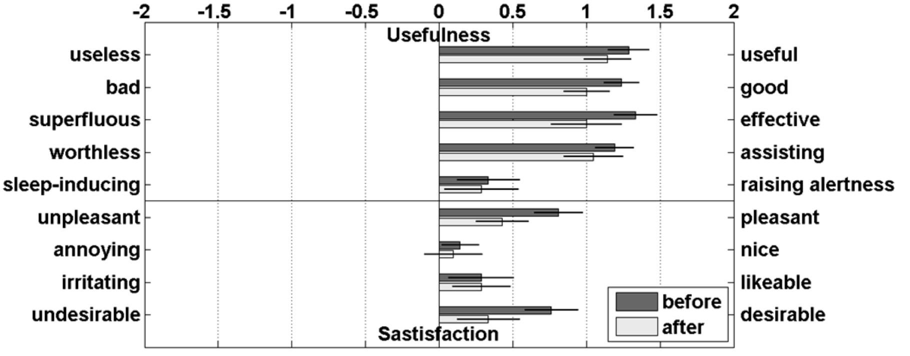

Figure 10.2 In the high information condition, perceived usefulness as well as perceived satisfaction did not reduce significantly after exposure to the advice in the driving simulator. Error bars show the standard deviation

10.3.5 **Purchase propensity**

The purchase propensity before and after exposure to the system is shown in Figure 10.3

Before exposure to CIVA After exposure to CIVA

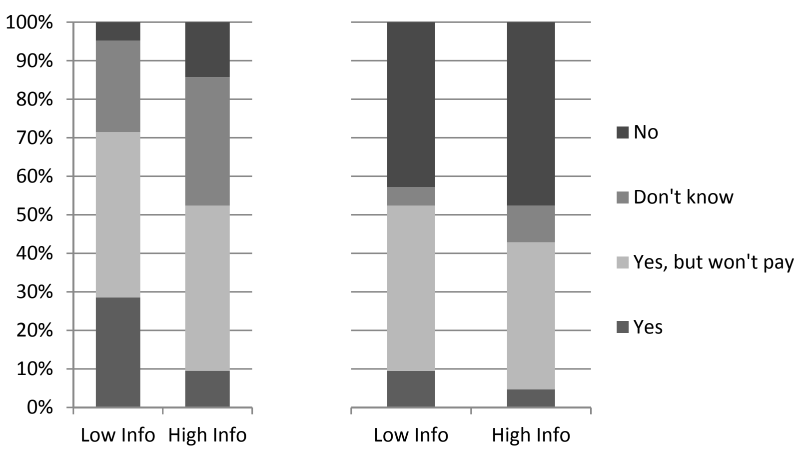

Figure 10.3 Participants' answers to the question (per Level of Information) whether they would be willing to buy the system

Eight drivers were willing to buy the system before exposure and to pay an average of 118 (SD: 76) euros for it. After Exposure, three drivers were willing to pay on average 93 (SD: 60) euros for it.

10.3.6 **Behavioural response parameters**

10.3.6.1 Lane change distance and duration

Lane change advice led to the majority of lane changes taking place within 500 metres after the advice had been given (see Appendix E.11). At the lane drop location, the majority of drivers without lane change advice changed lanes around the road sign that indicates the lane drop in a distance of 1 kilometre. The lane change advice was given 2 kilometres before the lane drop. Again drivers did not wait until they saw traffic signs for the lane drop approaching, but changed lanes shortly after the advice. At the on-ramp location, unadvised lane changes started around the distance where the lane change advice would have been given. Again, in advised trials the lane changes took place within a smaller area. Compared to the advised conditions the unadvised lane changes are spread more evenly before the on-ramp starts. At the straight motorway location, unadvised lane changes were distributed over the whole distance of the test track. For the cumulative percentage of lane changes as a function of distance see Appendix E.12.

10.3.6.2 Missing lane changes

In two trials a participant failed to change lanes after a lane change advice (once at the lane drop, once in the on-ramp location). Moreover, in approximately half of the unadvised trials no lane change was carried out by a participant.

The lack of lane change data decreases the power of a statistical analysis of the lane change based behaviour response parameters (i.e. accepted gap size, speed difference at the time of line crossing). Therefore, no comparison of advised and unadvised lane changes was carried out. The average values for accepted gap size, and speed difference at the time of line crossing can be found in Appendix E.13.

10.3.6.3 Gap size change after gap advice

After a gap advice was given, the participants' gap size at the time of the advice as well as fifteen and thirty seconds after the gap advice was recorded. An overview of the recorded gap size at the three different locations is shown in Table 10.9.

Table 10.9 Time gap adjustment after advice

Density	Trial	Time		
		Advice	+15 sec.	+30 sec.
Lane drop	16	2.2 (0.8)	3 (0.9)	2.8 (1.5)
	17	2.4 (1.1)	2.7 (1.1)	2.2 (1.0)
On-ramp	18	2.0 (1.0)	3 (1.3)	2.3 (1.2)
	19	2.1 (1.0)	3.2 (1.4)	1.8 (0.9)
Straight motorway	20	3.4 (0.9)	3.2 (1.3)	2.3 (1.1)
	21	3.2 (1.1)	3.0 (1.1)	2.6 (1.4)

note. Standard deviation in parentheses.

For Figures of the data see the Appendix E.16.

Time gaps were compared in a repeated measures ANOVA with Location (lane drop vs. on-ramp vs. straight motorway) and Time of Measurement (time of advice vs. plus fifteen seconds vs. plus thirty seconds) as within-participant factors. Mauchly's test indicated that the assumption of sphericity had been violated for the interaction effect of Location and Time of Measurement, W = 0.5, p = .001. For this effect the degrees of freedom were adjusted using Greenhouse-Geisser estimates of sphericity (ε = 0.77).

A main effect of Location was found, F(2,82) = 7.48, p = .001, η_G^2 = .036, as well as a main effect of Time of Measurement, F(2,82) = 9.52, p < .001, η_G^2 = .054. Also, an interaction effect to Location and Time of Measurement was found, F(3.07,125.99) = 10.44, p < .001, η_G^2 = .075. The interaction is shown in Figure 10.4.

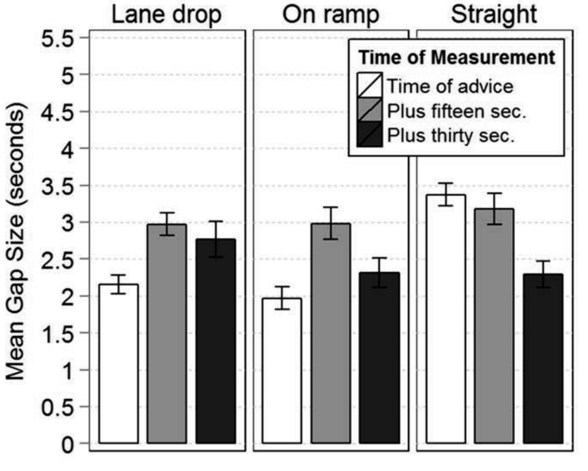

Figure 10.4 Interaction of Location and Time of Measurement on time gap

This interaction effect was further analysed by doing three separate ANOVAs, one for each Location (i.e. lane drop, on-ramp and weaving section), with Time of Measurement (time of advice vs. plus fifteen seconds vs. plus thirty seconds) as the within-participant factor and gap size as dependent variable.

For the lane drop location, Mauchly's test indicated that the assumption of sphericity had been violated for the main effect of Time of Measurement, W = 0.85, p = .037. Therefore, degrees of freedom were adjusted using Greenhouse-Geisser estimates of sphericity (ε = .87). A main effect of Time of Measurement on time gap was found, F(2,82) = 5.83 , p = .004, η_G^2 = .092. Subsequent pairwise comparisons with Holm-Bonferroni correction (k = 3) revealed that gap sizes at the time of advice (M: 2.16, SE: 0.15) were significantly smaller than gap sizes fifteen seconds after the advice (M: 2.97, SD 0.18), t(41) = -4,15, p < .001, r = .54 (two-tailed), as well as thirty seconds after the advice (M: 2.77, SD: 0.28), t(41) = -2,36, p = .046, r = .35

(two-tailed). Gap sizes fifteen seconds after the advice were not significantly different from gap sizes thirty seconds after the advice, t(41) = 0.71, p = .480, r = .11 (two-tailed).

For the on-ramp location, Mauchly's test indicated that the assumption of sphericity had been violated for the main effect of Time of Measurement, W = 0.66, p < .001. Therefore, degrees of freedom were adjusted using Greenhouse-Geisser estimates of sphericity (ε = .75). A main effect of Time of Measurement on time gap was found, F(2,82) = 15.15 , p < .001, η_G^2 = .116. Subsequent pairwise comparisons with Holm-Bonferroni correction (k = 3) revealed that gap sizes at the time of advice (M: 1.97, SE: 0.18) were significantly smaller than gap sizes fifteen seconds after the advice (M: 2.98, SD 0.25), t(41) = -8,23, p < .001, r = .79 (two-tailed). Also, gap sizes fifteen seconds after the advice were significantly larger than gap sizes thirty seconds after the advice, t(41) = 3.05, p = .008, r = .43 (two-tailed). Gap sizes thirty seconds after the advice (M: 2.31, SD: 0.23) were not significantly different from gap sizes at the time of advice, t(41) = -1,68, p = .100, r = .43 (two-tailed).

For the straight motorway location, a main effect of Time of Measurement on time gap was found, F(2,82) = 11.41 , p < .001, η_G^2 = .154. Subsequent pairwise comparisons with Holm-Bonferroni correction (k = 3) revealed that gap sizes at the time of advice (M: 3.37, SE: 0.18) were not significantly different from gap sizes at fifteen seconds after the advice (M: 3.18, SD 0.24), t(41) = 0,83, p = .412, r = .13 (two-tailed). However, gap sizes at the time of advice were significantly larger than gap sizes thirty seconds after the advice (M: 2.29, SD: 0.21), t(41) = 5.09, p < .001, r = .62 (two-tailed). Also, gap sizes fifteen seconds after the advice were significantly larger than gap sizes thirty seconds after the advice, t(41) = 3,22, p = .005, r = .45 (two-tailed).

The gap size development plots in the Appendix E.16 show how gap size changes in the time between advice and second measurement. These plots further illustrate the gap size development. It can be seen that participants lower their speed after an advice, leading to an increase in time gap fifteen seconds after the advice. The resulting gaps are than filled up by merging vehicles from the adjacent lanes, leading to a reduction in gap size at thirty seconds after the advice.

10.4 Discussion

10.4.1 Effects of information on advice comprehension and system acceptance

In this second part of the present study it was tested, whether additional information about the advice strategy would improve perceived comprehension of the advice, perceived advantage in the situation that followed compliance to an advice and increase system acceptance overall.

Before experiencing the advice in a driving simulator, informed drivers generally agreed with the effectiveness of the advice strategy at the three presented locations. This agreement may be regarded as a precondition for acceptance of the advice and the system as a whole.

During the experiment, additional information led participants to claim a better comprehension of the reason behind the given advice messages. However, this does not imply that actual comprehension also improved.

Additional information did not lead to higher frequencies of drivers who regarded their own situation as advantageous after having complied to an advice. Furthermore, the overall frequency of a perceived disadvantage after compliance exceeded that of a perceived advantage, as well as “no effect” perception. This negative imbalance of the perceived outcome following compliance to an advice can cause problems for long term adoption of the system. Drivers who experience more disadvantage than advantage from following the advice may be considered less likely to use the system without requesting a strong beneficial effect that would justify their use of the system. In the absence of such a beneficial effect, drivers may lack the intrinsic motivation to use the system and require extrinsic motivation (e.g. in the form of a reward for compliance).

Usefulness and satisfaction scores decreased for the low information group after being exposed to the advice in the simulator. A similar reduction of perceived usefulness and satisfaction was not observed for the high information group. It may be argued that acceptance of the system did not decrease due to the additional information, despite the higher frequency of perceived disadvantage from following the advice. The results also suggest a link between perceived comprehension of the advice and acceptance of the system. However, from the data generated in the experiment it is not possible to denote a causal relationship between improved comprehension of the advice an measured acceptance.

Self-reported purchase propensity was reduced after exposure to the system in the experiment. This result was observed in the low as well as high information condition, despite stable acceptance ratings of participants in the high information condition. The results suggest a willingness to use the system without having to pay for it. This reflects the attitude that the wide scale implementation of a system that creates a collective benefit for all road users, should be financed not by the individual users.

10.4.2 **Behavioural response parameters**

Similar to the previous experiment, lane change advice led participants to change their lane within a short region after the advice had been given. Due to the lack of comparable lane changes in the unadvised conditions, statistical analyses were not carried out on gap sizes and speed difference to the target lane at the time of line crossing. The behavioural response parameters to lane change advice can be used as input to further refine the calibration of driver behaviour models of compliance behaviour.

Analysis of the results with regard to gap advice showed that less specific advice resulted in the intended driving behaviour. In response to the advice, participants in the experiment increased their gaps in order to facilitate merging at the lane drop and the on-ramp locations. At the straight motorway location participant were already driving at a larger gap size, compared to the other two locations, and therefore did not increase their gap size. This result suggests that the advice does not lead drivers to increase their gap size when they are already driving at a gap size that is considered large enough.

10.5 Concluding remarks on both parts of the experiment

The present study has shown that providing additional information about the advice strategy may prevent a reduction of acceptance of the system, compared to no information, despite frequent perception of disadvantageous outcomes of compliance in both groups. This would suggest that, providing drivers with general information about the advice strategy can support the successful implementation of the system.

However, the first part of the experiment has also shown that additional information about the advice strategy can lead to a reduced perceived compliance of other road users. According to theories of conditional cooperation and the goal-expectation theory, this could decrease drivers' willingness to use the system, as they perceive their own effort as insufficient to create a beneficial effect. From, this standpoint it would be advised not to provide additional information about the advice strategy. Further research may explore the effect of other forms of general information about the system that can increase acceptance and perceived compliance alike.

11 On-road evaluation of the user experience[5]

11.1 Introduction

At this stage in the project a first prototype of the system has been developed that can be used in real traffic. The system's prediction and advice algorithm have been implemented on a roads-side server and work with real traffic data. The choice of which advice to present in what situation, the timing and the frequency of the advice are now determined by the algorithm. The human-machine interface has been installed in a test vehicle and is able to receive, process and present advice messages generated by the advice algorithm.

As has been argued in chapter 3, the individual driver's willingness to follow the advice that is provided by the CIVA system is a critical determinant for the system's effectiveness.

Due to the use of traffic loop and floating car data, the system's "perceptual horizon" and, as a result, the available amount and richness of situational information exceeds that of the driver. Furthermore, the system's algorithms and processing power allow it to deal with the amount of situational information in real time. In contrast, drivers lack that degree of information and

[5] Parts of this chapter are based on the following publication:

Risto, M., & Martens, M. H. (2013). Factors Influencing Compliance to Tactical Driver Advice: An Assessment Using a Think-Aloud Protocol. *Proceedings of the 16th International IEEE Annual Conference on Intelligent Transportation Systems*, October 6-9, The Hague, The Netherlands.

processing capacity when analysing a traffic situation and choosing a behavioural response. It is unclear how this gap in situational knowledge between the driver and the system will influence a driver's compliance with the advice.

There is no guarantee that an awareness of the systems capability will lead to unconditional compliance with the advice. A lack of trust in the system may lead drivers to follow only those advice messages that seem appropriate to them. Similar reactions have been observed in tests with a dynamic maximum speed limit (Rijkswaterstaat, 2010). Compliance was reduced when the projected speed limit did not correspond with the traffic situation that drivers observed on the road. While it may be argued that drivers are not well equipped to properly evaluate the advice that they are given, it may be the outcome of their evaluation of an advice that influences their willingness to comply with it.

In the previous experiment, additional information about the advice strategy improved reported comprehension of the advice and prevented a reduction of acceptance after experience with the system in the driving simulator. With regard to compliance, additional information about the traffic situation that triggered an advice may improve comprehension of the advice and therefore compliance. Therefore, the advice messages will be preceded by information about the traffic situation that triggered the advice. The main aim for providing this information is to motivate the system's choice for a particular advice to the driver.

However, information about the upcoming traffic condition might also reduce a driver's willingness to comply in cases where the driver perceives the advice as ineffective for improving the situation that is described. Especially drivers that have experience with a route (e.g. commuting traffic) may have developed expectations about the behaviour of traffic in certain situations and have become accustomed to a certain response that has led to a desired outcome in the past (see rule-based behaviour, Rasmussen, 1983). These drivers may be more inclined to choose their own experience based response over the advised response.

The present study explores what factors influence a driver's conscious decision to comply to different advice messages. Therefore drivers' considerations whether or not to follow a given advice are studied. For this drivers were asked to articulate their thoughts with regard to the given information and advice messages that they receive in real traffic situations. Moreover, in some situations drivers may expect an advice or expect information that is not provided by the system. These expectations, when articulated by participants, can give additional insight in their mental model of how the system ought to work and their belief of the optimal response to a perceived situation.

11.2 Method

11.2.1 **Study design**

A concurrent think-aloud design was used to obtain verbalisations of participants thoughts at the moment that they reacted to individual advice messages. The dependent variables were the results of the content analysis performed on the driver's verbal responses to the advice. In addition an acceptance questionnaire (van der Laan et al., 1997) was administered.

11.2.2 **Participants**

Thirteen participants (11 men, 2 women), aged 27 to 66 years (M: 52.9, SD: 10.8) completed the procedure. Participants had no prior experience with the system. All participants were in possession of a driver's license for at least eight years (M: 32.2, SD: 10.9) and drove at least 10.000 annual kilometres by car. All participants have been respondents to an advertisement in the local newspaper of the city of Gouda. A screening was administered to every prospective participant including a set of open questions, asking about motivation to participate, accordance with being videotaped and prior experience with user-testing. Participants that appeared talkative (i.e. giving longer than one-word responses) were accepted for participation (for a copy of the questions that were used in the screener see Appendix F.1). All participants indicated to have experience with traffic conditions on the track (see test area). Participants received a compensation of 50 euros for their participation. Additional demographics of the participants are shown in Table 11.1.

Table 11.1 Demographics of participants

Category	#	%
Gender		
Women	2	15.4
Men	11	84.6
Age (in years)		
20 – 29	1	7.7
30 – 39	0	0
40 – 49	2	15.4
50 – 59	7	53.8
60 – 69	3	23.1
Lowest value	27	
Mean (SD)	52.9 (10.8)	
Highest value	66	
Possession of driver's license (in years)		
0 – 9	1	7.7
10 – 19	0	0
20 – 29	3	23.1
30 – 39	5	38.5
40 – 49	4	30.8
Lowest value	8	
Mean (SD)	32.2 (10.9)	
Highest value	47	

Annual mileage (in km)		
10.000 – 19.999	5	38.5
20.000 – 29.999	7	53.8
30.000 – 39.999	1	7.7
Lowest value	10000	
Mean (SD)	19346 (6122)	
Highest value	35000	

11.2.3 **Think aloud protocol**

An elaborate measurement of the driver's initial understanding of the advice was desired. Thinking-aloud allows participants to verbally respond directly to a given advice, even before any behavioural actions is observed. This method is suited to give insights into cognitive processes in a natural setting (Ericsson & Simon, 1980; Walker, Stanton, & Young, 2001; Walker, 2005). The advantage of the measure in addition to a direct measure of compliance is that thinking-aloud provides insight into underlying cognitive processes that precede the behavioural response to a given advice. Concurrent think-aloud means that the verbal response data was recorded while participants reacted to the advice.

Before the study, the "think aloud" procedure was explained to the participants. Participants were instructed to verbalize what was on their mind after receiving the information and advice. Furthermore, they were instructed to verbalize their thoughts in situations where they expected information or an advice or anything specific that they thought was worth mentioning. Participants were being instructed that providing a verbal response was more important than reacting to the advice in a timely fashion. In case that participants had problems with the concurrent think aloud technique they were instructed to first express their thoughts and then follow the advice. Also participants were explained that compliance to the advice was not compulsory. In case that a participant decided not to comply to the advice, (s)he was encouraged to state the reason that led to that decision.

11.2.4 **The test area**

As a test area the A20 motorway between Rotterdam Alexander and Gouda was chosen. This location was chosen as it had several of the physical properties (e.g. lane drop, on-ramps) that were already studied in the simulator. Furthermore, traffic loop data, that could be used in the prediction algorithm, was available for this location. Figure 11.1 gives an overview of the test area which consisted of a rather straight piece of motorway. At location 1 and 2 a combination of off-ramp and on-ramp allowed for other traffic to exit or enter the motorway. In addition a lane drop was overlapping the area of the off-ramp at location 1. Figure 11.2 gives an schematic representation of the piece of motorway where the system was used.

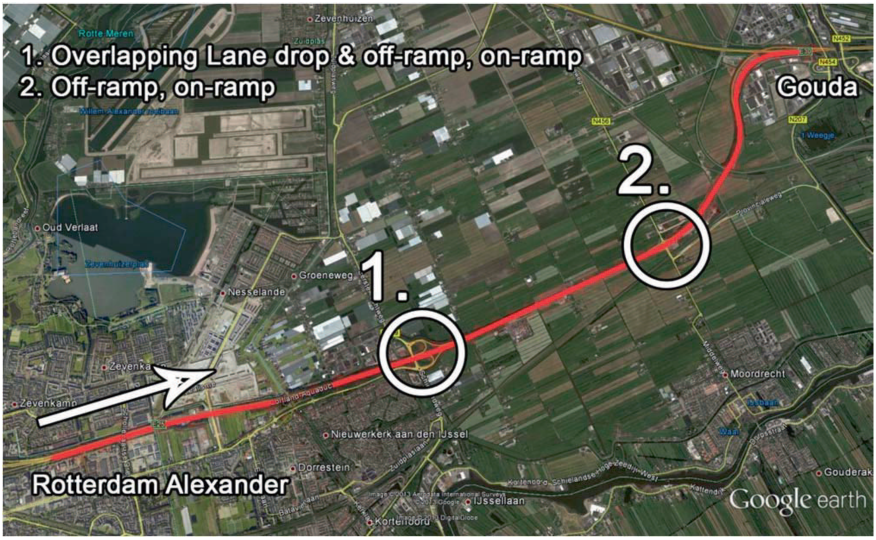

Figure 11.1. The test area between Rotterdam Alexander and Gouda

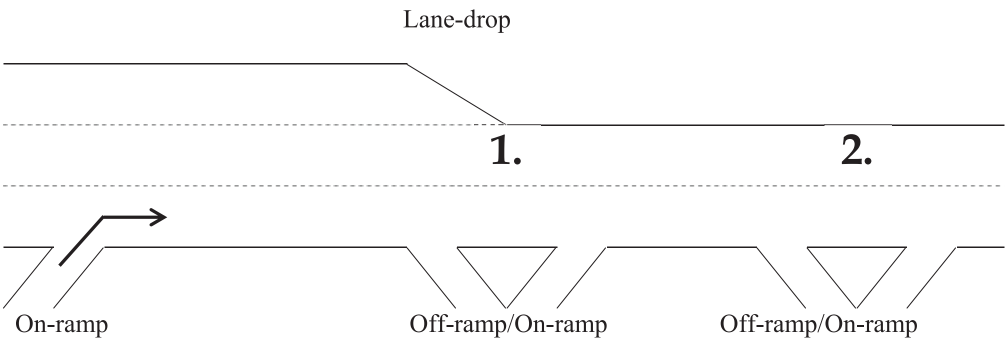

Figure 11.2 Schematic representation of the layout of the test area

11.2.5 **Instrumented vehicle setup**

The test vehicle for the study was a Toyota Prius with automatic gear box, equipped with a prototype of the system. The CIVA human-machine interface consisted of a "Samsung Galaxy Tab" tablet PC with an external speaker connected to it (Figure 11.3). Video of the traffic scene was recorded using a Canon EOS 550 D camera that was attached to the driver's back seat outside of the driver's field of vision. Participants had a headset around their neck with the microphone connected to the camera. During the test the advice was generated on a road-side server and was transmitted via 3.5G to a Mobibox that contained the on-board electronic of the preliminary system. From the Mobibox the advice was sent to the tablet PC via Bluetooth. Vehicles state data from the CAN-bus was recorded on the Mobibox (van Arem, 2013). Gap size information was recorded separately via the vehicle's internal radar, due to problems with the MobilEye camera that was previously dedicated for gap size measurement.

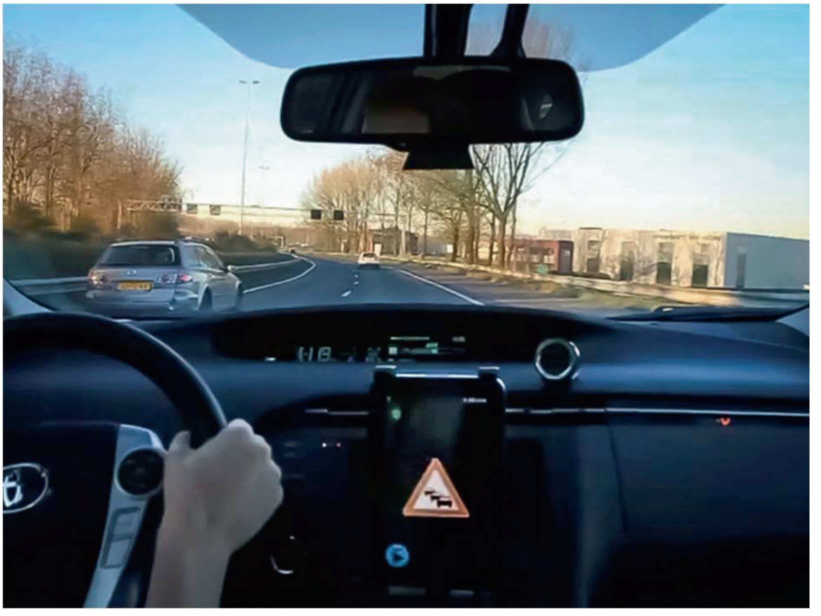

Figure 11.3 The in-vehicle advice HMI during the field trial

11.2.6 **Advice messages**

The combination of motivation and advice was presented via the visual and auditory modality. First, the information on the upcoming traffic situation (or motivation) was presented as an icon on the in-car display (i.e. tablet PC) as well as spoken text through the external speaker of the tablet. Second, the respective advice message was presented only as spoken text.

The advice that a driver received incorporated a traffic state prediction based on current traffic loop data that was calculated on the roadside (Schakel & van Arem, 2013), as well as the current lane position of the equipped vehicle. A combinations of these variables produced a unique combination of advice messages. As a result not all drivers received the same advice in the same situation. Also some drivers received advice messages that others did not encounter during their session. Table 11.2 shows the motivations and advice messages that drivers could encounter during the study.

The advice to keep a short but safe gap has not been tested in earlier experiments. The goal of the advice is that drivers accelerate more efficiently out of a traffic jam. However, in their acceleration drivers are restricted by the speed of the vehicle in front. If this vehicle is driving slowly, an advice to increase the speed at the end of a traffic jam may have little effect. Therefore, the short gap advice would ensure that drivers will accelerate at a similar rate as the vehicle in front. At the lane drop location no lane change advice was given to drivers on the left lane that was about to end.

Table 11.2 Possible advice messages for the test area

Event	Motivation icon	Motivation text	Possible advice left lane	Possible advice middle lane	Possible advice right lane
End of traffic jam		*"Attention, you are approaching the end of the traffic jam"*	*"Keep a short but save gap"*		
Shockwave		*"Attention, shockwaves due to heavy traffic"*	*"Adapt speed to the middle lane"* AND *"Go to the middle lane"*	*"Adapt speed to the right lane"* AND *"Go to the right lane"* --- "Make room for merging vehicles"	*"Make room for merging vehicles"*
Change of congestion		*"Attention, chance of congestion"*	*"Adapt speed to the middle lane"* AND *"Go to the middle lane"*	*"Adapt speed to the right lane"* AND *"Go to the right lane"*	*"Make room for merging vehicles"*
Busy on-ramp		*"Attention, you are approaching a busy entry"*	*"Make room for merging vehicles"*	*"Adapt to the speed of the left lane"* AND *"Go to the left lane"*	*"Adapt to the speed of the middle lane"* AND *"Go to the middle lane"*
Lane drop		*"Attention, left lane is ending"*	*"Adapt to the speed of the right lane"*	*"Adapt speed to the right lane"* AND *"Go to the right lane"* --- *"Make room for merging vehicles"*	*"Make room for merging vehicles"*

Note. In the study the spoken advice messages were provided in the Dutch language.

11.2.7 **Procedure**

The drives were scheduled short before evening peak traffic hours and started around 3 p.m.. Upon arrival at Technolution in Gouda, participants read information about the procedure of the study. Furthermore they received additional information about the advice strategy of the system in different situations (i.e. at a lane drop, on-ramp, with a predicted traffic jam and at the end of a traffic jam/shockwave), similar to the previous experiment. Participants also received an explanation of the think aloud procedure. After the participants had read the information and questions had been answered, they filled out the informed consent and the first part of the survey. All of the administered documents can be found in Appendix F.2 and F.3.

Then, the participant and a study supervisor took a seat in the instrumented test vehicle. The participant was seated in the driver seat while the supervisor took the backseat behind the passenger seat. The supervisor explained the functions of the vehicle and asked the participant to head in the direction of Rotterdam Alexander via the A20 motorway. On the way to Rotterdam the supervisor repeated the most important points of the think aloud procedure. Participants were told that they would not have to comment on all aspects of their own driving behaviour, but rather focus on their thoughts about the advice and information or express a request for an advice or information where they expected one. Participants were also told that they were free to choose whether to comply with the advice or not. They were asked to provide their reason for (non-)compliance.

After a turn in Rotterdam Alexander the first session started. The supervisor turned on the camera and informed the participant that the session had started and instructed the participant to start with the think aloud protocol. During the recording the supervisor remained mostly silent to avoid guiding the participant in his/her response. In some cases the supervisor encouraged the participant to think aloud by asking questions like “What is on your mind?” or “What did you think about that advice?” in cases where the participant did not verbalize for a longer period of time. After every recording session the participant was given advice on how to improve the relevance of the verbal response.

Participants repeatedly drove the road from Rotterdam Alexander to Gouda until the end of the study. Depending on the traffic situation every participant completed three to four runs in the test area. After the last run in the session, participants were instructed to drive back to Technolution where they were given the second part of the evaluation survey. After having completed the survey participants were debriefed and dismissed.

11.2.8 **Transcription of the video material**

First the video material was transcribed word for word while the time of an advice, the type of an advice, the time of a lane change, vehicle speed at lane change, content of matrix signs, as well as driver gestures were noted alongside the transcript of the verbalisations. For further analysis the transcripts were divided into blocks starting with a particular motivation and advice combination and followed by the participant’s response. For every block participant’s verbalisations were categorized into similar themes.

The emerging categories were based on the thoughts that participants had after having received an advice (such as verification of the information provided in the advice, prediction of future traffic, statements of the intention to (not) comply). For example, utterances about the behaviour of matrix signs were placed in the category "verification of information with available information". In other cases remarks were categorised as "verification based on experience" when participants recalled earlier experience with traffic in the situation to evaluate a given advice. Also requests for advice or information where categorised according to the behaviour that should have been advised or the kind of information that was expected. Advice and requests, plotted at the location of their occurrence in the test area are shown in Appendix F.4 and F.5.

11.3 Results

11.3.1 **Frequency of individual advice messages**

Overall 76 advice messages have been presented to participants in the duration of the study. Table 11.3 breaks these down into the separate motivations and advice combinations.

Table 11.3 Frequency of individual information advice combinations

#	Information	Advice	Abbreviation
61	End of traffic jam	Keep a short but safe gap	ET/SG
11	Chance of congestion	Go to the middle lane	CC/GM
2		Go to the right lane	CC/GR
7	Dense on-ramp	Go to the right lane	DO/GR
5		Adapt to speed of the right lane	DO/ASR
1		Go to the middle lane	DO/GM

11.3.2 **Spatial location of the advice messages**

Appendix F.4 includes an overview of the spatial location of the advice messages. Different advice regions can be distinguished at different locations. Before location 1 (lane drop, off- and on-ramp combination) drivers mainly received speed and lane change advice. Just before and after passing location 1, drivers were mainly advised to keep a short but safe gap.

11.3.3 **Participant's response to the advice messages**

This section contains the analysis of the transcripts of the video material. Per motivation/advice combination. Findings regarding the advice message itself, as well as observations by the study supervisor during a session, are presented first. Then, similarities in participants' cognitive and the behavioural response to the advice will be illustrated by transcripts of remarks made by the participants. Every quoted response is a response by a participant after having received the respective advice from that category. In the text, references to the transcript of the video material are made in the form of a timestamp (hh:mm:ss).

11.3.3.1 Advice: End of traffic jam / Keep a short but safe gap (ET/SG)

The average speed at which ET/SG advice has been given was 55.1 km/h. However a standard deviation of 22.1 indicates a high variability in speeds. The frequency distribution (Figure 11.4) shows two peaks. At speeds between 30 - 40 km/h and between 60 - 70 km/h a high frequency of ET/SG advice has been given. At low speeds the advice was usually given at the end of a shockwave or congestion. At higher speeds where was often no visible sign of congested traffic at the time of the advice.

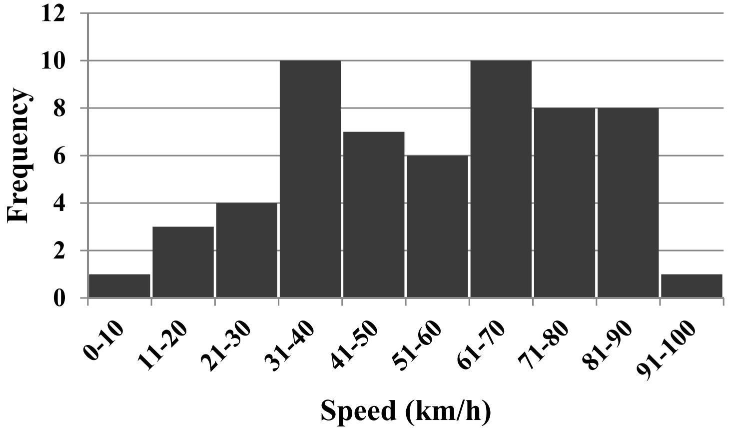

Figure 11.4. The distribution shows the high variability of speeds at which ET/SG advice has been given

In situations in which the advice was given in what appeared congested traffic conditions (e.g. low speed, small inter-vehicle distances), the time from the advice until the first visible sign of the end of congestion (e.g. speed increase, inter-vehicle distance becoming larger) varied. Sometimes there was an immediate increase in speed observable, at other times there were several seconds or even minutes between advice and signs of congestion visibly resolving. In some cases no visible signs, that congestion was about to dissolve, could be observed after the advice had been given.

Verbal response to ET/SG advice

A common response to the ET/SG advice was that participants tried to verify whether the traffic jam actually ended in the following minutes. Therefore, participants observed the behaviour of their environment. Three participants indicated to look at matrix signs further down the road. Apart from the speed that was displayed on the signs, the mere fact that they were on (sometimes flashing) or off was used as information.

Driver	Round	Time	Reaction
49	4	3:36:26	He [the matrix sign] simply remains on 50, so i think that this is not the end of the traffic jam.
49	4	3:37:48	Now it is good. Now he [the system] did it right. Because the light above was out. Therefore, now, he gave the right information.
53	2	3:50:56	I am a bit suspicious whether I can trust that information and whether this is indeed the moment where traffic is dissolving. I might as well, all of a sudden, come to a hold. Particularly, as I can see the matrix signs in the distance and they show a lower speed than what I am currently driving.
53	3	4:4:20	Matrix signs are showing 70 km/h. This would correspond with the end of a traffic jam.
69	3	5:16:22	Matrix signs are showing 50 km/h. Therefore I don't think that this is the end of the traffic jam. It's just slowly driving traffic.

Six participants indicated to search for signs of the end of congestion by observing the behaviour of traffic around them as well as their own speed over the following minutes.

Driver	Round	Time	Reaction
16	1	0:26:50	Well, he [the system] was right, we are driving again.
23	1	1:25:16	I cannot see it very well, yet. We are approaching the end of a traffic jam, therefore you might say that the traffic would slowly speed up again.
23	1	1:27:36	Everyone can drive faster, so the advice is true.
23	3	1:52:18	I think that this was a useful advice, because I can see traffic flowing nicely. So, I may expect that it is going to speed up soon. Therefore, I am going to speed up as well.
23	3	1:52:56	The advice is true. It is going faster. I can see that everything is driving faster. A useful advice.
49	2	3:16:36	This is not entirely true, the traffic jam is still there. He [the system] says that we are approaching the end of a traffic jam, but I don't believe it.
53	3	4:3:0	The advice does not correspond with my own perception. I don't have the feeling yet that the end of the traffic jam is approaching.
69	3	5:14:0	I don't see the end of a traffic jam, so I just proceed at the same speed.
92	2	5:47:8	I saw indeed that traffic is dissolving.

Several times participants received an ET/SG advice only to perceive a slowing down of traffic less than a minute later. Eight participants verbally expressed their confusion and frustration about the situation.

Driver	Round	Time	Reaction
18	4	1:18:24	There is another traffic jam approaching…
18	4	1:19:10	He [the system] was right, that we are at the end of a traffic jam, but a bit later there is another traffic jam approaching. So, actually it is good that he says it, but then he has to add that a new traffic jam is approaching.
23	2	1:39:26	I don't see it yet. It is interesting, that advice, but now I have to brake, even to stop. So, the advice… it… yeah… you know that it [the traffic jam] ends, but we are not there yet.
45	2	2:49:54	[as the participant comes to a hold after the advice had been given] I thought that I was approaching the *end* of a traffic jam?
49	3	3:25:32	Only that we are not driving yet…
53	2	3:49:4	I think that the *end of the traffic jam* is a very strange remark. In my opinion I am at the *beginning* of a traffic jam.
53	3	4:4:2	Look, we are visibly slowing down. When you receive the information that the end of the traffic jam is approaching, then you would not expect having to reduce your speed.
55	3	4:21:0	Is this the end of the traffic jam, or the beginning of the traffic jam?
69	4	5:26:52	Look, there is a traffic jam approaching again, while the system tells me that the traffic jam would dissolve.
92	2	5:45:32	And thank you, that is a good advice. [20 seconds later] Be it that the information is not true. Because at this moment I am stranding again in a traffic jam, in contrast to the end of a traffic jam.

Three participants appear to have interpreted the advice as an instruction to increase their gap size rather than reducing their gap size.

Driver	Round	Time	Reaction
55	3	4:20:40	Yes, I think this is a good advice, I shall indeed keep more distance.
69	2	5:6:42	But that you have to keep a distance, that is obvious, herein I agree with the system.
92	2	5:47:10	I gladly accept the advice to keep a safe gap size.

Two participants were not sure about what a “short but safe” gap size actually meant in terms of the distance to choose.

Driver	Round	Time	Reaction
45	2	2:48:50	What is a short and safe distance?
69	2	5:6:0	But what is short and what is safe?

Participants usually received several ET/SG advice during a single run. Sometimes these were given in short succession, with less than a minute pause in between. This confused and annoyed two participants to a level that they verbally responded to it. The rest of participants did not respond verbally to the repetitive advice messages.

Driver	Round	Time	Reaction
49	2	3:17:14	This is irritating, that he does this two times in a row.
55	3	4:23:28	I am a bit confused, because I got the same advice as I already did a minute ago.

Behavioural response to ET/SG advice

The development in time gap three minutes before and after gap advice is shown in Figure 11.5. Gap advice was only included in this figure, when it was not preceded by another gap advice within three minutes (resulting in 48 of 61 included data sets).

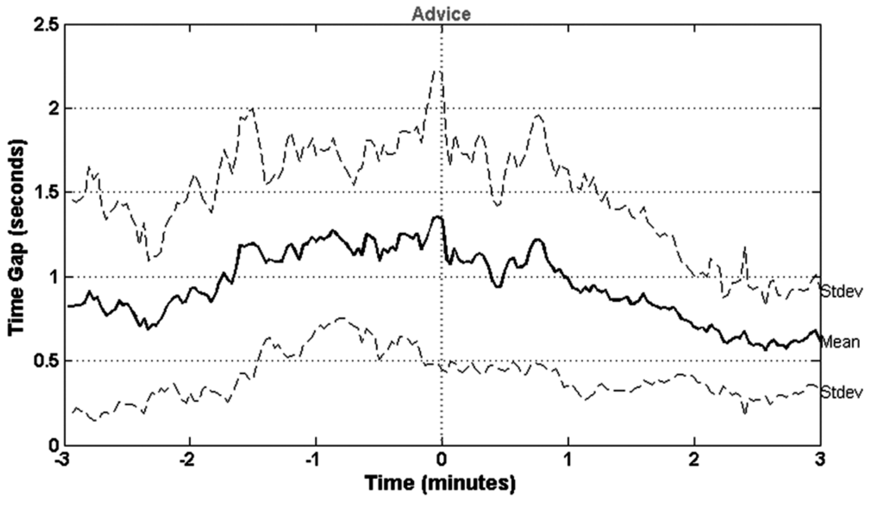

Figure 11.5 Average changes in gap size after “short but safe gap” advice

From the Figure it can be seen that participants' time gaps only show marginal changes within one minute after a "short gap" advice. Over the length of three minutes, gap sizes reduced slowly. Also the variability in gap size reduced within this time period.

However, as it was indicated before, within a short period of time the ET/KA advice was often followed by new congestion, which included braking manoeuvres by the vehicle in front. Therefore, the observed reduction in gap size may partly be caused by a braking front vehicle and not only by the participants' actions.

11.3.3.2 Advice: Chance of a congestion / Go to the middle lane (CC/GM)
As has been remarked earlier this advice was almost entirely given at a section with only two lanes and the predicted congestion never occurred.

Verbal response to CC/GM advice

Five participants verbally responded with confusion over the lacking of a middle lane.

Driver	Round	Time	Reaction
4	3	0:20:10	Now I think, what middle lane? I only have two of them!
45	2	2:53:0	The middle one? Well, i shall go to the right… no advice about speed?
53	2	3:51:56	I do not get this at all…
55	4	4:31:40	Yes, this instruction, I do not really understand and it does not seem correct to me…
65	3	4:54:46	Middle lane is not there, and this lane is still going above 100 km/h, so I will not change lanes.

One participant remarked that he did not see signs of a traffic jam thirty seconds after having received the advice.

Driver	Round	Time	Reaction
45	2	2:53:32	I don't see any traffic jam…

Behavioural response to CC/GM advice

Usually no action was taken by participants after the advice had been given. One participant (although noticing the lacking of a middle lane) changed lanes to the right in order to comply to the advice in any way.

11.3.3.3 Advice: Chance of congestion / Go to the right lane (CC/GR)
In both occasions the predicted congestion did not correspond to any sign of real congestion.

Verbal response to CC/GR advice

In both occasions participants initially refused to comply to the advice. Therefore, they drew from their prior experience with the situation, both concluding that it would not make sense to change lanes to the right.

Driver	Round	Time	Reaction
4	2	0:7:56	No, not really… In my opinion I just have to stay in this lane. Also because I am experienced with the traffic here.
53	1	3:43:8	I don't get this. Why the right lane? There is an off-ramp approaching and the right lane becomes congested regularly. If I go right it will become even more congested. Therefore, I will stay on the left lane.

Later one of the participants remarked that his non-compliance had been the correct decision since soon after the advice, matrix signs switched off.

Driver	Round	Time	Reaction
53	1	3:44:32	Matrix signs are off again. So after all it was the right decision to stay on the left lane and not to follow the advice to go to the right.

Behavioural response to CC/GM advice

Both participants initially refused to comply to the advice and gave explanations of why they considered the lane change counter-effective. However, about 25 seconds later (Time 0:8:16) participant 4 appeared to comply anyway. At the time that the advice was issued the right lane appeared crowded with two trucks on the target lane, driving in front of the participant.

11.3.3.4 Advice: Dense on-ramp / Go to the right lane (DO/GR)

In three cases in which the advice was given, participants had already changed to the right lane less than ten seconds earlier (Time 3:48:38; 5:31:58; 5:40:48). In another occasion the participant had changed to the right lane less than a minute ago (Time 1:22:12) and in yet another occasion the participant was already driving on the right lane for three minutes, where he had been driving since entering the motorway (Time 1:33:12). In one occasion the advice to go to the right lane preceded the advice to adapt to the speed of the right lane (Time 2:46:22).

Verbal response to DO/GR advice

Again one participant referred to his experience with the road to explain his non-compliance with the advice.

Driver	Round	Time	Reaction
4	3	0:15:6	I won't do that. Because I know that it will all be over at the off-ramp. Therefore I stay in this lane.

And again, one participant referred to the matrix signs and the current traffic behaviour to evaluate the advice.

Driver	Round	Time	Reaction
23	1	1:22:28	The advice may be helpful. I cannot interpret it so good at this point, as traffic is still driving. But I see the matrix signs lighting up. So… well… useful advice, maybe… for throughput.

One participant, driving on the left of three lanes, did not know which lane was meant in the advice "change to the right lane". Either the lane on her right or the right lane of the motorway.

Driver	Round	Time	Reaction
45	2	2:46:38	So, now I don't know if it [the system] meant the lane all the way to the right or the middle lane.

She complied to the advice in the right way (by changing to the middle lane) but kept observing the situation. As the lane that she had changed to appeared to slow down, while the right lane was still driving, she concluded that something must have been wrong with the advice or she must have complied in the wrong way.

Driver	Round	Time	Reaction
45	2	2:47:6	I think that I should have gone all the way to the right lane.

Behavioural response to DO/GR advice

The advice was complied with in 2 out of 7 occasions. However often the reason for that was not the participant's unwillingness to comply. Rather participants had already changed lanes following an "adapt speed" advice or out of their own motivation.

When there was enough room on the target lane, lane changes immediately after the advice were observed (Time 1:22:12; 2:46:22).

11.3.3.5 Advice: Dense on-ramp / Adapt to speed of the right lane (DO/ASR)

This advice was given five times, exclusively to participants driving on the left lane, that was about to end.

Verbal response to DO/ASR advice

The advice was only to adapt the speed to the right lane. However, three participants, in four of the five times, appeared to interpret it as a lane change advice.

Driver	Round	Time	Reaction
49	2	3:15:0	[when the immediate lane change was addressed] Yes, actually I did change immediately. It was a bit of an automatism.
53	1	3:42:16	My normal behaviour would be to change as soon as I reach the traffic sign that tells me to. However, now I will pass this vehicle and change to the right.
53	2	3:48:24	I ask myself if I should merge here already
55	4	4:26:56	It seems to me that this advice is a bit early, however I will follow the instruction [changes to the right].

Behavioural response to DO/ASR advice

In four occasions the "adapt speed" advice triggered a lane change to the right, even though this was not specifically advised.

11.3.3.6 Advice: Dense on-ramp / Go to the middle lane (DO/GM)

This information/advice combination was given once on a two lane piece of the motorway. The participant, that received the advice, was driving on the right lane, approaching an off-ramp right before reaching the on-ramp that the advice was given for. At first he was confused over the lack of a middle lane. However, as he approached the off-ramp, the advice suddenly appeared to make sense to him.

Driver	Round	Time	Reaction
55	2	4:15:42	Uh… I am a bit confused, because there are two lanes and I don't know what the middle lane is. I assume that I have to go to the right lane [changes lanes to the right lane as the off-ramp appears on the right]. Now there are indeed three lanes!

11.3.4 **Requested information and advice by participants**

During the study, participants verbalized 9 requests for information about the current traffic state and 34 requests for advice from the system (only counting information or advice that the system would be able provide based on the current implementation). The following Table 11.4 gives an overview of the frequency of individual requests per advice category.

Table 11.4 Requests for information or advice uttered by participants during driving

#	INFO	#	ADVICE
8	Approaching congestion	14	Lane change
1	End of traffic jam	7	Speed reduction
		6	Make room
		5	Stay on lane
		1	Adapt speed to other lane
		1	Short gap
9	**TOTAL**	**34**	**TOTAL**

The line between a request for information and an advice was not always clear, as, for example, in the case of "approaching congestion". Often people requested a message indicating that that they were approaching congestion in order for them to be able to timely reduce their speed.

11.3.5 Spatial location of the requests

The table in Appendix F.5 gives an overview of the spatial locations where participants expressed the need for information or expected an advice.

Usually participants did not vocalize their request for an advice or for information at the point where they wanted to receive it, but at the point where they noticed that they would have benefitted from it, had they received it earlier. Therefore, the location of the request usually appears further down the road (further upwards in the road layout, shown in the Appendix) than the location where participants would have needed the information or advice.

Similar requests for information or advice had no distinguishable spatial location (as it was observed for the given advice messages). Participants' requests were often triggered by external events. For example, when participants where approaching a traffic jam they wished that they had been warned about that. When participants were standing in a traffic jam they wanted to know how long it was and what lane best to choose to move faster. When the traffic jam resolved they wanted a message that would have informed them about that.

11.3.6 Acceptance

Acceptance was measured on two dimensions as perceived usefulness and perceived satisfaction before and after exposure to the system. It can be seen (Figure 11.6) that direct experience with the system led to a decrease in perceived usefulness while perceived satisfaction remained constant. Wilcoxon signed rank tests revealed that on average participants perceived the system as more useful before (M: 1.23, SD: 0.55) compared to after exposure (M: 0.56, SD: 0.94), $Z = -2.29$, $p = .011$, $\delta = -.48$ (two-tailed). No difference was found in perceived satisfaction before (M: 0.7, SD: 0.44) compared to after exposure (M: 0.7, SD: 0.82).

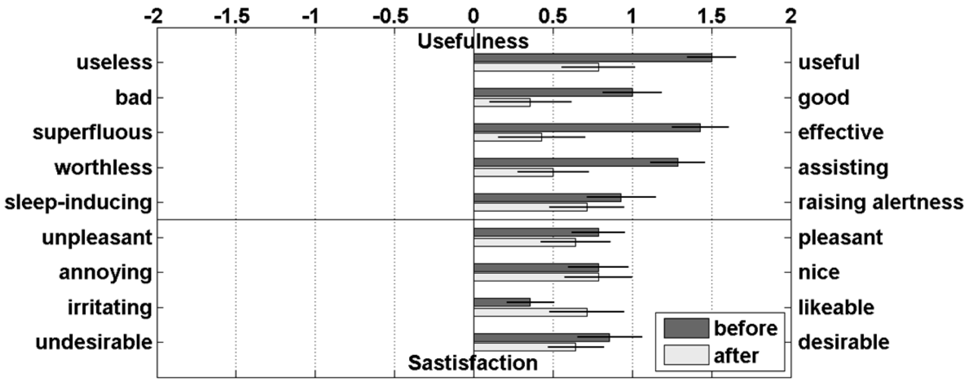

Figure 11.6 After exposure to the system perceived usefulness decreased while perceived satisfaction remained constant

11.4 Discussion and Recommendations

In the present study a functional prototype CIVA system was evaluated on a real road. Advice messages were given to participants based on a real time prediction of bottlenecks in the traffic situation. In the following section the verbal responses are discussed and recommendations are given for improving the advice.

11.4.1 Participants' reactions to information/advice combinations

11.4.1.1 Advice: End of traffic jam / Keep a short but safe following distance (ET/SG)

Variability in speed and distance to the end of the traffic jam

There was a high amount of variation in speeds at which ET/SG advice was given. In situations with slowly driving traffic, the information, that the end of congestion was approaching, created an expectation of a visible change in the behaviour of the slowly driving traffic. When no change became visible over time, the information began to lose its credibility in the eyes of participants. In situations in which speeds were higher, participants would get the impression that there had been no traffic jam at all. The variability in speed at which the same information ('the end of a traffic jam') was provided led to confusion. Here the advice may need to provide a different motivation when traffic accelerates from 70 km/h compared to 40 km/h.

Also, the variability in time between the advice and first noticeable signs of an ending of a traffic jam, led to confusion. Information about the distance towards the predicted end of a traffic jam, that has also been demanded by participants, could help drivers prepare for a change in gap size and speed of the lead vehicle and react more timely to it.

Verification of "end of traffic jam" information

Often, participant were trying to verify the information of an ending traffic jam by observing the road ahead in search of any visible signs that congestion really did dissolve. These included matrix signs, the behaviour of traffic further downstream, and their own speed over the coming minutes. Drivers used the information that they could perceive at that time to verify the information given by the system. This behaviour illustrates the information gap between the system and the driver. While the system made predictions about traffic based on loop data and floating car data, drivers tried to spot, in real-time, signs that the information that they received was correct. This led to situations where participants mistrusted the system when they themselves could not see the end of a traffic jam.

Searching for verification of the information given by the system may be considered typical behaviour, given participants' first encounter with the system. In the eyes of the participant, familiar matrix signs appeared more trustworthy than the CIVA system. Trust in the information may develop over a longer period where the information is repeatedly verified by the observations of the driver. If, over time, drivers repeatedly perceive that the information contradicts the actual traffic development, they may lose trust in the information as well as the advice.

In this light, ET/SG advice, that is provided shortly before a participant had to brake, due to another shockwave or traffic jam, will inhibit the formation of trust in system information and advice. This will again have implications for behavioural compliance with the advice. One participant expressed this very clearly, by remarking that the information and advice are not beneficial, if he still has to constantly keep his attention on the traffic to see whether the congestion actually dissolves or not (Time 1:39:12).

Currently it appears that the system detects the endings of individual shockwaves that are followed by other shockwaves. This might lead to problems. The actual distance in time or distance between shockwaves may be so small, that the advice to close the gap, and to speed-up in the process, may be given just before the driver is about to enter the next shockwave. Given a higher resolution of real-time traffic information it may be possible to distinguish between different shockwaves in short succession and to improve the advice given to drivers. Also, drivers might benefit from a more nuanced classification of the sort of congestion that is about to end (e.g. end of shockwave, end of slow driving traffic end of traffic jam). Independent of the formulation, a re-evaluation is needed whether a short gap size should be advised in situations that have a certain chance of sudden braking (e.g. driving through a succession of shockwaves) manoeuvres, as this can lead to unsafe situations.

Compliance to "short gap" advice

Most of the times it was difficult to tell whether participants were complying to the advice. No substantial change in gap size could be observed within the first minute after the advice. However, in this study, gap sizes were already around one second when the advice was given. One second is below the two second gap size that is recommended as a safe gap size in several countries. Furthermore, in other studies one second was the preferred gap size of drivers (Taieb-Maimon & Shinar, 2001; van Winsum & Heino, 1996). Therefore, the gap size that participants had at the time that the advice was given may already be considered rather short in terms of traffic safety. Further reducing the gap size would not be a desired response to the advice.

Uncertainty about "short but safe" gap

Some participants were uncertain how to interpret the "short but safe" gap advice. It appears that drivers understood the advice, however they were not sure what distance would be considered short but safe. The uncertainty and the perceived inability to follow the contradicting advice may reduce the likelihood of compliance.

A reformulation of the advice could reduce uncertainty about contradicting messages. However, the challenge lies in the design of a message that prompts drivers to follow at a short inter-vehicle distance without advising behaviour that can lead to dangerous situations or that is perceived as tail-gaiting by the driver in front. Alternatively, it might already have a beneficial effect to make drivers more attentive to the acceleration of the vehicle in front with an advice to prevent the development of large gaps.

11.4.1.2 Advice: Chance of a congestion / Go to the middle lane (CC/GM)

Participants reacted to the advice mainly with confusion due to the lack of a middle lane when the advice was given. The impossibility to comply to the advice resulted in participants just ignoring it. Furthermore, one of the eight participants, that had received this information/advice combination, later remarked the lack of any sign of congestion. This is noteworthy, regarding participants' eagerness in spotting signs of the dissolving congestion. Drivers did expect congestion to resolve in the seconds following ET/SG advice and noticed when there were no visible signs of congestion actually dissolving. In contrast, CC/GM advice did not establish such an expectation that congestion would occur within the coming seconds. The information that is preceding the CC/GM advice indicates that there is merely a chance of congestion, it does not indicate whether the chance is low or high. Thereby the message implies less certainty than the one predicting the ending of the traffic jam. It is possible that the difference in formulating the prediction had influenced driver expectations about the event actually occurring.

11.4.1.3 Advice: Chance of congestion / Go to the right lane (CC/GR)

This advice has been given in two situations and both times participants refused to comply due to disagreement with the advice. In both cases the advice triggered, among drivers, an evaluation of the traffic situation and their own lane position. In both cases drivers disagree with the CIVA system about the optimal behaviour in that situation. Drivers' experience with traffic behaviour at those locations appears to negatively influence compliance with advice that they disagree with. When drivers have more experience with a route (as it is the case with commuter traffic) non-compliance, due to disagreement with the advice, may become more likely and frequent.

In one case (Time 3:43:4) the participant (approaching location 1) refused to comply with the advice to change to the right lane and kept observing traffic behaviour for signs that confirmed his decision not to comply with the advice. As an argument for non-compliance he had given his own prediction that traffic on the right lane would become congested due to the off-ramp. When he perceived that his non-compliance was not followed by congestion on his lane, as it had been predicted in the information preceding the advice, he regarded this as a confirmation that his non-compliance had indeed been the right choice. It may be argued that the participant responded in his own interest and did not follow an advice that seemed not beneficial for him. However, the advice to change to the right lane is also problematic due to the approaching off-ramp/on-ramp.

In the other case (Time 0:7:52) the participant initially refused to comply, also stating that he expected the target lane to become congested. However, seconds later, as the target lane emptied due to vehicles exiting at the off-ramp, he complied. It appears that his refusal to comply immediately stemmed from the advice being given too early, at a time that the target lane was still crowded with vehicles that would later exit at the off-ramp. When seconds later an opportunity emerged, compliance followed.

In itself a lane change to the right lane, in anticipation of congestion due to an unequal distribution of vehicles over the lanes (the CC/GR advice), may be justified. However, location 1 is difficult to provide an advice for. At this location a lane drop and an on-ramp/off-ramp fall together. On the one side the left lane ends due to a lane drop, on the other side the right lane may become crowded due to traffic exiting at the off-ramp. Normally, when approaching only a lane drop, vehicles are advised to change lanes to the right. In turn, when approaching only an off-ramp, vehicles drivers that do not want to exit at the off-ramp are advised to change lanes to the left. In situations where these two locations fall together it may be difficult to provide an optimal advice. Therefore, the participant's decision to wait for traffic exiting the off-ramp before changing to the right lane to make room for vehicles merging from the left lane is understandable. the participants may have refused to comply due to the expected a disadvantage from immediate compliance. However, also from a traffic flow efficiency standpoint, immediate compliance, by merging into the vehicle stream that was about to exit at the off-ramp, would not be desirable.

11.4.1.4 Advice: Dense on-ramp / Go to the right lane (DO/GR)

This advice has been given several times while participants approached location 1. In this situation the word "on-ramp" confused participants. The road layout at that location shows that first the off-ramp is visible, followed by the lane-drop and the on-ramp is the last element. Only the lane-drop is shown on the road-side message boards. Participants approaching the lane drop may not expect an advice about an on-ramp. The fact that, according to the advice strategy, the advice (i.e. go to the right lane) that followed the information was indeed about the upcoming lane drop, is even more confusing. Here the motivation should match the advice, to avoid refusal to comply due to the argument that merging to the right before an on-ramp is ineffective behaviour (as seen in Time 0:14:58).

The low compliance rate (i.e. two out of seven) following the advice was due to the fact that that in four occasions, participants had already carried out a lane change from the middle to the right lane short before the advice had been given. In two other cases participants had already been driving on the right lane for a an extended time. The "adapt speed to the right lane" advice that preceded the "go to the right lane" advice played a certain role by triggering an early lane change. Therefore, these two advice messages should be combined. For vehicles, that only receive an 'adapt speed' advice (i.e. on the left lane approaching a lane drop), the timing may need to be adapted, in anticipation that the advice may likely trigger a subsequent lane change.

In two more occasions (Time 1:22:12; 2:46:22) participants did not verbally disagree with the advice and complied short after the advice had been given. However again the behaviour of other traffic was monitored by the participants to check the relevance of the advice after they had complied. And again an evaluation of the advice was determined by the beneficial effect compliance had for the participant. Here the participant assumed that she misunderstood the advice as it did not improve her situation.

11.4.1.5 Advice: Dense on-ramp / Adapt to speed of the right lane (DO/ASR)

With three of four participants the "adapt speed" advice also triggered a lane change. A similar outcome had already been observed in experiments in the driving simulator. In the simulator participants changed from the right lane to the left lane of a two lane motorway, approaching an on-ramp. In the present study participants received the advice on the left of three lanes, that was about to end. In both cases the resulting speed differences with vehicles on the same lane may be the reason for the premature lane change. In most cases, drivers on the left lane, who adapt their speed to the middle lane, will have to slow down. However, while they remain on the left lane, the reduced speed could lead to irritation among the other drivers behind them on that lane. To avoid this a lane change to the right is carried out. Another explanation may be that drivers habitually connect the speed adjustment to another lane with a lane change manoeuvre. Therefore, an "adjust speed to the right lane" advice is interpreted as a prompt to change lanes to the right.

In this case, the motivation of a dense on-ramp approaching, can be confusing. This advice was exclusively given to participants on the left lane, approaching the lane drop. Therefore, the information that a dense on-ramp is approaching may not be a convincing motivation to adapt the speed to the right lane before merging to the middle lane. A different motivation for these drivers may be, for instance, that the left lane ends or the distance that is left before the lane drop.

To avoid a premature lane change, the advice message may prompt drivers to "adapt your speed before merging". Instead of initiating the speed adjustment process with the advice, this alternative would merely remind drivers to adjust their speed before merging.

11.4.1.6 Advice: Dense on-ramp / Go to the middle lane (DO/GM)

This advice was given only once during the study, and it appeared misplaced in several ways. First, there was no middle lane that the participant who received the advice could have possibly changed to. Second, a lane change from the left lane (where the participant was driving) to the right lane would lead to a higher demand on the right lane were vehicles from the on-ramp would merge onto. Normally, the advice should reduce the demand on the right lane in order to create room for vehicles from the on-ramp. Participants had been familiarized with the possible advice messages before the study. However, this participant did not remark the anything about the suitability of the advice message in this situation. First he seemed confused about the lack of a middle lane, still, he changed to the right lane. Then, the sudden appearance of the off-ramp restored his faith in the correctness of the advice. That an on-ramp, instead of an off-ramp, is mentioned in the motivation of the advice is not remarked.

11.4.2 **Requests for information and/or advice**

A visualisation of the positions where advice messages are given in the test area (Appendix F.4) show distinct regions where certain advice messages are predominantly given. Compared to this, the locations of requests for information and advice emerges in a scattered, more chaotic pattern (Appendix F.5). Rather than triggered by a particular physical bottleneck, the requests seems more event driven. This means that participants experienced a certain event and remarked that they would have valued information or advice beforehand. Participants were experienced with the test area so they also anticipated on the development of traffic behaviour around the two prominent locations (1 and 2) and requested information or advice on how to approach these situations in an optimal way.

Often participants were caught in congestion while approaching location 1 (lane-drop, off-ramp combination). Although they were able to see signs of approaching congestion by looking ahead and noticing the flashing of matrix signs and braking lights, they also requested to be informed about the approaching congestion by the system.

Providing this information before drivers are able to perceive the emergence of congestion themselves may not necessarily benefit congestion mitigation but may strengthen participants' trust in the system. It provides a way to demonstrate that the system can provide information before it is perceived by the driver. This would mean that information is not only provided by the system as a motivation for an advice, but also in situations where it is desired by a driver. This is further supported by a study by van Driel and van Arem (2005). The study shows that drivers express a need for information about upcoming traffic conditions on motorways. Therefore, additional information about upcoming traffic situations may also improve the systems penetration rate by providing drivers a benefit if they switch on the system during driving. The system might also augment the information that drivers already perceive. For example, this extra information would include information about the cause of congestion, in case that this is known. Alternatively, the information about could be provided only when drivers are requesting it (e.g. pressing a button to know the size of a traffic jam). This would put the control over whether or not to receive information into the hands of drivers and reduce the likelihood of being perceived as a nuisance.

11.4.3 **User interface**

Participants remarked sparsely about the icons used in the motivation of and advice. Some participants stated that they would not notice the icons and were mainly listening to the audio messages. This may be considered a desirable result as the icons are not meant to capture the attention of the driver, but rather support the audio messages.

11.4.4 **Acceptance**

The acceptance score depicts the average perceived usefulness and satisfaction in a situation with a very low penetration rate of the CIVA system. In the previous experiment, additional information about the advice strategy had mitigated a reduction in usefulness and satisfaction ratings after experience with the system in the driving simulator. In this study all drivers received the same information. After experiencing the system in real traffic, usefulness ratings were reduced while satisfaction ratings did not change significantly. Participants were free to either refuse or comply with advice. Often they refused to follow the advice (especially lane change advice) that they deemed ineffective or unbeneficial to them. The liberty whether to comply with the advice messages or not may have had a positive effect on the perceived satisfaction with the system. However, this form of selective compliance may reduce the effectiveness of the system when practiced by the majority of equipped users.

11.4.5 **Concluding remarks**

The application of a think aloud protocol proved useful in gaining insights on participants' decision process regarding their compliance with a given advice. Several re-occurring themes were identified in participants' thoughts about the advice messages. Also, requests for advice and information showed what expectations participants had about the information and advice.

Results indicate that, after having received the motivation for an advice, participants found themselves guessing over the accuracy and reliability of the provided information. However, for the participants these qualities were often difficult to verify, using the information that they could directly perceive in the environment, at the moment they received the advice. Especially with information about the imminent end of a traffic jam, drivers were uncertain whether the traffic jam actually dissolved. Over time, cues were found in the behaviour of other traffic or matrix signs that were used to decide whether the information was trustworthy or not.

The majority of participants in the study had experience with the test area. This led to situations where participants disagreed (and refused to comply) with the advice, stating that they had a different opinion about the optimal behaviour in the given situation. Participants would regard the system as a form of driver support that would guide them through dense traffic in the most efficient way. This may have implications for long term acceptance if the system fails to deliver the expected individual benefit.

The behaviour that was shown by participants, indicates a lack of trust in the system. All participants were first time users of the IVA system. This suggests that a proclamation of the expertise of the system, stemming from superior information and logic, may not be enough to win the trust of its user. It may be expected that trust in the system will build up over time, given that there is a low error rate in the predictions made by the system and the advice consistently meets the expectations of drivers.

The system is still in a stadium of development and some of the given advice messages appeared erroneous or inaccurate. Some advice messages were impossible to carry out (e.g.

due to the lack of a middle lane), while sometimes motivations were given that made it difficult to determine the actual reason for an advice. An example would be the information of an approaching on-ramp, while the participants were approaching a lane drop on the left lane and would receive an advice to adjust their speed to the right lane. Although in this situation the advice is correct, the preceding information may confuse participants more than it provides a motivation for compliance. Further improvement of the advice algorithm is necessary to increase the accuracy of the information and the advice. In situations where a certain traffic state development is predicted (e.g. upcoming congestion, end of a traffic jam) the reliability of the information may be improved through adjustments to the prediction algorithm. Reliable information will be an important prerequisite for users to develop trust in the system.

The present study has produced insights into drivers' first impressions of the system. However, further experiences with the system may change the impression that drivers have of CIVA. Further research needs to assess how long term use of the system influences drivers' attitudes toward certain advice messages and the system in general. Individual users may therefore repeatedly evaluate the system several weeks, while using it for the same trips each day. Studying drivers' perception of the effect that the system has in real traffic would be a further step. This requires several test units to create scenarios with different penetration rates in a testing area.

12 General discussion and conclusion

The Cooperative In-Vehicle Advisory (CIVA) system aims to improve suboptimal traffic flow conditions by influencing driver behaviour in peak hour motorway traffic. The approach that is taken with the system is that of microscopic dynamic traffic management (Daamen et al., 2011). Individual drivers are provided with an advice on their driving behaviour that is based on traffic state and floating car data.

The literature contains several examples of road-side as well as in-vehicle systems that provide tactical driver advice in order to improve traffic flow (Hatakenaka et al., 2004; van den Broek, Ploeg, et al., 2011; Xing et al., 2013). CIVA takes a novel approach in that the advice targets different aspects of the driving task (i.e. speed, lane, gap size). The system coordinates advice messages so that some drivers on a lane may receive an advice to change lanes while others receive an advice to stay on the lane and make room for merging vehicles from other lanes. Also, the system dynamically adapts the advice that individual drivers receive based on their current speed, lane and gap size.

When using the system, the control over the vehicle is with the driver at all times. The effect that the CIVA system will have on traffic flow is therefore dependent on the number of drivers that have the system operating at a given moment on a particular road (i.e. the penetration rate) and the amount of advice messages that are followed by those drivers (i.e. the compliance rate).

The objective of the present research was to evaluate design decisions during the development of the CIVA system with regard to their effect on drivers‘ ability and willingness to follow the advice messages and to adopt the system. Basic research questions have been formulated in the beginning of the research:

- Are drivers able to follow CIVA?
- Are drivers willing to follow CIVA?
- Are drivers willing to adopt the CIVA system?

These basic questions have been broken down into related sub-questions, several of which have been posed in the introduction to this thesis and were studied while the system was being developed in a research and development project.

Regarding the design and implementation of the CIVA system, the theoretical and empirical contributions of this research include:

- An assessment of the attitude of potential users towards advisory drivers support that aims to improve traffic flow on motorways. In addition, factors affecting the acceptance of the CIVA system and the willingness to adopt and use the CIVA system are provided.
- Methodological research towards a better understanding of the suitability of mid-range driving simulators to study the choice of inter-vehicle distances.
- Empirical results regarding drivers' response to tactical driver advice in a driving simulator and on a real road. This includes results regarding: (1) Drivers' ability to follow time-gap and distance-gap instructions in a driving simulator and on a real road. (2) The intended and unintended effects that various advice messages have on driver behaviour. (3) Factors that influence drivers' intention to follow a given advice is real world traffic. (4) The effect that exposure to the advice has on the user acceptance of the CIVA system.
- Theoretical considerations regarding the social dilemma that can arise when improving traffic flow through driver advice, and an assessment of drivers' ability to perceive CIVA compliance rates among other road users.

The main findings of this research are now discussed in the light of the three basic research questions.

12.1 Discussion of the main findings and recommendations

In the following section the main findings from these studies will be discussed. The results are summarized under three broader topics regarding (1) drivers' ability to follow cooperative in-vehicle advice, (2) drivers' willingness to follow the cooperative in-vehicle advice and (3) drivers' willingness to adopt the CIVA system.

12.1.1 **Ability of drivers to follow CIVA**

The driving simulator experiments provide insights into the behavioural response of drivers to tactical driver advice. One aim of these experiments was to study drivers' ability to follow given advice messages. This included the ability to perceive, comprehend and carry out the advice. It was assumed that the difficulty to carry out CIVA advice messages would be different for the different advice categories (i.e. lane, speed, gap size). For instance, when attaining a certain speed, drivers are supported by specific speed feedback (by their tachometer), while gap size feedback is commonly not provided by the vehicle. Few studies have assessed drivers' ability to follow gap advice (Taieb-Maimon & Shinar, 2001; Taieb-Maimon, 2007). For these reasons the first driving simulator experiment studied drivers' ability to follow specific gap advice messages, while later experiments broadened the focus to gap, speed as well as lane advice messages. In the overview of the results from these experiments each advice category (i.e. gap size, speed and lane) is discussed separately to better illustrate the development of the advice messages from lessons learned during earlier experiments.

Gap advice

In the first experiment (chapter 7), drivers had to respond to specific gap advice messages in relatively stable traffic conditions in a driving simulator (i.e. no lane changes by other vehicles, lead vehicle driving at constant speed). Under these conditions drivers were able to perceive the auditory advice messages and understand the advice, both for advised time gap and distance gap. However, drivers were not able to attain the exact gaps that were advised. Driver support in the form of discrete gap size feedback improved the accuracy of the chosen gap size only when drivers were instructed to decrease their gap size.

In the following experiment (chapter 8) the effects of specific gap advice (as well as lane and speed advice) on driver behaviour were assessed in dynamic traffic conditions in a driving simulator (i.e. lane changes by other vehicles, dynamic speed profiles). In these traffic conditions, drivers were advised to increase their time gap to two seconds in order to make room for merging vehicles in anticipation of a weaving section. Drivers increased their gap size even when their current gap size at that time was already close to or larger than the target gap size. These results, together with the results from the previous experiment, indicate that drivers are unable to follow specific gap advice with great accuracy in stable as well as more dynamic traffic. Based on these results it was decided to test alternative ways to provide gap advice in future experiments.

In a subsequent experiment (chapter 10), also in dynamic traffic conditions in a driving simulator, less specific gap advice (i.e. "leave room for merging vehicles") was provided to drivers that were driving on the lane to which other vehicles would merge at a lane drop, an on-ramp or a straight motorway location. In response to the advice drivers increased their gap size. The larger gaps were subsequently filled by merging vehicles. After vehicles had merged, gap sizes did not increase any further. The results suggest that less specific advice messages are more suitable to be provided for these type of situations.

For the real road study (chapter 11) with the prototype system it was decided to provide drivers with less specific gap advice. For instance, drivers who were accelerating out of congestion would receive the advice to "attain a short but safe gap size". In the study this advice led to a subsequent reduction in gap size. However, often the gap advice was given as drivers neared the end of one of several successive traffic shock waves. Therefore, it is unclear whether the change in gap size is entirely the product of participants intentionally reducing their gap size. The behaviour of lead vehicles reducing their speed in the emergence of the next shockwave was also leading to a reduction in gap size. Participants' average time gap at the time of the advice was around 1 second. Earlier studies have suggested that a time gap of 1 second may be perceived as "short but safe" by drivers thereby making further adjustments in gap size by the advised participant unnecessary (Ayres et al., 2002; Taieb-Maimon & Shinar, 2001).

In sum, with regard to gap advice the present experiments have shown that drivers are able to correctly perceive and understand the given advice, while the inaccuracy in attained gap size when following specific gap advice reduced the merit of a specific formulation in favour of a less specific formulation. The results show that less specific gap advice can lead to the intended effect on driver behaviour, without requiring the estimation of a specific time or distance gap by drivers, thereby improving drivers' ability to carry out the advice. For the design of the CIVA system it is therefore recommended to provide gap advice not in terms of a target time- or distance gap, but in terms of a target manoeuvre that produces a similar effect.

Supporting the driver in carrying out a gap advice can make the task easier, which may lead to higher compliance rates to the advice even when driver motivation is low (Fogg, 2009). However, the specific gap choice experiment in stable traffic conditions has indicated that in some situations discrete gap size feedback can also reduce the accuracy of the attained gap. As an alternative to discrete gap size feedback the system may provide continuous headway feedback. However, this would introduce another source of information in the vehicle that would compete for a driver's attention. Alternatively, providing an advice that does not require drivers to attain a specific gap size with great accuracy would also make specific gap size feedback obsolete.

The present experiments do not indicate whether the observed gap size adjustment following the advice is sufficient to improve traffic flow efficiency when carried out by a greater number of road users. However, from a user-centred design standpoint it is recommended to assess and further optimize the effect of less specific advice messages on traffic flow.

Lane advice

It was decided not to substantially change the formulation of lane advice messages in the course of the research project. Early in the project is was decided that drivers would not be required to change lanes more than once with a single advice. In the first experiment that included a lane advice (chapter 8), the formulation of the message was "Change lanes to the right/left" depending on the target lane. The behavioural response to a lane advice was assessed experimentally in dynamic traffic conditions in a driving simulator. Results show that in general drivers were able to follow the lane change advice, changing lanes shortly after the advice had been given.

When following a lane advice drivers appeared to change lanes as they would normally do with the exception that the decision to change lanes was triggered by the advice. As an indicator of potential dangerous and annoying driving behaviour, accepted gap sizes (between vehicles on the target lane) were compared between lane changes with and without lane change advice. Accepted gap sizes in the advised trials were not shorter compared to unadvised trials, where drivers could change lanes whenever they felt it was appropriate to do so.

However, when drivers had to change lanes in dense traffic conditions to a faster driving left lane (as this was the case at the on-ramp location) it was observed that they would occasionally wait for several vehicles to pass before a larger gap appeared on the target lane. Vehicles on the target lane were driving at a faster speed (approximately 15-25 km faster) with gap sizes around 2 seconds (between vehicles on the adjacent target lane) before the larger gap appeared. The combination of speed difference to the target lane and gap size on the target lane that was accepted varied between drivers. While some drivers in this situation were changing lanes soon after the advice, others were waiting for a larger gap to appear. It may therefore be assumed that drivers, who waited, would have been able to change lanes earlier, but decided to wait. Therefore, this can be regarded as lack of perceived opportunity by drivers (rather than inability) to change lanes.

In the next experiment (chapter 10) the formulation of the advice was to change to a specific lane (e.g. “Change to the right lane”). This change in advice formulation was chosen to better fit the preceding message to adjust the speed to the speed of the target lane. It was assumed that the change in formulation would not affect drivers’ ability to perceive, comprehend or carry out the advice. Driving behaviour parameters showed no difference in the behavioural response to this formulation compared to the previous formulation (to change lanes to the left or right). Participants changed lanes shortly after the advice had been given. In half of the unadvised trials participants did not change lanes. This indicates that although participants were able to carry out a lane change, often they had no urge to do so, when not prompted by an advice.

For the on-road study (chapter 11) the advice message remained in the form that was used in the last experiment (i.e. “Change to the right/middle/left lane). During the study, the verbal response of a participant, driving on the left of three lanes and having received an advice to change to the right lane, showed that she was confused whether to change to the adjacent right lane (the middle lane) or the right lane of the motorway. This confusion could have been avoided if the participant would have been informed that the system would only advise single lane changes. On the other hand, it appears that in these cases the initial advice formulation to “change lanes to the right” would be less ambiguous.

In sum, it has been demonstrated that drivers are able to follow lane change advice within a short time after the advice is given, provided that they perceive an opportunity to do so. While compliance to the advice is important to have an effect on traffic flow, it can be argued that a driver, who is willing to change lanes but perceives no opportunity to do so, should not be further urged to carry out the lane change (for instance, by repeating the advice message). At this moment the CIVA system does not have the capability to check whether a lane change can be carried out safely, this task is still with the driver. Therefore, the system should respect when a driver hesitates to carry out the advice because he/she feels that compliance may lead to an unsafe situation. In the future the system may even adapt to drivers' preferences about safe and unsafe driving manoeuvres. For instance, the system may receive driver feedback when compliance to a given advice is perceived as causing an unsafe situation. Alternatively, the system may gather data about a driver's driving style and adapt its advice messages accordingly.

Speed advice

In the present experiments, speed advice was given to reduce the difference in the speed of a vehicle to the speed of vehicles on the target lane before a lane change. For the first experiment involving speed advice (chapter 8), it was decided not to present the speed advice as a specific target speed in kilometres per hour. Due to constant fluctuations in the speed of the lead vehicle or traffic on other lanes, attaining and maintaining a fixed speed would be difficult for driver to carry out and in addition could lead to dangerous situations. Instead, the speed advice consisted of an advice to adapt one's speed to the speed of the target lane before merging into an adjacent lane.

In the experiment it was observed that, in response to the advice, drivers carried out a speed adjustment in the direction of the speed on the target lane. At the lane drop location participants reduced their speed on average by 8 km/h, while at the on-ramp location they increased their speed by about 8 km/h. However, despite the speed adjustment, participants did not attain the exact speed of the vehicles on the target lane. Despite an increase in speed at the on-ramp location, at the time of the lane change participants were still driving slower (8-13 km/h) than the average speed on the target lane. At the lane drop location, participants were also driving slower (0-4 km/h) than the average speed on the target lane.

These results show that drivers are able to adjust their speed in the direction of the average speed on the target lane. However, they may not attain the exact speed of the adjacent lane before a lane change. There was no specific target speed advised, so drivers had to estimate the speed on the target lane in order to adjust their speed accordingly. The lack of accuracy may be the result of estimation errors in the speed on the target lane. On the other hand drivers may have felt that the speed adjustment would be sufficient in order to change lanes.

In the experiment no difference was found between advised and unadvised drivers for the speed difference relative to the target lane at the time of the lane change. Regarding that merging with speed differences was among the top ten annoyances in the survey in chapter 5, this could indicate that drivers in the experiment showed desirable driving behaviour due to the fact that their behaviour was monitored. Therefore, in the relative anonymity of real world traffic their driving behaviour might still be different. Despite the lack of a difference between advised and unadvised drivers, it is recommended to provide the speed advice before merging to make drivers more attentive to the speed differences before a lane change.

Combinations of advice messages

In the driving simulator as well as on the real road, several drivers who had received an 'adjust speed' advice tended to carry out a (premature) lane change before an advice to change lanes was given. The literature on audio messages argues that messages should be kept short in order not to distract the driver and avoid forgetting of (part) of the message (Spence & Ho, 2008; Wickens & Hollands, 1999). The pause between the two related advice messages had been intentionally designed to reduce the size of the message and to allow the driver to execute one advice before another advice is given. However, the results suggest that in case of related advice messages (e.g. speed and lane change advice) the separation of the advice messages can lead to the premature execution of lane changes and make the following advice message inappropriate. In situations where drivers changed lanes just before the actual lane change advice is given, these drivers may feel urged to change lanes another time.

No increase in self-reported workload was observed and drivers did not forget to change lanes when the advice was given in combination. It may therefore be recommended to provide such related advice messages without a pause in order to avoid confusion due to premature lane changes before a lane change advice has been given.

Safety of advice execution

In the simulator experiments, accepted gap sizes (between vehicles on the adjacent target lanes), gap sizes to a lead vehicle (on the same lane) as well as speed differences at the time of a lane change showed no signs that drivers were engaging in risky driving manoeuvres when following advice messages. An exception may be the "short but safe" gap advice in the real road study (chapter 11). On average, two minutes after following the advice, drivers had a gap size close to 0.5 seconds. While this may be considered an unsafe following gap it can be seen that, two minutes before the advice, drivers were already driving at a similar gap size.

The intended effect of the short but safe gap advice is to reduce the size of gaps that develop at the head of a traffic jam when vehicles speed up. Advising vehicles to keep a small gap to the lead vehicle could improve the rate at which vehicles exit the traffic jam and thereby reduce the duration of the traffic jam (Vergeest & van Arem, 2012). From a traffic flow standpoint it is argued that a gap size close to one second (i.e. 1.2s) should be advised as this is regarded as a small gap size while still being accepted by drivers (Schakel & van Arem, 2014). The intention was that the short but safe gap advice would lead drivers to maintain such a short but acceptable gap without requiring them to estimate a specific gap size. However, the gaps below 1 second, that have been observed in the on-road study are below the intended gap size.

When driving in successive shockwaves the chance for dangerous situations increases with smaller gap sizes. Verbal response data also show that some drivers regarded the advice to keep a short gap size as inappropriate when it is not clear whether the end of a traffic jam has actually been reached or whether it is the head of one of several shockwaves. While it may be important that drivers avoid to let the gap to the lead vehicle widen when they exit the traffic jam, results have shown that it may not be necessary to advise them a short gap size. As an alternative to advising a short gap size, making drivers more attentive of the acceleration of leading vehicles and instructing them not to leave large gaps may already have a beneficial effect while reducing the occurrence of gap sizes below 1 second.

Results from one of the first driving simulator experiment in dynamic traffic conditions (chapter 8) show no increase in self-reported mental workload when following advice messages in comparison to unadvised driving. This may be regarded as a positive sign for acceptance as the advice is not perceived as requiring large amounts of additional effort.

12.1.2 **Willingness of drivers to follow CIVA**

In the driving simulator experiments, participants were instructed to follow each given advice message regardless of their own judgement on whether or not it was an advice that they were willing to follow. This allowed for a better comparison of driving behaviour with and without advice during analysis. However, in reality there is no guarantee that drivers are willing to follow each advice that the system provides. The real-road experiment (chapter 11) assessed factors that can influence drivers' willingness to comply with an advice. Participants in the experiment were asked to respond verbally to advice messages that were generated by the CIVA advice algorithm and to follow the advice at will. Especially, reasons that would be given for non-compliance with an advice provide important clues how to improve the future compliance rate.

It has been shown that dynamic speed limits, that are perceived as "illogical" by drivers, are less likely to be complied with (Burgmeijer et al., 2010). Here the perceived lack of logic may be interpreted as a lack of understanding (on the driver's side) of the reasons why the speed limit had been triggered in a particular situation. It was assumed that improved comprehension for the reason for an advice could improve the compliance rate with the advice messages. In the last driving simulator experiment (chapter 9) participants received additional information about the advice strategy before the experiment. Participants that had received the information reported to comprehend the reason behind a advice message more often. Although this does not guarantee that actual comprehension of the advice was improved as well, drivers who had received the information had a more favourable attitude towards the advice after having experienced it in the driving simulator. A driver's impression to better understand the reason for an advice may be sufficient to improve the attitude towards the system and with it future compliance to the advice. Based on this result, it was decided to also provide drivers in the real road experiment with additional information about the advice strategy.

In addition, drivers in the real road experiment (chapter 11) received information about upcoming traffic situations that served as a motivation for the following advice message. Initially, participants remained sceptical about the reliability of the information and tried to validate it with other information that they had accessible at that time (e.g. behaviour of other traffic, variable message signs). However, this information was often not sufficient to immediately validate the information that was given by the system. This shows that the information that the system provides can have an added value for drivers by providing them with extra information that they would otherwise not have. Past research has shown that drivers want to know the reason for a given advice and information on downstream traffic conditions is something that drivers value (Happee et al., 2011; van Driel & van Arem, 2005). Results from this study support that finding. On the other hand, drivers' attempts to validate the reliability of the information shows that a certain amount of trust in the system is required to accept the motivation for an advice. In situations where drivers noticed the emergence of congestion, without having been warned beforehand by the system, they argued that the system should have warned them about the approaching congestion. These results show that in general drivers value additional information about an upcoming traffic situation but also express a desire for that information to be reliable. Especially in the early stages of system use drivers may be sensitive to faulty predictions of traffic situations (false positives as well as false negatives).

Trust in the accuracy and reliability of the provided information can also affect drivers' compliance with the advice. An example is the information that a traffic jam would end, followed by the advice to keep a short but safe gap. During the experiment, the traffic state prediction algorithm detected successive shockwaves as individual traffic jams. As drivers followed the advice they observed that a new shockwave approached shortly after having received the advice. This can lead to a loss of trust in the information and a decreased willingness to follow the advice in the future.

Although the motivation for the advice was not trusted immediately and occasionally proved to be unreliable it is recommended to improve it rather than remove it from the system. The prediction algorithms should be further improved to provide information that is reliable and regarded by drivers as a valid reason for the given advice. This include for instance a more accurate prediction whether shockwave that ends is followed by another shockwave.

Drivers in the experiment mainly refused to comply to lane change advice. The main reason that was given by drivers for not following a given advice was the belief that the advised manoeuvre would not improve the current situation. Drivers would reference their familiarity with that specific road section to support their view. Participants in the study were experienced with driving in the test area, since this was a public road and the main road between Rotterdam and Gouda. Drivers with less familiarity of the road may have not yet developed such rule based behaviour and may therefore be more susceptible for the advice. However, since the system is intended to be used by commuting traffic this can be a problem for compliance.

In the study drivers who refused to comply to a given advice also looked for signs that would render their decision right or wrong. They would feel supported in their decision when traffic flow did not deteriorate as a response to their non-compliance. This shows that the outcome of compliance (or in this case non-compliance) plays an important role in drivers' evaluation of an advice. However, in an earlier simulator experiment (chapter 10) participants perceived the effect of compliance to the advice as predominantly disadvantageous for them. This may be the result of a lack of a directly observable benefit as a result of compliance.

When the effect of compliance to a certain advice is repeatedly perceived as disadvantageous, over time the willingness of drivers to follow the advice may diminish. Furthermore, the lack of an observable negative effect for non-compliance may strengthen drivers' beliefs that no harm has been done by refusing to follow a given advice. The result may be a selective following of only those advice messages whose outcome is seen as beneficial.

The examples above shown that direct feedback mechanisms (such as observations of traffic) can mislead drivers by providing on the one hand the impression of a lack of beneficial effect when following the advice as well as a lack of detrimental effect as a result of non-compliance. It appears that an understanding of the effect that driver behaviour has on traffic flow (positive as well as negative) must be an essential part of the information that driver are aware of in order to appraise the effects that (non-)compliance to the advice can have. Furthermore, an awareness that compliance to an advice may rarely have a beneficial effect for the driver who is complying to the advice will also be essential. Otherwise drivers may use the system under the false impression that they should gain an direct advantage from compliance with the advice, and refuse to comply with advice messages that do not appear to provide said benefit.

When drivers are aware that the beneficial effect that anyone can gain from compliance to the system is mainly indirect through the compliance of other road users, the (perceived) compliance of other road users to CIVA advice becomes an important factor to influence drivers' willingness to comply themselves. A low perceived compliance may demotivate drivers to contribute themselves.

In the last driving simulator experiment drivers were confronted with different simulated CIVA compliance rates among other road users. Participants' estimates of the simulated compliance rates included high as well as low ratings, although in general these ratings had a low correlation with the simulated compliance rates. However, this result suggests that drivers perceived signs that signalled to them an increased or decreased compliance rate. Surprisingly, participants that had received additional information about the CIVA system perceived overall compliance to be lower than participants that had received no information.

The knowledge that a weak individual benefit may be gained by following the advice can also influence drivers' willingness to adopt the CIVA system. It can be argued that there is an overlap in the factors that influence compliance to the advice and adoption of the system. This will be discussed in the following section.

In sum, while the presented experiments suggest that drivers are able to follow the provided advice messages, these studies also show that drivers sometimes lack the willingness to follow certain advice messages. The reasons that drivers have given for their non-compliance include: their experience with regard to the behaviour of traffic in the situation and doubts about the effectiveness of the advised behaviour to improve the situation. Efforts for improving future compliance with the advice may therefore focus on building of trust that the system does have an accurate representation of the situation and that compliance actually improves the situation in case of higher penetration rates. Also, the perception of the effect that compliance to an advice has on a driver's own situation may be improved by better understanding of what situations are perceived as disadvantageous. Advice messages that have a higher potential of leading to disadvantageous outcomes should be balanced among all users of the system.

12.1.3 **Willingness of drivers to adopt the CIVA system**

The survey among potential CIVA users (chapter 5) shows drivers' level of annoyance with the driving behaviour of other road users. The results suggest that there may be a general need for systems to improve tactical driving behaviour on motorways. In the following section results will be discussed that can indicate whether drivers would be willing to adopt a system that aims to influence their own driving behaviour in order to improve traffic behaviour.

The willingness of drivers to adopt the CIVA system can be divided into the willingness to obtain the system, to have it operating during trips as well as to keep using the system in the future. As indicators of the willingness to obtain the system this research assessed: the acceptance of CIVA based on a description of the system goal and approach, purchase propensity of potential users as well as the level of agreement with the advice strategy. Indicators for the willingness to use the system in the future were participants' acceptance of the system after experience with it. Furthermore, an evaluation of the systems effectiveness in improving traffic flow effectiveness would also be an important indicator for the willingness to adopt the system. However, this was not studied due to the preliminary state of the system.

Based on a description of the system participants in the last driving simulator experiment had a favourable attitude towards cooperative in-vehicle advice to improve traffic flow on motorways, indicated by moderately positive acceptance ratings. It was also shown that participants, who had been given additional information about the advice strategy, regarded it as an effective approach for improving traffic flow in the lane drop, on-ramp and weaving section. Willingness to purchase the system was moderate to low while participants were willing to obtain the system however were not willing to pay for it.

Acceptance ratings of the system as well as willingness to purchase the system reduced after experience with the advice in a driving simulator. For participants who had received additional information about the advice strategy, acceptance ratings remained constant after experience with the advice in the driving simulator, however purchase propensity was still reduced. It is unclear why the difference in acceptance after use is not reflected in the willingness to purchase the system. What is noteworthy, however, is that the willingness to use the system when it is free of charge remains stable from before to after use. This would reflect the attitude that a system that is beneficial for the collective of road users should not be paid for by individual drivers.

In the real road study, participants received the same additional information about the advice strategy as in the driving simulator experiment. However, in this study acceptance after experience with the system was reduced (compared to acceptance ratings before experience with the system in real traffic) despite the additional information.

The factors (shown in chapter 5) that can influence the adoption or rejection of the CIVA system illustrate what users demand from the system. These factors may be used to explain why acceptance of CIVA is lower after experience with the system and provide directions for improving acceptance in the future.

A factor that was important to potential users was that a noticeable benefit is created by using the system. However, at the time of the research the system was still in an early stage of development and due to the use of a single in-vehicle unit there was no effect on traffic flow. A lack of a beneficial effect may therefore be a reason why system acceptance decreased after experience with it.

This raises the question whether use of the system will have any beneficial effect that can be noticed by drivers using the system. In this research it could not be clarified whether an individual benefit may be gained by following the advice. However, it was observed that participants perceived to have a disadvantage rather than an advantage from compliance to an advice. The perceived ratio of perceived advantage to disadvantage from compliance was not affected by additional information about the advice strategy.

Individual users may rate a perceived (dis-)advantage from compliance to the advice as less important, provided that compliance to the system by several equipped drivers does indeed create a beneficial effect for the traffic situation (in contrast to what is commonly experienced on a road). Therefore it is important that the system will indeed have a beneficial effect on traffic flow efficiency.

Traffic simulations have shown that sometimes compliance to the advice at lower penetration rates may lack a beneficial effect on traffic flow efficiency and that negative side effects (such as the temporary oversaturation of a lanes or spillback of congestion from an off-ramp to the motorway) may occur (Schakel & van Arem, 2014). The advice algorithm may be further refined in order to reduce negative side-effects. However, especially in the early phase of a large scale implementation, the system may be used by fewer drivers and penetration rates may be low. Even at this stage, the system will have to provide a benefit for its users in order to build acceptance of the technology. Early adopters of the system will be searching for reasons to keep using the system while potential users will be searching for signs that would justify he use of the system.

Another factor that was important to potential users was the use of the system by a wider population of road users. This indicates that participants in the survey showed an awareness of the interdependence between road users when it comes to traffic flow improvement. Some drivers even requested that the system should be made mandatory in order to use it themselves. In day to day use, drivers may be unwilling to turn on the system themselves (or turn it off) when they perceive the penetration rate of the system or the compliance rate of other road users to be low. However, in an experiment drivers were not able to differentiate between different compliance rates from through observations of traffic behaviour. Ability to estimate overall compliance rate was also not improved by additional information about advice strategy, while on the other hand, additional information reduced the average estimated compliance. It shows that while drivers seem to be aware of the interdependence inherent in traffic flow improvement, they are unable to deduct compliance rates from the observations of traffic behaviour. This apparent inability to perceive compliance may be beneficial for CIVA in case of low penetration rates.

In sum, these issues seem to be related to the absence of a perceived beneficial effect from using the system, rather than related to the usability of the advice or the interface.

That the use of the CIVA system can have an actual beneficial effect of traffic flow efficiency at higher penetration and compliance rates has been demonstrated in traffic flow simulations by Schakel and van Arem (2014). However, the authors also observed a lack of a beneficial effect and negative side effects at low penetration rates.

A lack of an observable beneficial effect may be the greatest hindrance to the adoption of the system and will have implications for a strategy to introduce the CIVA system to potential users. When users do not experience a beneficial effect from using the system (i.e. lack of intrinsic motivation), additional incentives could be provided to justify the use of the system for drivers (i.e. extrinsic motivation). For instance, the system may assess the level of compliance of drivers and provide reward accordingly. However, besides being a cost factor, an extrinsic motivator may have certain disadvantages such as compliance limited to the time that a reward is provided (as shown in chapter 3).

The role of the additional information about upcoming traffic situations may be extended from being purely a motivation for a given advice to a general service system users. Drivers requested information, such as the length or duration of a traffic jam, that would not be used to motivate an advice but that reduced uncertainty about the current situation. Providing such information, even when not followed by an advice, can be of value to drivers and a reason to have the system operating during a trip, thereby increasing penetration rate.

12.2 Discussion of the methodology

Drivers' response to the early concept system has been assessed in driving simulator studies while response to the prototype system was assessed in a real road study. The use of driving simulators allowed for a better control of the environment variables (such as traffic density or the behaviour of other road users), and a more precise assessment of behavioural response parameters to the advice. However, in the driving simulator experiments the advice was not generated by the CIVA algorithm, but was determined in advance. In contrast, the real road study provided a greater diversity and complexity with regard to the surrounding traffic and infrastructure. Furthermore, in the real road study the advice was generated by the advice algorithm in real time, which increased the validity of the timing and content of the advice messages. While the simulator experiments focussed on the potential effect of the system on driver behaviour, the on-road study focussed more on the readiness of the prototype system to be used on a real road.

A single in-vehicle unit of the CIVA system was used in the real road study. Therefore, drivers' perceptions of effects of compliance behaviour on traffic flow could not be assessed experimentally. For this reason the evaluation of the prototype system was focussed on drivers' evaluation of a given advice message in real traffic. Furthermore, the prototype system was tested by participants for a limited number of trips (between 3-5). Therefore, reactions to the system can be described as first impressions. No long term effects of the system on driver behaviour were studied.

The tested prototype was the first implementation of the CIVA system in a vehicle (TRL level 6). Some bugs in the software could not be eliminated and some functionalities were not implemented at the time of the test drives. For instance, lane changes during a trip had to be updated manually in the software. These circumstances may have affected the reliability of the real road study results. However, it is argued that testing the real system in a real traffic environment added to the validity of the obtained results.

12.3 Suggestions for further research

Before the system is studied further with participants it is recommended to improve the traffic state prediction and advice algorithms and carry out a thorough technical evaluation of the system in real traffic. During the technical evaluation it has to be determined in various situations whether the provided advice is indeed the advice that the system should give from a traffic flow improvement standpoint and whether all major technical bugs have been eliminated.

In the short term further research should focus on improving the advice messages in order to elicit safe driving behaviour that can produce the desired effect on traffic flow efficiency. Also drivers' response to the provided information should be studied to properly motivate the advice and provide additional information that may improve drivers' evaluation of the system.

Besides research focussing on improving the system, additional research may also focus on factors that can influence a successful implementation of the system on a large scale. When driver advice is used to improve traffic flow efficiency, no beneficial effect is created when only a small number of road users follows the advice. However, when a certain critical mass follows the advice all road users may benefit from an improved traffic flow. Furthermore, an individual driver's compliance to the advice may be beneficial for the collective road users behind him/her, while the individual driver may not benefit from following the advice. A situation, in which drivers benefit when the system is used by other road users, but do not directly benefit by using the system themselves, can create a temptation to not use the system, possibly leading to a free rider problem (Hardin, 2008).

Furthermore, the situation that is described here may be formalized as a social dilemma (Dawes, 1980). While the literature differentiates different kinds of social dilemma situation (e.g. take some vs. give some; 2 player vs. n-player, one round vs. multiple rounds), further research may determine the sort of the social dilemma that best describes the present situation. Also, research may investigate the influence of characteristics of motorway traffic on behaviour in the social dilemma. For instance, what role plays the anonymity of the individual driver and the lack of reciprocity in traffic, where drivers who benefitted from compliance of other road users are unlikely to return the favour in the future. Several solutions to social dilemma situations have been formulated (for an overview see Kollock, 1998). By formalizing the improvement of traffic flow on motorways as a social dilemma existing approaches to solve social dilemmas may be translated to the present situation.

For instance, the literature on social dilemmas suggests that the personality of road users may play a role in the decision to use the system and to follow advice messages. Social value orientations have been used to explain a person's preference about how to allocate a value between themselves and others (Balliet, Parks, & Joireman, 2009; Van Lange, Vugt, Meertens, & Ruiter, 1998; Van Vugt, Van Lange, & Meertens, 1996). Drivers' social value orientations may also affect how they value a beneficial effect that is created by the system. Drivers that tend to be pro-social may be more willing to help in the creation of a collective benefit for all road users, as long as they equally benefit from it. Drivers with a more individualistic social value orientation may be less willing to use the system when they do not perceive a clear individual benefit from it. Based on this classification it may be recommended to promote the use of the CIVA system among individuals with a pro-social orientation.

Also, more research is needed on the benefit that is provided by the CIVA system. A cost-benefit analysis may be carried out for different stakeholders (e.g. user of the system, traffic management, government agencies). For system users it would include questions such as: Does the effect, that the system creates, lead to an improvement in a variable that users care about (e.g. travel time saving, fuel saving)? Is the effect large enough that it can justify the use of the system for drivers? Is there an additional individual benefit from using the system, that may justify the use of the system for drivers (e.g. additional information)?

Currently, the system does not take over vehicle control from the driver in anyway. However, current vehicles and vehicles that will be manufactured in the coming years are equipped with a number of on-board systems that provide longitudinal and/or lateral driver support. Fogg (1999) argues that drivers who are less motivated to show a certain behaviour may still do so when is easy for them. It would therefore be interesting to study how the parallel use of CIVA and on-board systems changes drivers' ability and willingness to follow the advice. The on-board systems can facilitate the execution of certain advised manoeuvres and therefore may increase compliance rates.

12.4 Concluding remarks

The present research has demonstrated that in general drivers were able to understand and follow tactical driver advice that is aimed at improving traffic flow in motorway traffic. Driver behaviour parameters and self-reported workload for advised compared to unadvised driver behaviour indicate that the system can be used without major negative side effects on traffic safety.

Drivers were willing to follow the advice messages on a real road, while factors that affect drivers' willingness to comply with the advice, such as experience with a road and anticipation of the effect of compliance have been identified. However, for a successful implementation of the CIVA system it is crucial to obtain a better understanding of how the benefit that is created through the use of the system is evaluated by users of the system. Possible identified benefits for the individual driver are travel time saving (given sufficient rates for system penetration and compliance) and real time information on downstream traffic conditions. It needs to be evaluated whether these benefits justify the use of the system and compliance to the advice for drivers. In case of a lack of an intrinsic motivation to use the system an extrinsic motivation may be created by rewarding the use of the system and compliance to the advice by means of extrinsic incentives.

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Appendices

A. User survey

A.1 Frequencies of reported annoyance with other road users' driving behaviour

Annoyance related to…	#
Late and/or aggressive merging at…*	**93**
- Lane drop (3 to 2 lanes)	*45*
- Generic situation	*18*
- Off-ramp	*16*
- On-ramp	*14*
- No or improper "zipper" behaviour	13
Slow driving on the left lane without a cause*	**67**
- Driving left without a cause	*45*
- Slow driving on the left lane	*22*
Tailgating*	**56**
Excessive lane changing in congestion*	**56**
Hindrance with merging at*	**46**
- Lane drop	*17*
- Generic situation	*14*
- On-ramp	*13*
- Off-ramp	*2*
Incorrect or no use of the indicator*	**43**
Early merging at…*	**31**
- On-ramp	*19*
- Lane drop	*11*
- Generic situation	*1*
Merging with speed difference at…*	**28**
- On-ramp (merging with slow speed)	*24*
- Lane drop	*4*
Long-lasting passing manoeuvres by…*	**23**
- Trucks	*15*
- Cars	*8*
Deviating from the general speed limit*	**20**
- Driving slower than the limit	*14*
- Driving faster than the limit	*6*
Keeping too large gaps in a traffic jam	12
"Overtaking" a traffic jam via parking place, tank station, emergency lane…	10
Not keeping a constant speed	7
No light or constant high beam	7
"Cutting in" after overtaking	6
Overtaking on the right	5
Driving on the emergency lane before taking a dense off-ramp	4
Not driving at the overall speed that is driven by everyone	4
Late braking at traffic jam	3
Calling without hands-free	3
Not closing the gap when traffic speeds up at the head of a traffic jam	3
Driver that are busy with other things than driving	3
Changing lanes over more lanes at once	2
Driving on closed-off lanes (Rood kruis rijden)	2
Changing left before an on-ramp to make room for merging vehicles	1

* Included in the Top10 list of annoyances.

A.2 Factors influencing adoption / rejection of the CIVA system

Question 17:

I would use CIVA when…	#
Cost/Benefit oriented	
- it has a beneficial effect (for me/everyone) (on a try/constant)	**32**
- it saves me time / does not cost me time	**7**
- I get compensated financially for using it	**1**
- it does not cost me money	**1**
Penetration/compliance oriented	
- many people are / everyone is using it	**20**
- when its mandatory for everyone and enforced	**9**
Agreement oriented	
- it gives me the reason for a given instruction	**2**
System interaction oriented	
- it is save to use	**1**
- it does not distract me	**1**
- it is usable	**1**
- it integrates with my other support systems (e.g. Navigation aid, CC, ACC)	**2**
Traffic condition oriented	
- in dense (but flowing) traffic	**47**
- in rush-hour	**38**
- there is a bottleneck (accident or road work) down the road	**7**
- in a traffic jam or shockwave	**7**
- there is less traffic on the road	**4**
Situation oriented	
- in bad weather	**11**
- on unfamiliar routes	**6**
- in another specific situation	**3**

Question 18:

I would NOT use CIVA when…	#
Cost/benefit oriented	
- it has no clear beneficial effect	**16**
- it robs me of my autonomy	**6**
- it is expensive	**5**
- following the instruction causes irritation with other road users	**4**
- it extends my travel time	**3**
- I have to change my driving style a lot	**2**
- it threatens my privacy	**2**
Penetration/compliance oriented	
- penetration rate and/or compliance is low	**17**
- it is not mandatory for everyone	**2**
- in the test phase	**1**
Agreement oriented	
- the instruction is in conflict with my perception of the situation	**7**
- it conflicts with my opinion about the best action	**3**
- do not trust the instruction	**3**
System interaction oriented	
- it creates a lot of physical, mental, perceptual load	**3**
- it is unsafe to use	**2**
Traffic condition oriented	
- in free flow / low density traffic	**69**
- in a traffic jam	**4**
- in complex traffic situations	**2**
- in rush-hour	**1**
Situation oriented	
- on familiar routes	**7**
- in bad weather	**4**
- I am in a hurry	**3**

B. Driving simulator validation

B.1 Experimental instructions for the driving simulator validation

The goal of the present experiment is to get a better understanding about the ability drivers to follow time gap advice messages.

During the experiment you will be asked to follow different gap advice messages while driving on the motorway at a certain speed behind another vehicle.

In each of 21 trials you will start at a certain gap size behind the lead vehicle. In the beginning it is your goal to maintain that gap size that you have started with. After some time you will hear an advice message to change your gap size. After the message has played you will adjust your gap size to attain the advised gap size.

The distance from the back-bumper of the leading vehicle to the front-bumper of your vehicle is called distance gap. The time that it takes you to pass (with you front-bumper) a spot on the road that has previously been passed by the back-bumper of the lead vehicle is called time gap.

If you think that you have successfully carried out the advice, you will indicate this to the experimenter. Then you will proceed in maintaining the newly attained gap size as accurate as possible.

During execution of the task parameters such as speed, acceleration, distance to the lead vehicle will be recorded. The data will be stored and reported without any reference to your personal information.

The experiment will take approximately one hour. At first you will have the opportunity to get accustomed to the operation of the vehicle.

In case you wish to abort the experiment you can do so at any time. If you have any remaining questions please ask the experimenter now.

C. Gap choice experiment

C.1 Experimental instructions for the gap choice experiment

The goal of the present experiment is to get a better understanding about the ability drivers to follow time gap advice messages.

During the experiment you will drive in 15 different situations where you will be asked to follow a gap advice. In every trial you will drive on the motorway at a certain speed behind another vehicle. The distance from the back-bumper of the leading vehicle to the front-bumper of your vehicle is called distance gap. The time that it takes you to pass (with you front-bumper) a spot on the road that has previously been passed by the back-bumper of the lead vehicle is called time gap.

In the beginning it is your goal to maintain the gap size that you have started with. After some time you will hear an advice message to change your gap size. After the message has played you will adjust your gap size to attain the advised gap size.

Difference between instructions for distance and time headway condition

Time: It can help to count the seconds until your front-bumper passes the spot that has previously been passed by the lead vehicles back-bumper.

Distance: To attain the advised gap size you could try to estimate the distance between the back-bumper of the lead vehicle and your front bumper.

Additional information only seen in the support condition

Once the advised gap size has been attained, the simulator will indicate this by playing a sound.

If you think that you have successfully carried out the advice, you will indicate this by using the leaver for the high beam. After having used the leaver, try to use to maintain a constant gap size. During execution of the task the driving simulator will record parameters such as speed, acceleration, distance to the lead vehicle. The data will be stored and reported without any reference to your personal information.

The experiment will take approximately one hour. At first you will have the opportunity to get accustomed to the execution of the task in the diving simulator.

In case you wish to abort the experiment you can do so at any time. If you have any remaining questions please ask the experimenter now.

D. Behavioural response experiment

D.1 Experimental instructions for the behavioural response experiment

Currently a new form of driver support is being developed, whose aim it is to improve traffic flow on motorways during rush hours. Unique about the system is that the driver is at all times fully in control of the vehicle. The system merely gives an advice on the optimal speed, headway and lane that the driver should choose to improve traffic flow and throughput. Of course for the success of the system it is required that drivers are able to follow the given advice.

The aim of this experiment is to assess the ability of drivers to carry out the advice on speed, headway and lane use in dense motorway traffic. Furthermore, after experiencing the system in a driving simulator, questionnaires will be used to assess how drivers experienced the system during the experiment.

The experiment consists of 18 trials that are divided into three blocks of six trials. Between the blocks are pauses. During a single trial you will ride in one of three of the following locations:

1. A lane drop from 3 to 2 lanes
2. An on-ramp on a two lane motorway
3. A weaving section of a 3 and a 2 lane motorway

In the weaving section location it is required that you finally drive in the direction to RIDDERKERK.

During driving in the simulator you need to adhere to the road regulations. In your first trial you have the chance to get accustomed to the driving simulator. In some trials you will receive advice messages in the form of audio recordings. We are interested in driver behaviour when carrying out the advice, therefore we ask you to carry out the advice even if you do not agree with the behaviour that is requested in the advice.

It is important that you do not change lanes or increase or decrease your speed and headway before you receive the advice. This is to avoid that there will be a difference between the situation that the advice was developed for and your situation when the advice is administered.

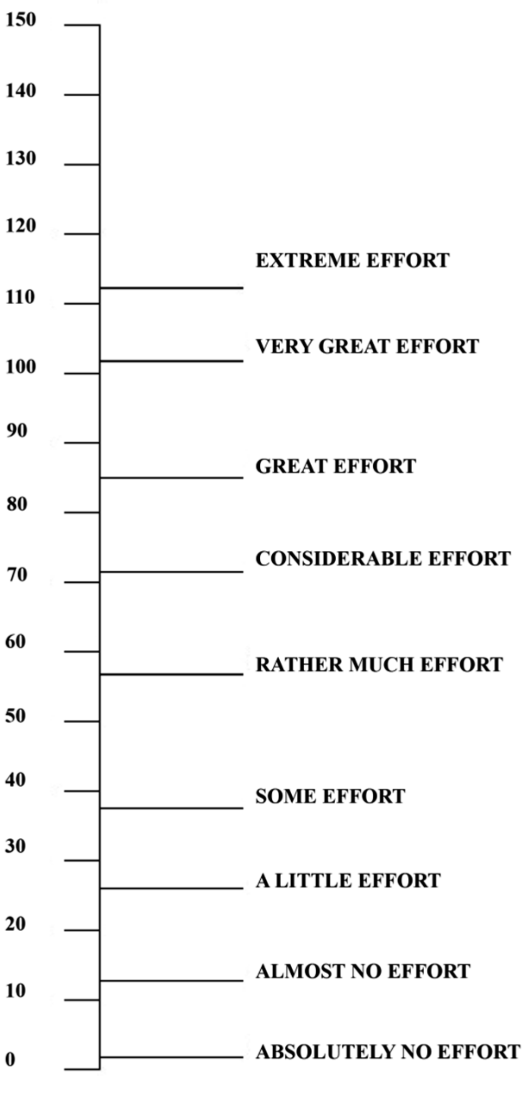
In some trials you will receive no advice. In these trials we ask you to drive as you would normally do. In the beginning of each trial you will be informed whether the current trial includes an advice or not. In case you wish to abort the experiment you can do so at any time.

The data of the experiment will be confidential. In case you have any remaining questions please ask the experimenter now.

D.2 Rating Scale Mental Effort

Rating Scale Mental Effort

Please indicate, by marking the axis below, how much effort it took for you to complete the task you've just finished.



D.3 Questionnaire (Before)

At this moment we are developing a system that can give you advice on the optimal driving lane, speed and headway to choose in order to better distribute traffic on the motorway. As an example, it is known that traffic jams in dense traffic develop later and resolve earlier when everybody adjusts his speed a little. The new system knows the exact state of the traffic situation further down the road and how drivers should adapt their driving to reduce the chance of traffic jams. This may sometimes result in advice that does not work in your individual benefit, yet, when followed, can improve the overall traffic situation. The more people adhere to the advice the higher the chance that traffic flow will improve.

Question 1 - A system that stimulates me to adhere to a particular speed, headway and lane to improve traffic flow on the motorway seems to me…

useful	◯◯◯◯◯	useless
pleasant	◯◯◯◯◯	unpleasant
bad	◯◯◯◯◯	good
nice	◯◯◯◯◯	annoying
effective	◯◯◯◯◯	superfluous
irritating	◯◯◯◯◯	likable
assisting	◯◯◯◯◯	worthless
undesirable	◯◯◯◯◯	desirable
raising alertness	◯◯◯◯◯	sleep-inducing

You have just experienced the system and have an impression of what the advice messages may be.

Question 1 - The system that I have just experienced seems to me…

useful	○○○○○	useless
pleasant	○○○○○	unpleasant
bad	○○○○○	good
nice	○○○○○	annoying
effective	○○○○○	superfluous
irritating	○○○○○	likable
assisting	○○○○○	worthless
undesirable	○○○○○	desirable
raising alertness	○○○○○	sleep-inducing

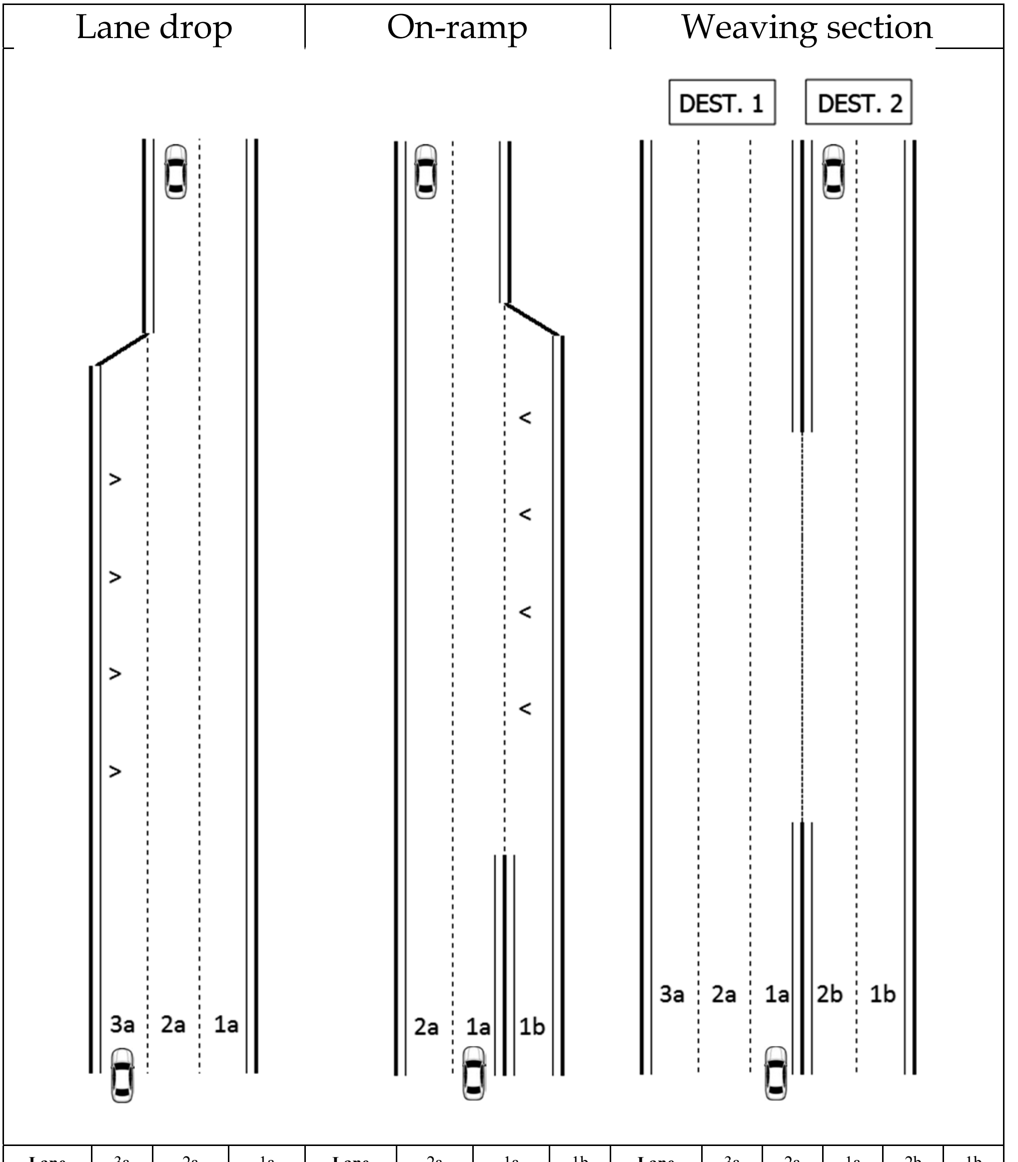
Question 2 - Are you under the impression that in some trials other drivers around you were using the system as well?

○ **Yes**
○ **No**

Question 3 - You have appreciated more information about the situation that you received an advice for?

○ **Yes**
○ **No**

D.5 Locations and starting conditions



Lane	3a	2a	1a	Lane	2a	1a	1b	Lane	3a	2a	1a	2b	1b
Speed [km/h]	120	110	85	**Speed [km/h]**	110	85	85	**Speed [km/h]**	100	90	85	85	85
Density [veh/h]	1500	2400	1700	**Density [veh/h]**	2200	1300	500	**Density [veh/h]**	2000	1800	1900	1800	1800
Trucks [%]	0	0	33	**Trucks [%]**	0	27	10	**Trucks [%]**	0	0	30	0	20

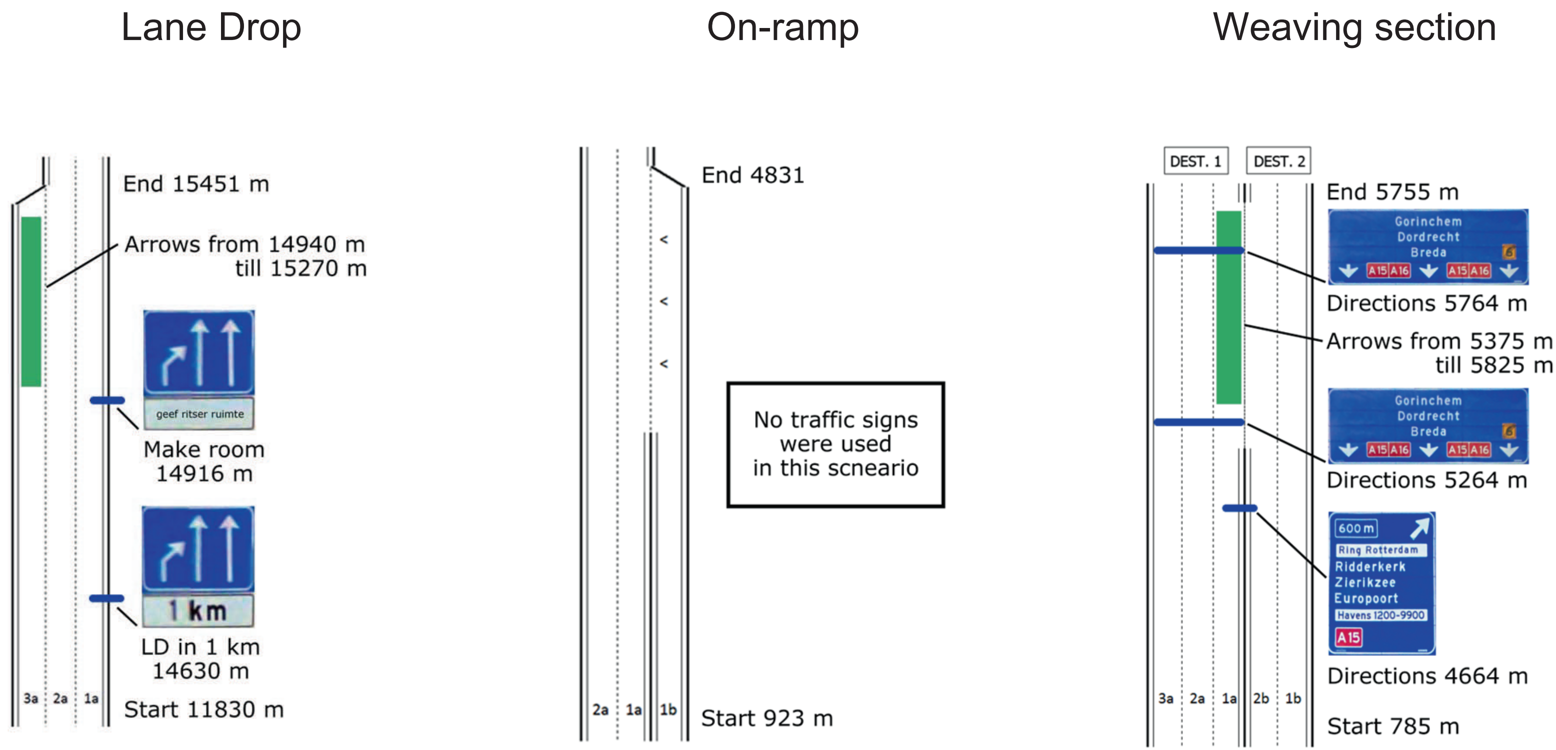
Note. The density values represent the low density condition. For the high density condition these values were doubled.

D.6 Trial list

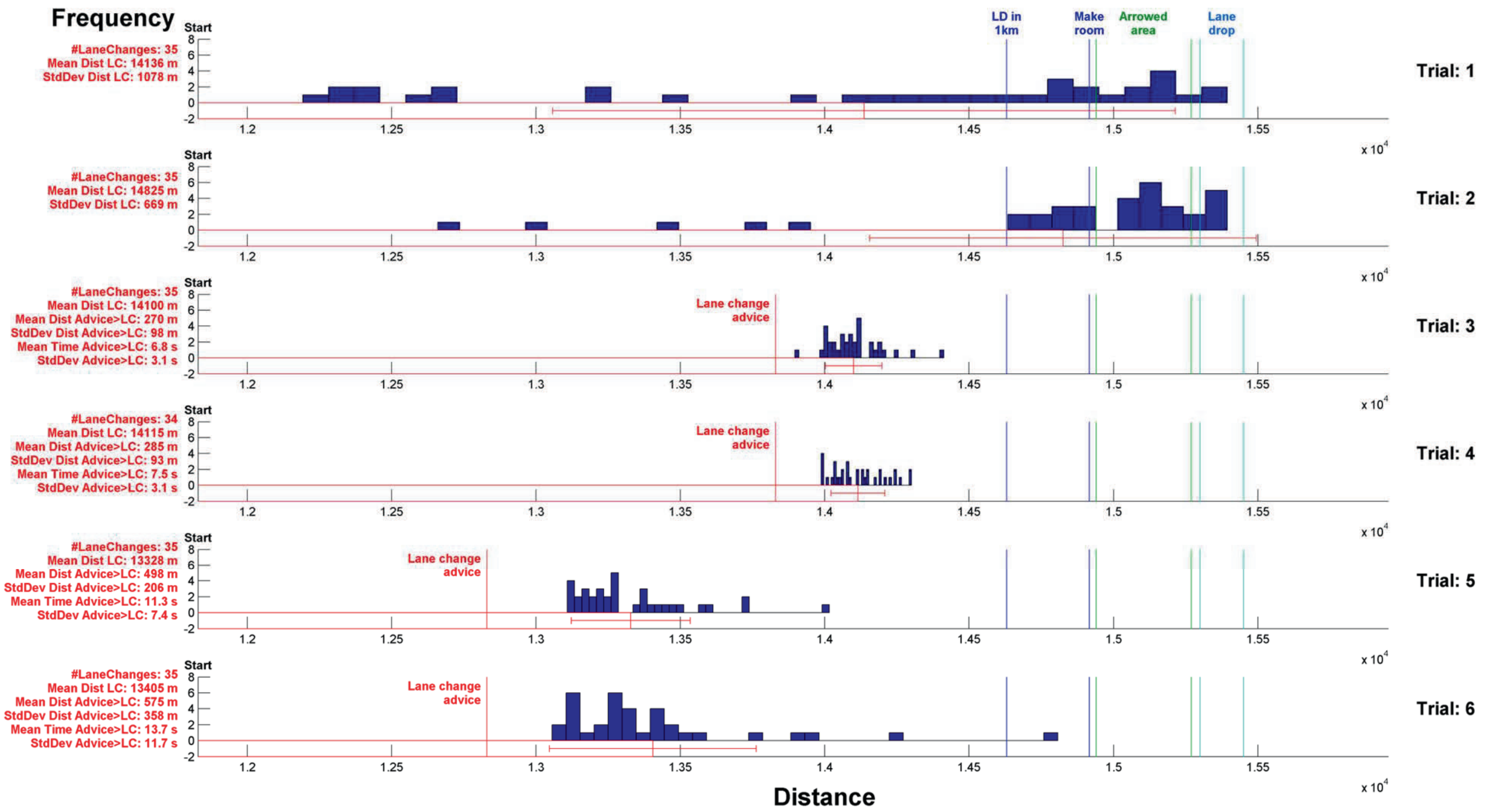
Trial	Location	Advice	Point of first advice	Point of second advice	Traffic density	Starting lane	Lane change
1	Lane drop	No advice	2 km before lane drop	1 km before lane drop	Low density	Left	Right
2	Lane drop	No advice	2 km before lane drop	1 km before lane drop	High density	Left	Right
3	Lane drop	Separate	2 km before lane drop	1 km before lane drop	Low density	Left	Right
4	Lane drop	Separate	2 km before lane drop	1 km before lane drop	High density	Left	Right
5	Lane drop	Combined	2 km before lane drop	1 km before lane drop	Low density	Left	Right
6	Lane drop	Combined	2 km before lane drop	1 km before lane drop	High density	Left	Right
7	On-ramp	No advice	3 km before on-ramp	2 km before on-ramp	Low density	Right	Left
8	On-ramp	No advice	3 km before on-ramp	2 km before on-ramp	High density	Right	Left
9	On-ramp	Separate	3 km before on-ramp	2 km before on-ramp	Low density	Right	Left
10	On-ramp	Separate	3 km before on-ramp	2 km before on-ramp	High density	Right	Left
11	On-ramp	Combined	3 km before on-ramp	2 km before on-ramp	Low density	Right	Left
12	On-ramp	Combined	3 km before on-ramp	2 km before on-ramp	High density	Right	Left
13	Weaving	No advice	3 km before weaving section	2 km before weaving section	Low density	Right	Right
14	Weaving	No advice	3 km before weaving section	2 km before weaving section	High density	Right	Right
15	Weaving	Separate	3 km before weaving section	2 km before weaving section	Low density	Right	Right
16	Weaving	Separate	3 km before weaving section	2 km before weaving section	High density	Right	Right
17	Weaving	Combined	3 km before weaving section	2 km before weaving section	Low density	Right	Right
18	Weaving	Combined	3 km before weaving section	2 km before weaving section	High density	Right	Right

Note. Low density starting conditions in Appendix D.5; High density starting conditions = 2 x low density

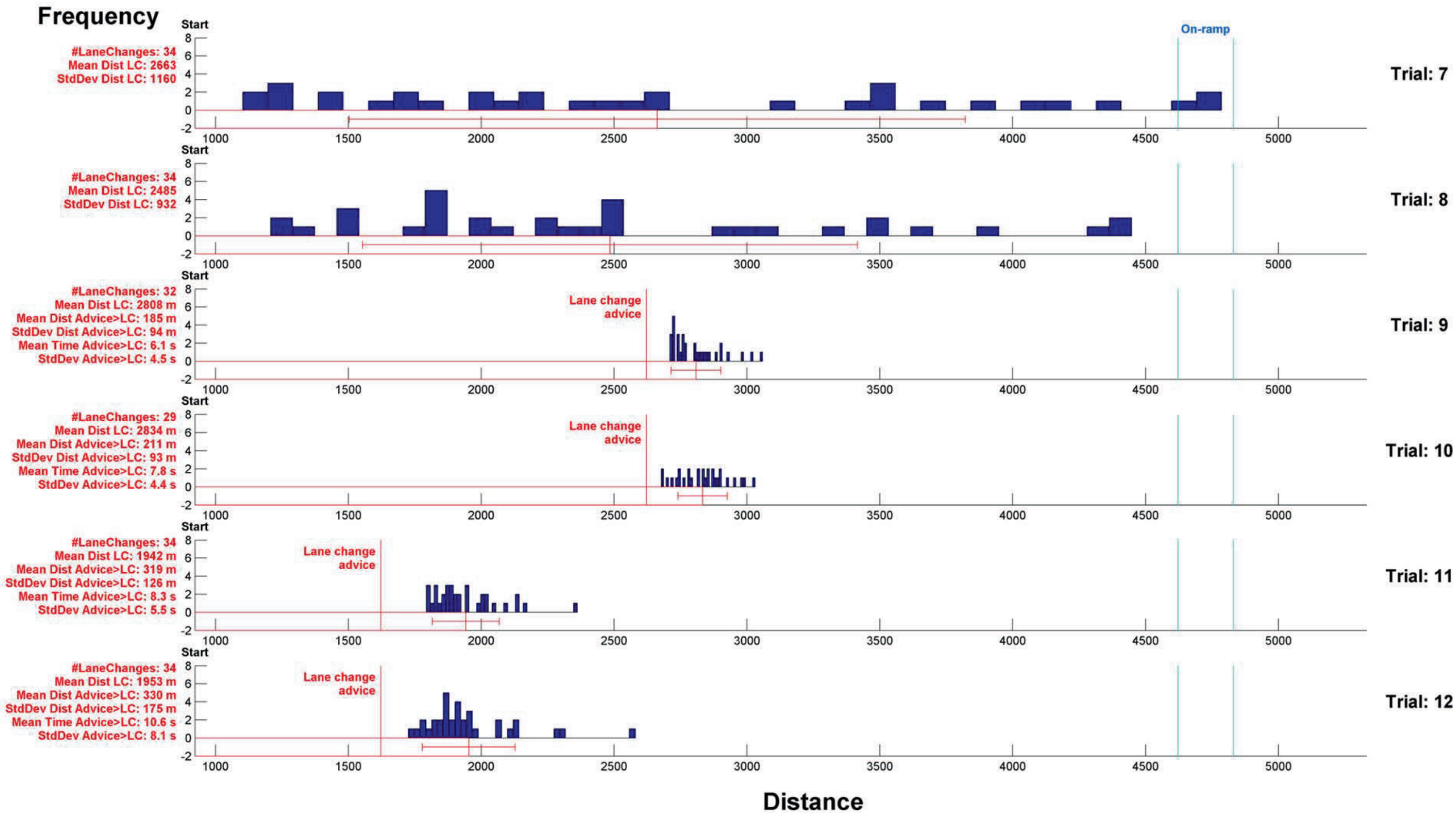
D.7 Distribution of traffic signs at the three locations



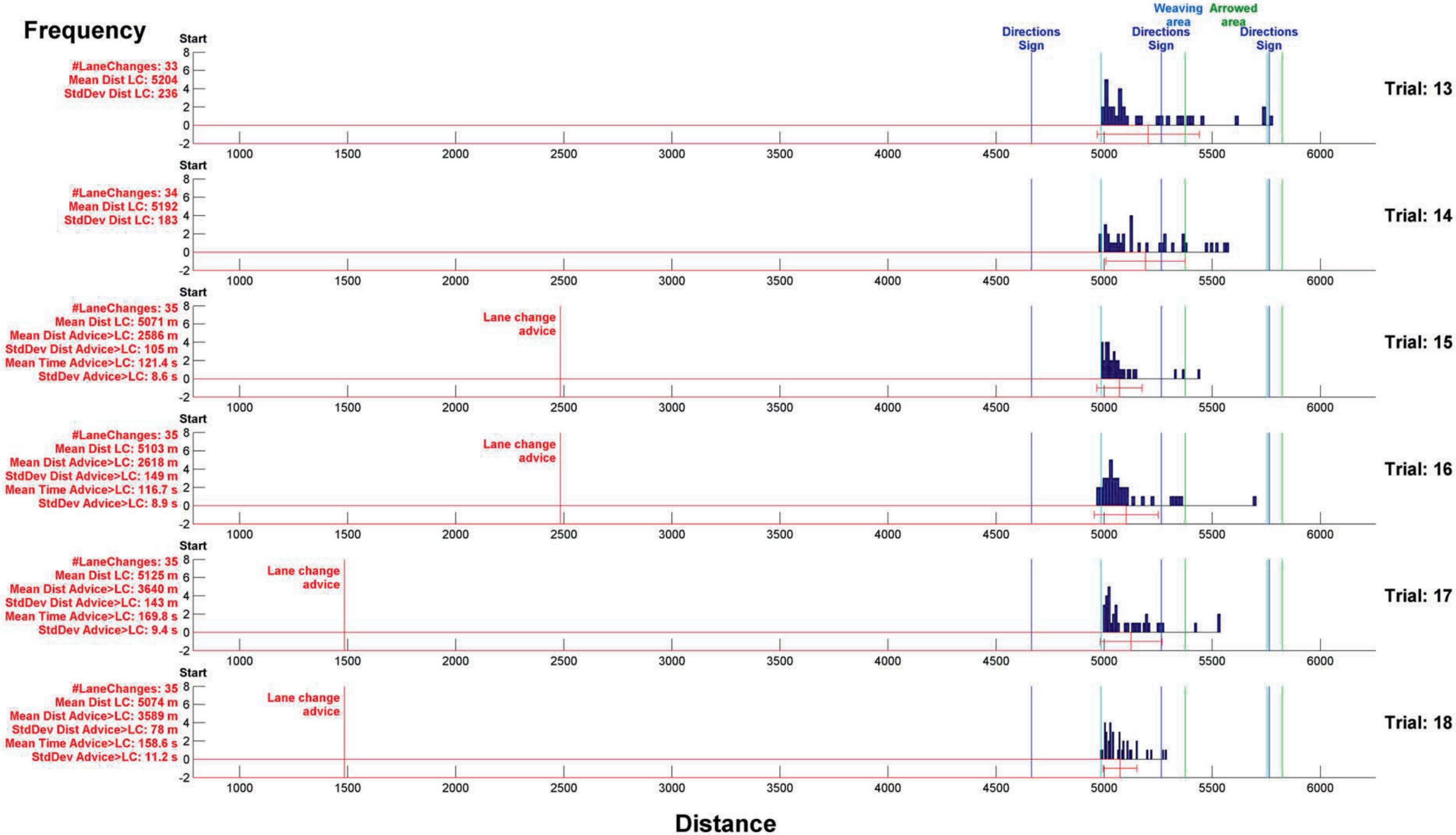
D.8 Lane change distance at LANE DROP



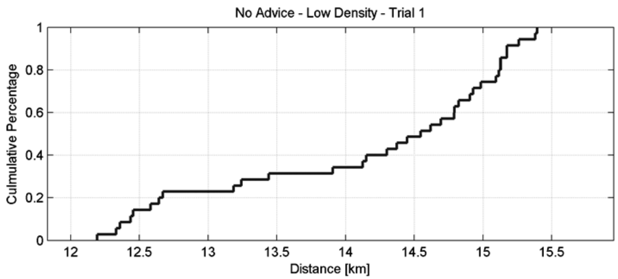
D.8 Lane change distance at ON-RAMP

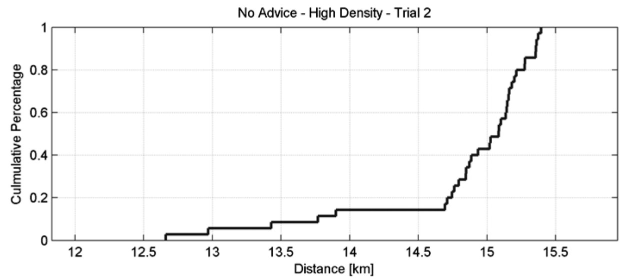


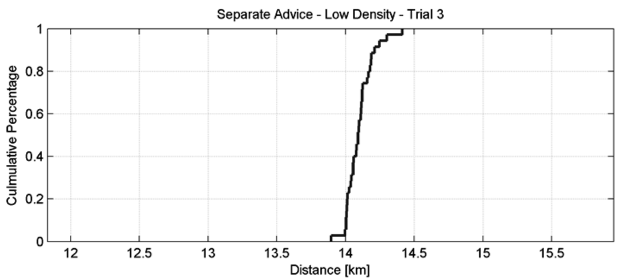
D.8 Lane change distance at WEAVING SECTION

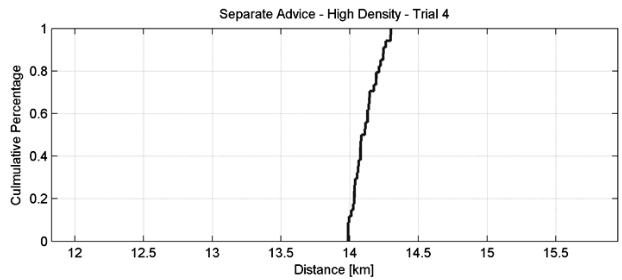


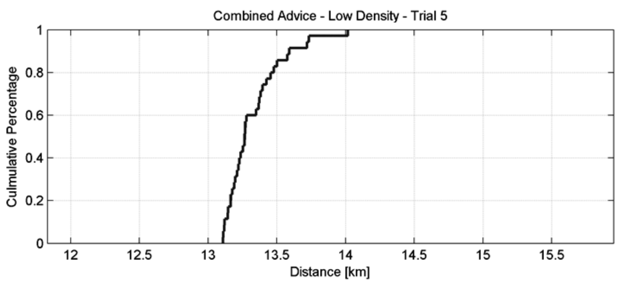
D.9 Cumulative frequency distribution of lane changes at LANE DROP

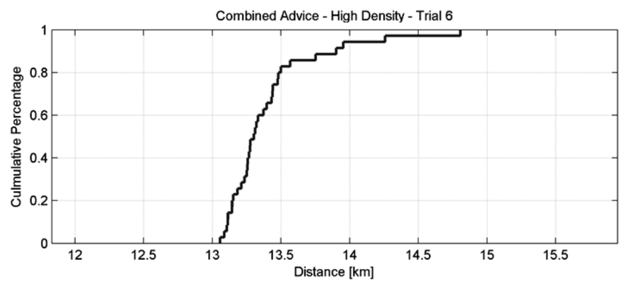




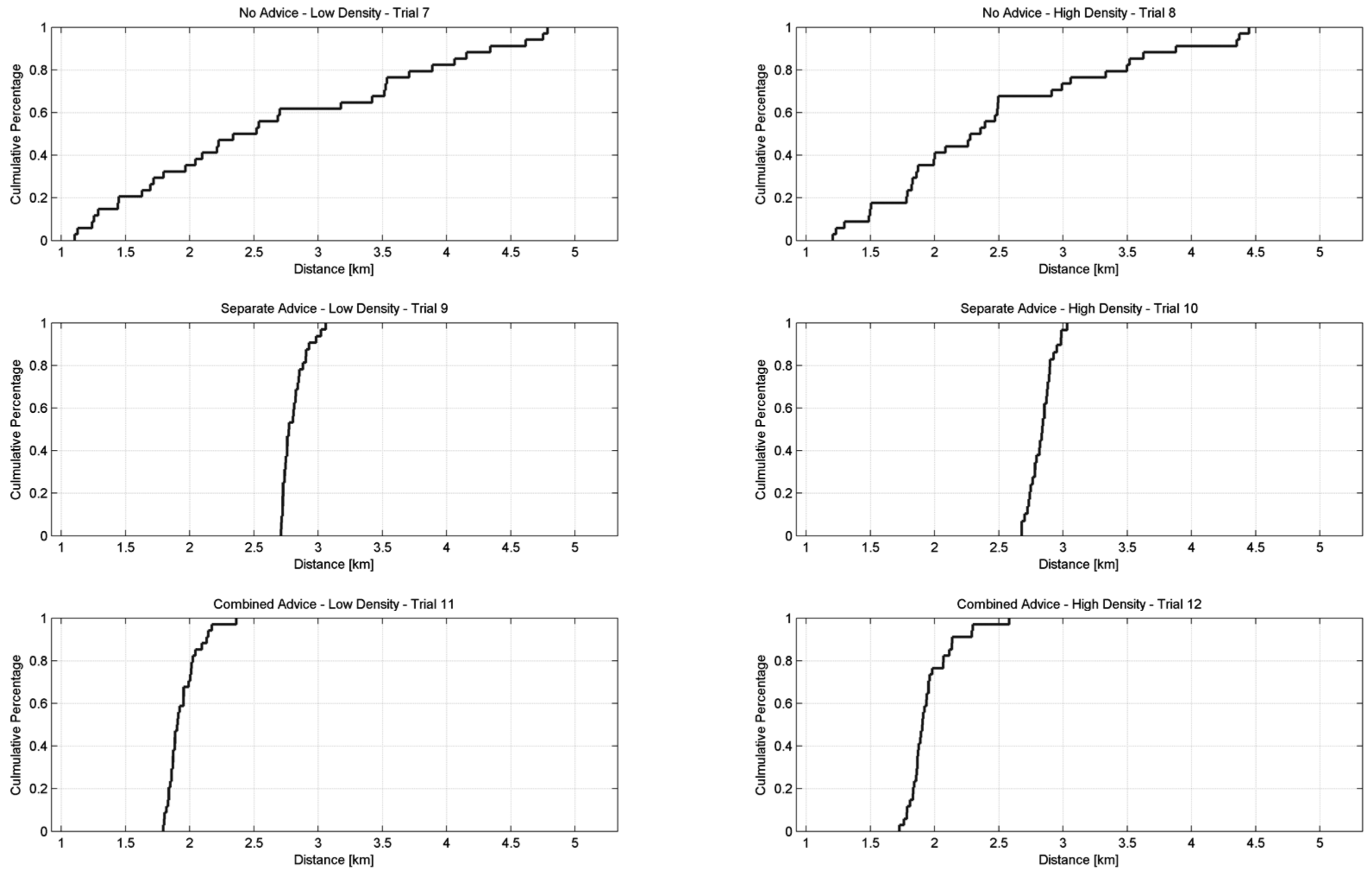




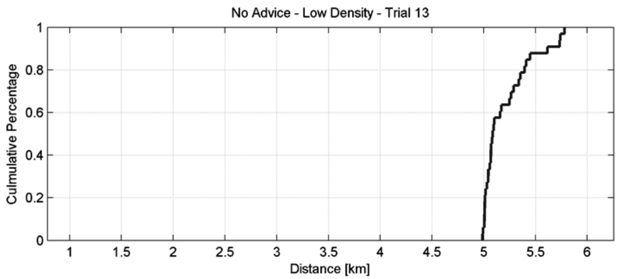


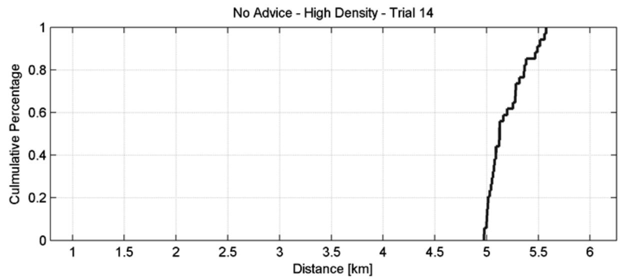


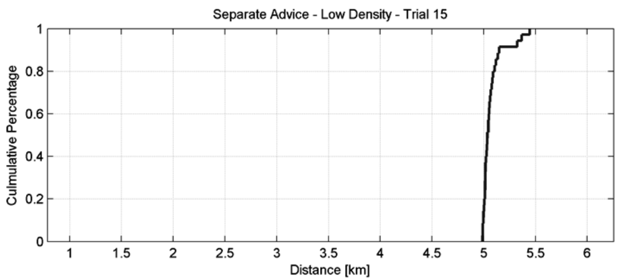
D.9 Cumulative frequency distribution of lane changes at ON-RAMP

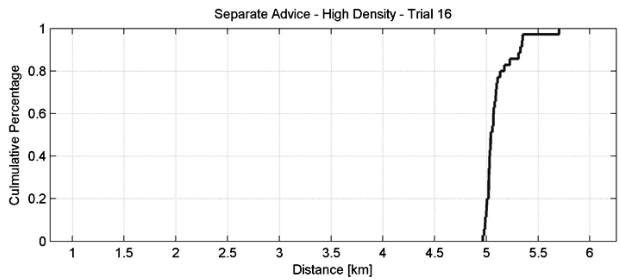


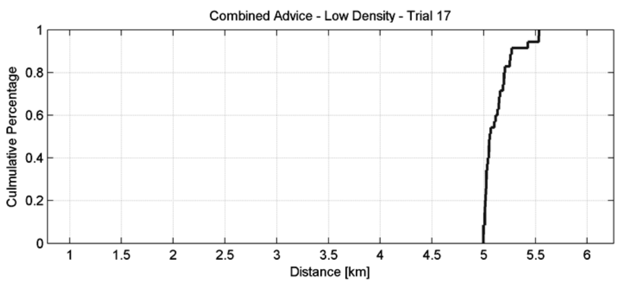
D.9 Cumulative frequency distribution of lane changes at WEAVING SECTION

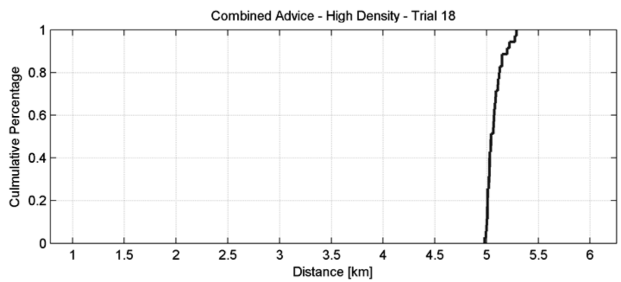




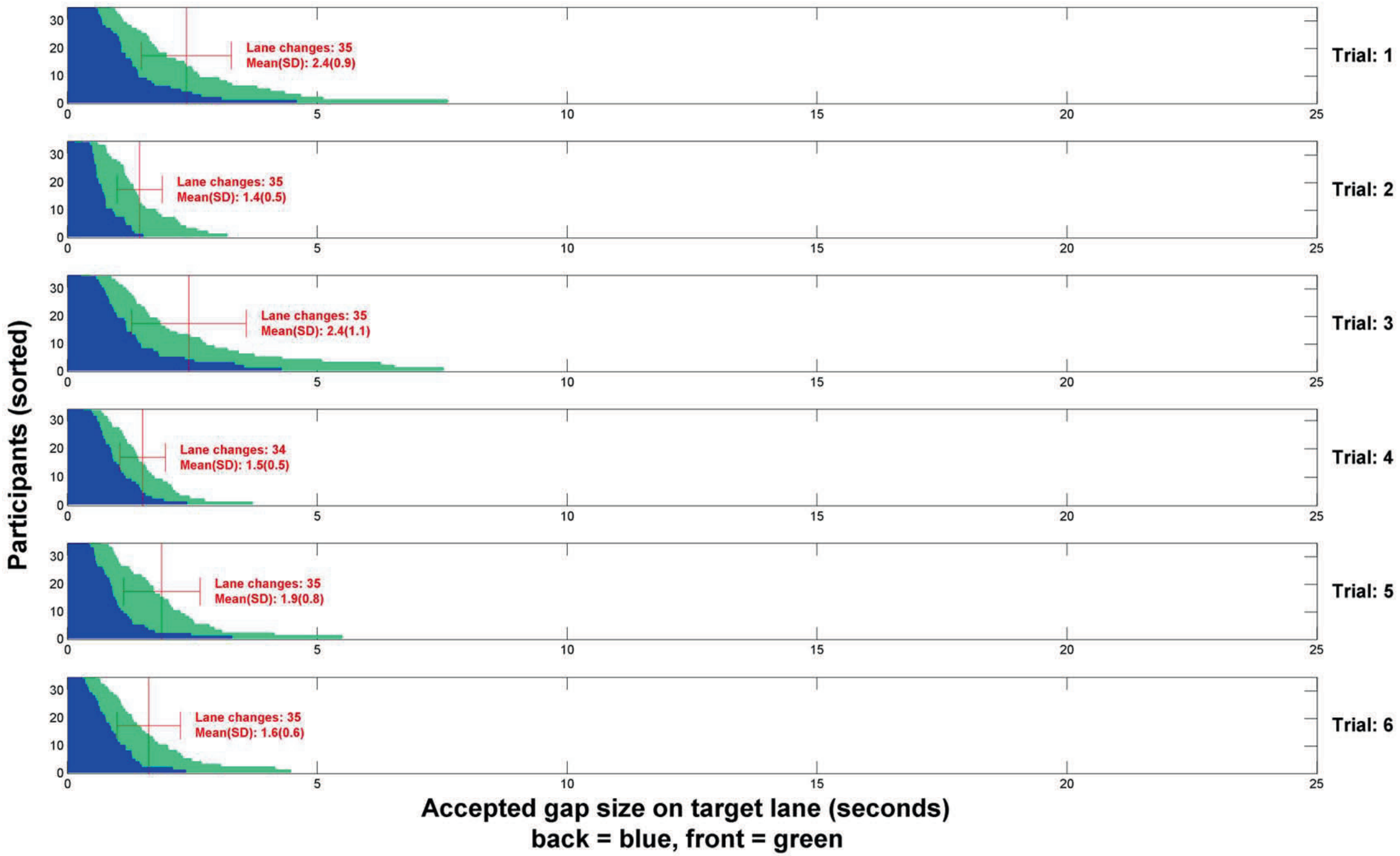




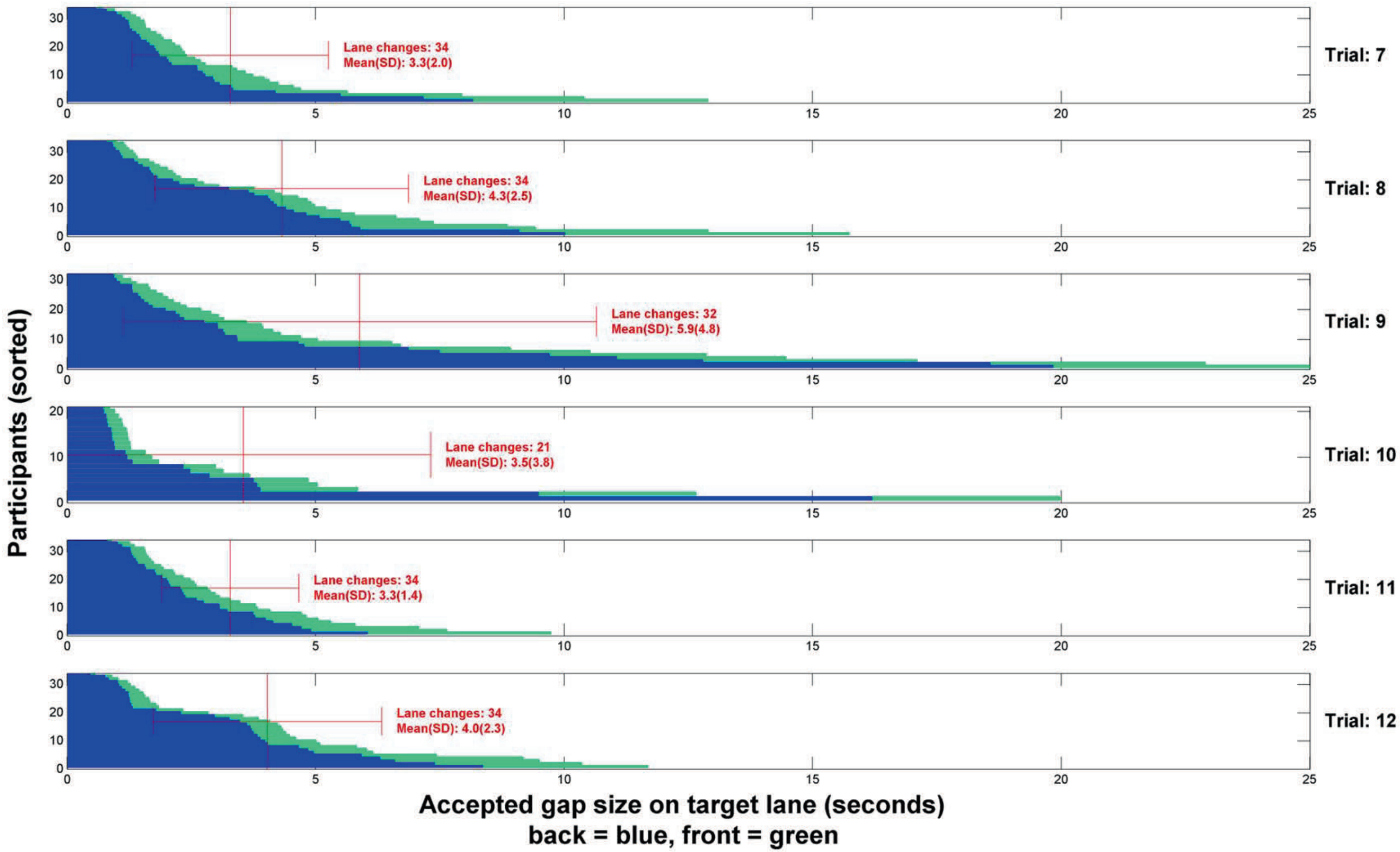




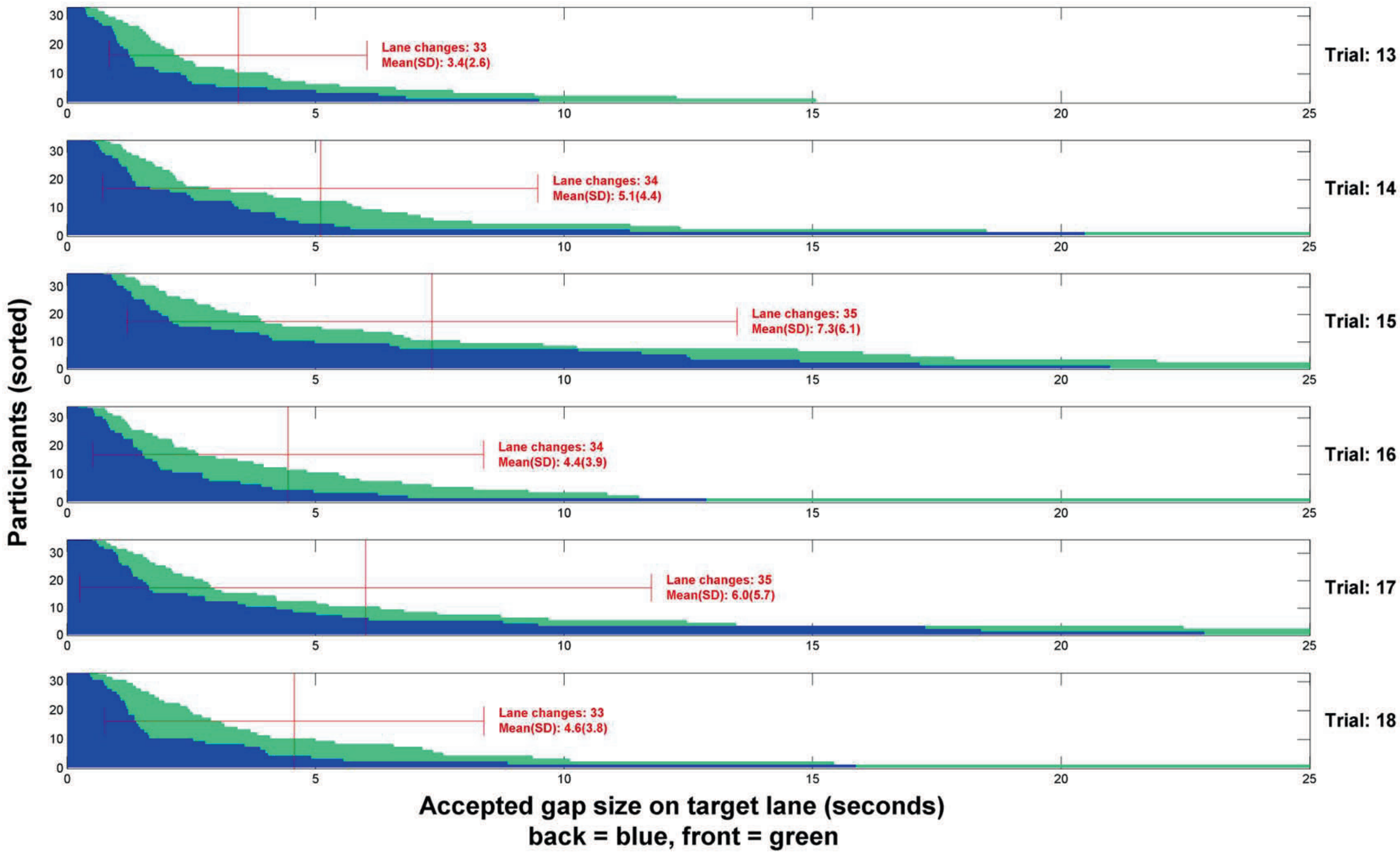
D.10 Gap size on the target lane at the time of line crossing at LANE DROP



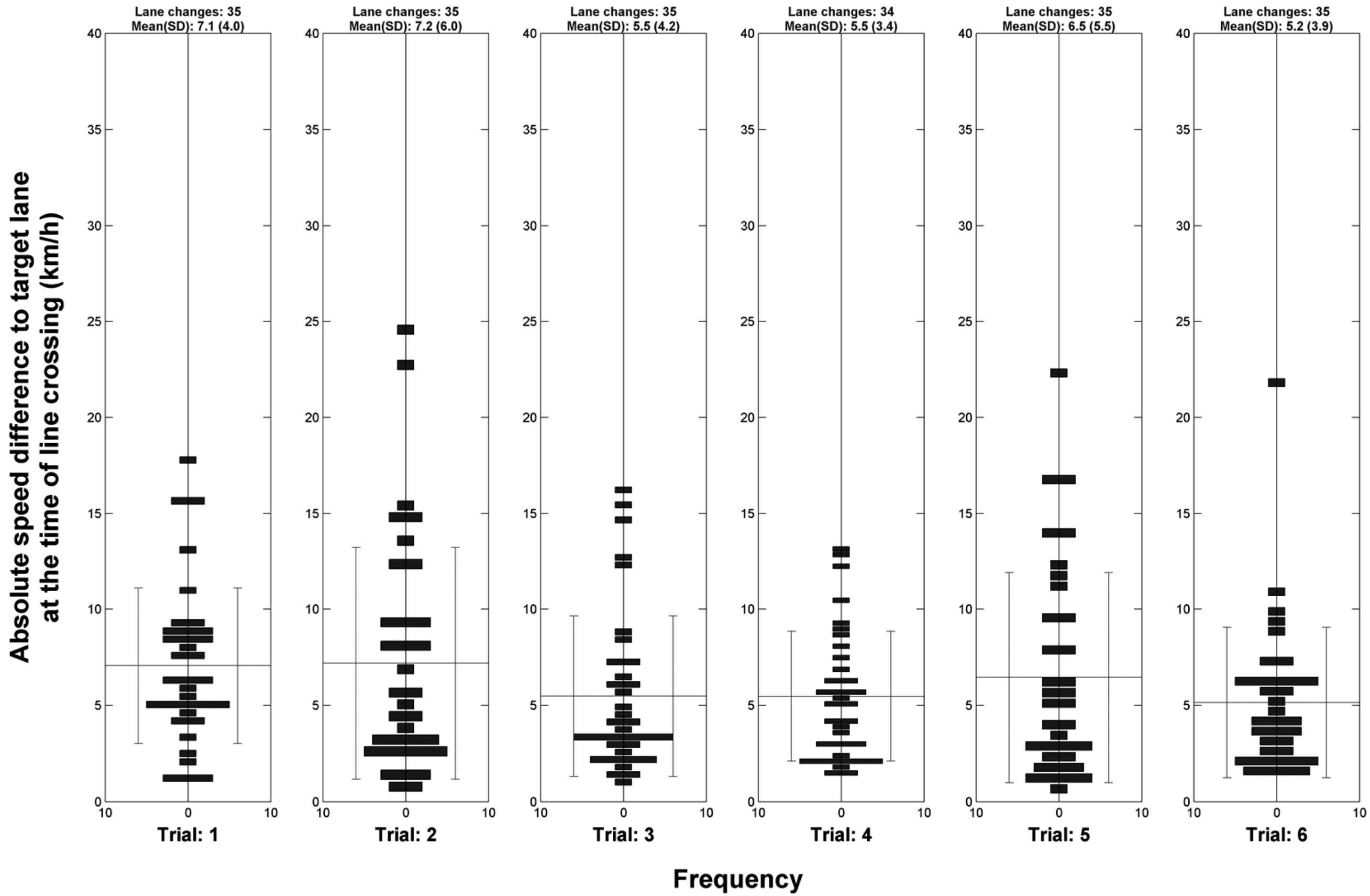
D.10 Gap size on the target lane at the time of line crossing at ON-RAMP



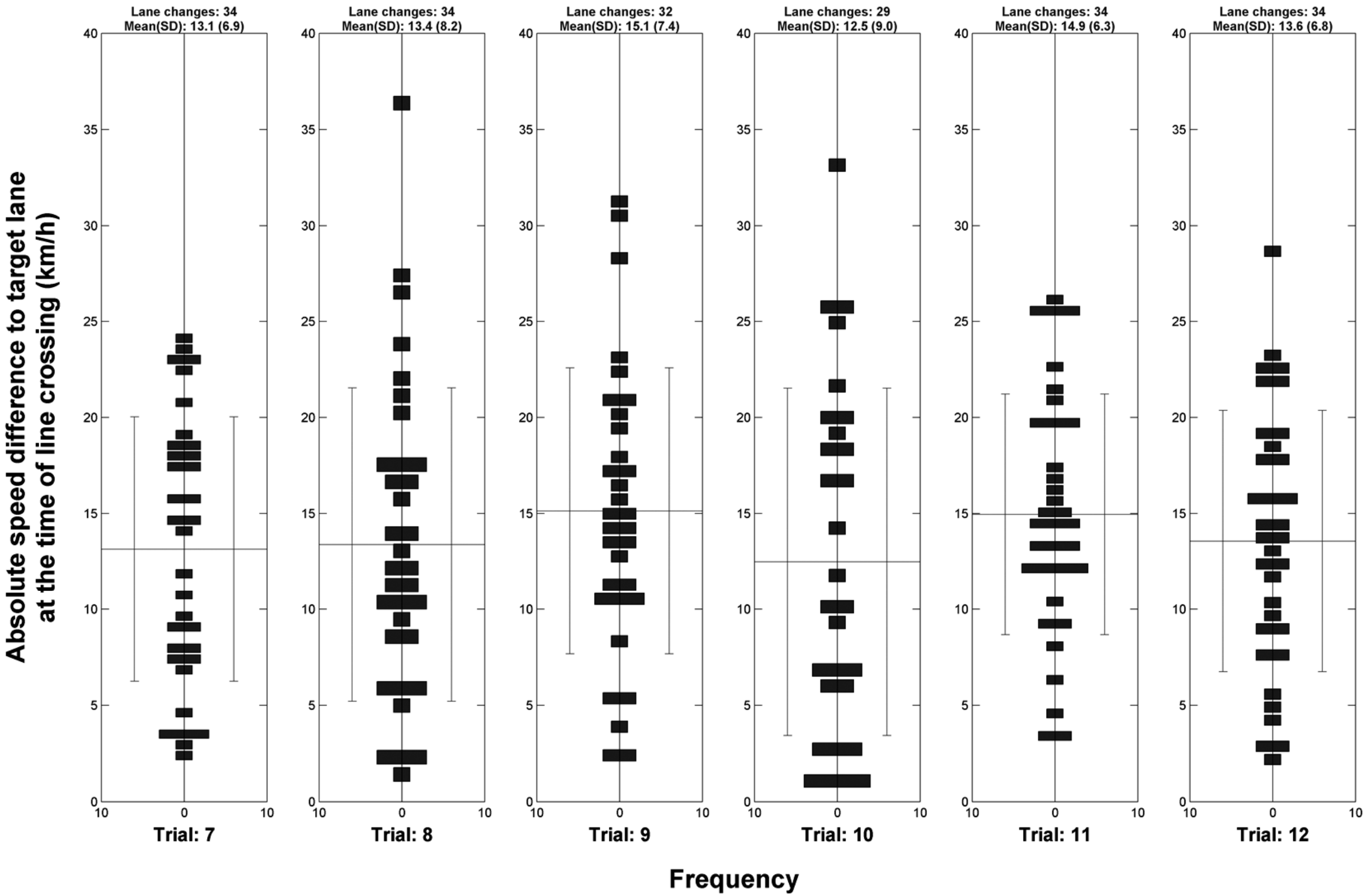
D.10 Gap size on the target lane at the time of line crossing at WEAVING SECTION



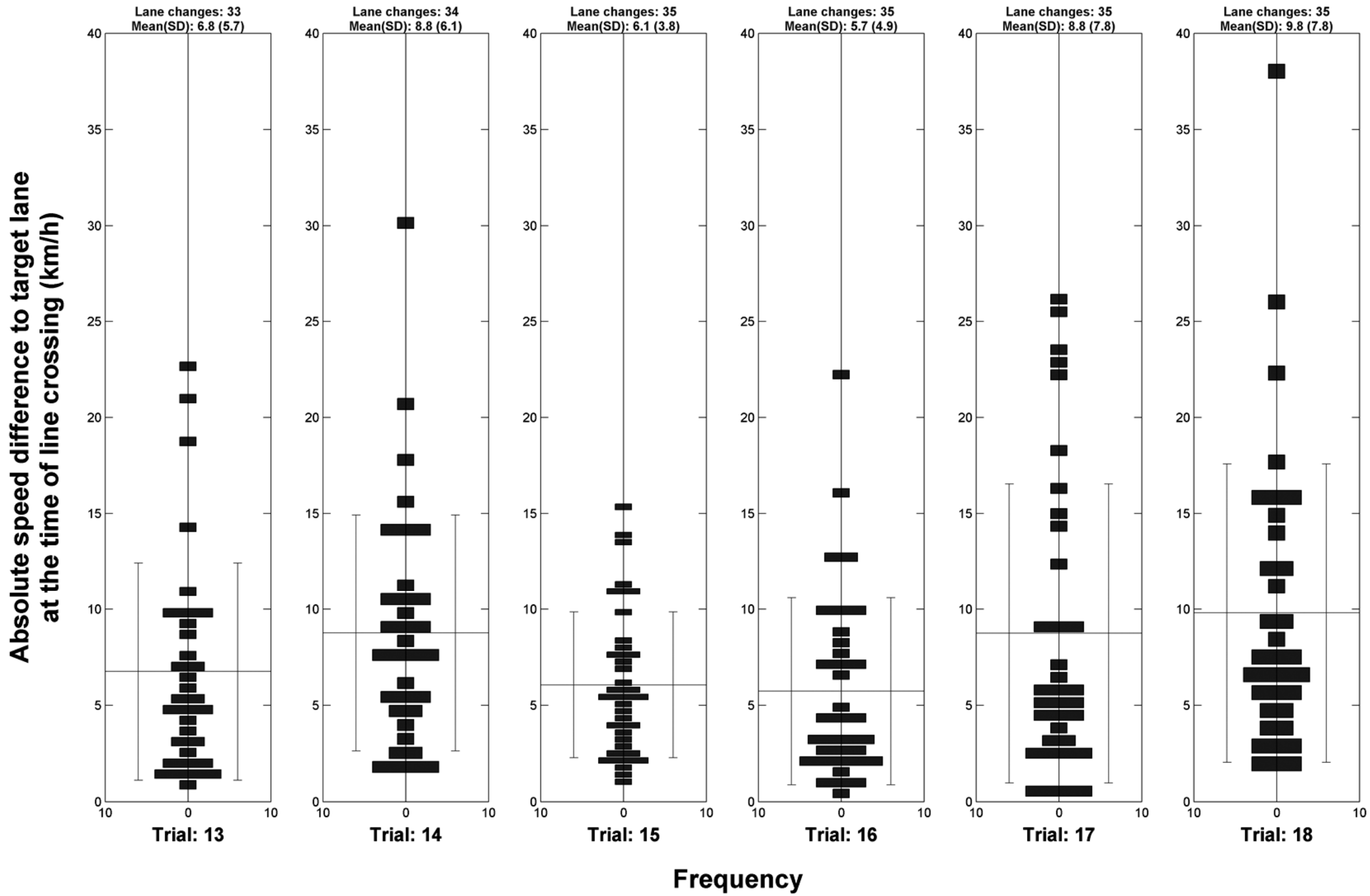
D.11 Speed difference to the target lane at the time of line crossing at LANE DROP



D.11 Speed difference to the target lane at the time of line crossing at ON-RAMP



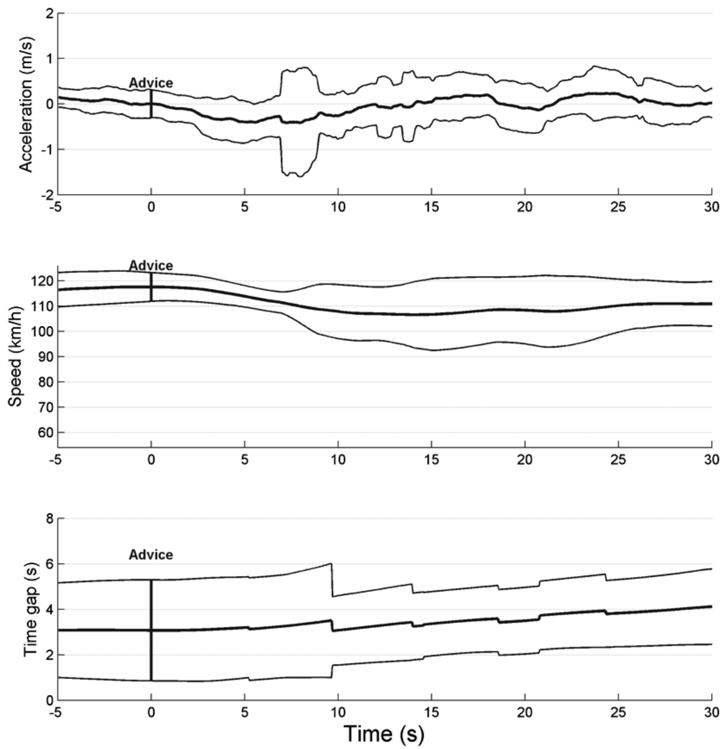
D.11 Speed difference to the target lane at the time of line crossing at WEAVING SECTION



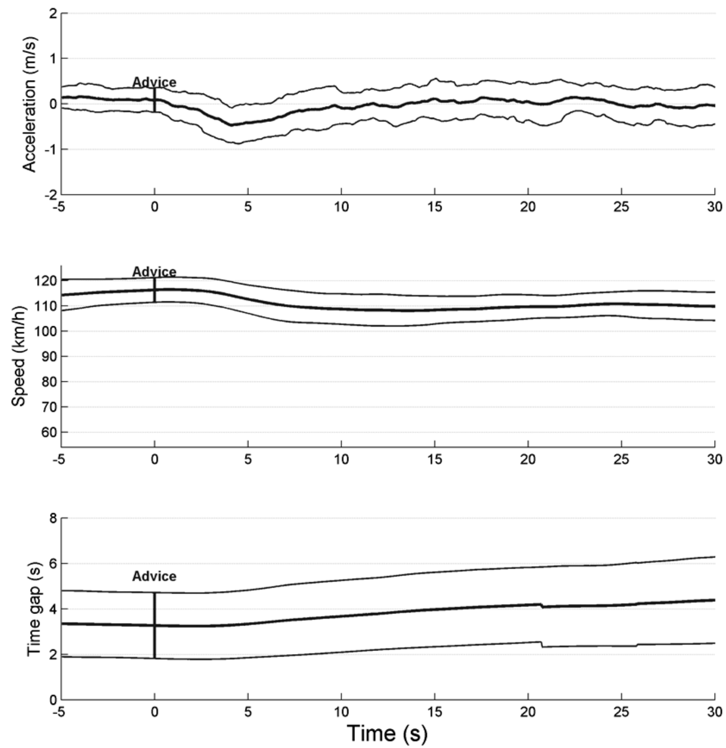
D.12 Speed development after advice

SEPARATE speed and lane change advice in the LANE DROP

Low density



High density

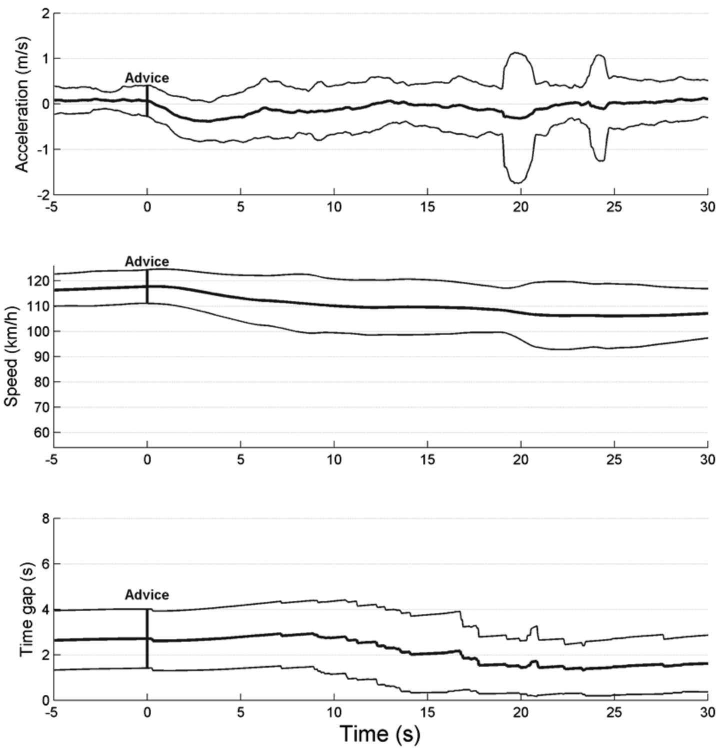


Note. Inner line denotes mean value, outer lines denote standard deviation

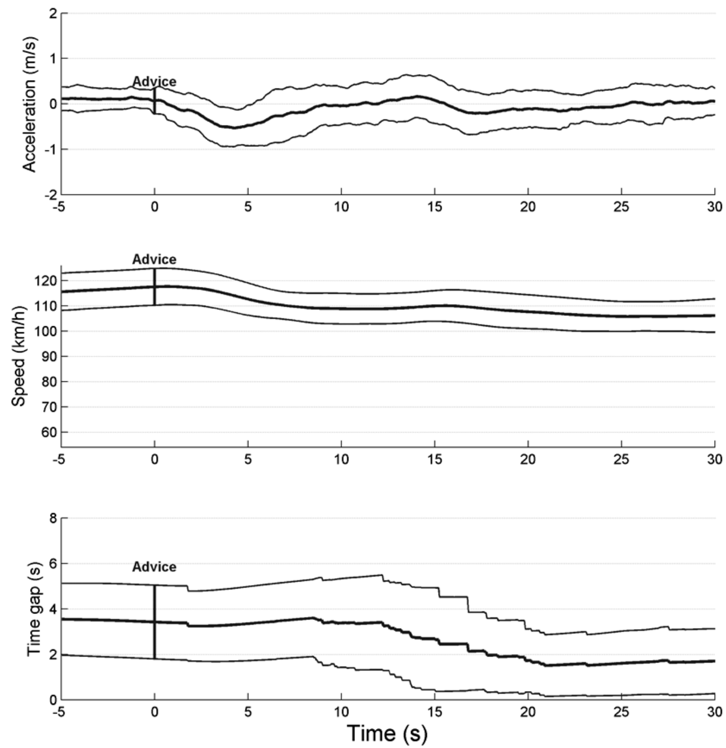
D.12 Speed development after advice

COMBINED speed and lane change advice in the LANE DROP

Low density



High density

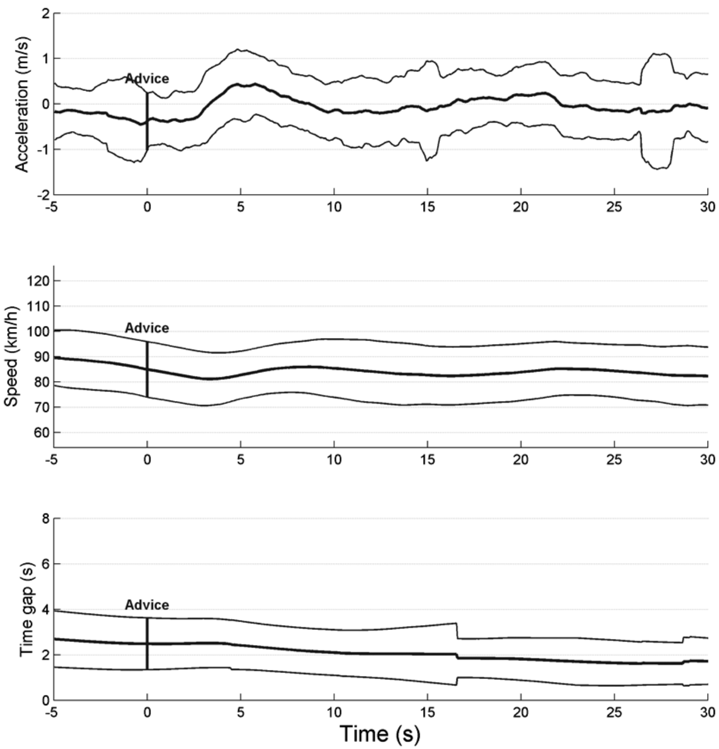


Note. Inner line denotes mean value, outer lines denote standard deviation

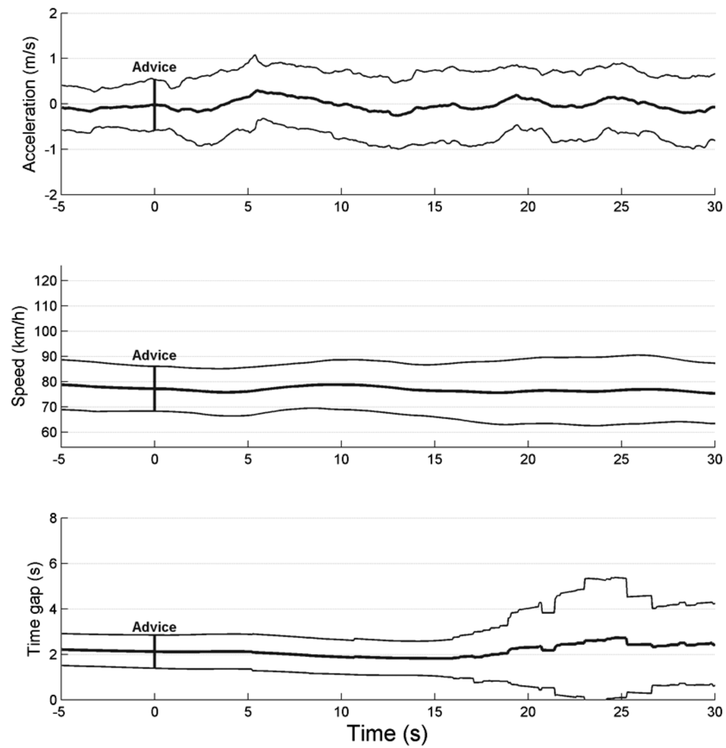
D.12 Speed development after advice

SEPARATE speed and lane change advice in the ON-RAMP

Low density



High density

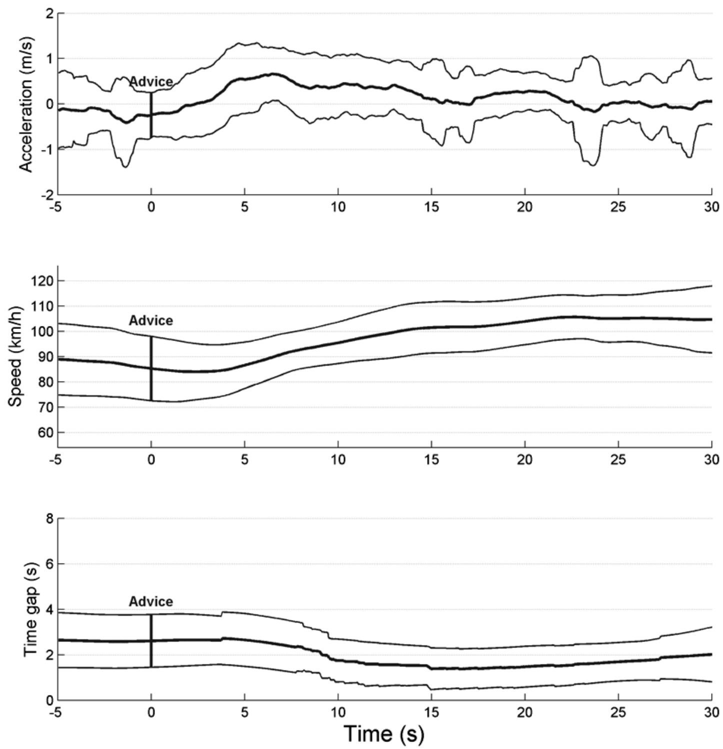


Note. Inner line denotes mean value, outer lines denote standard deviation

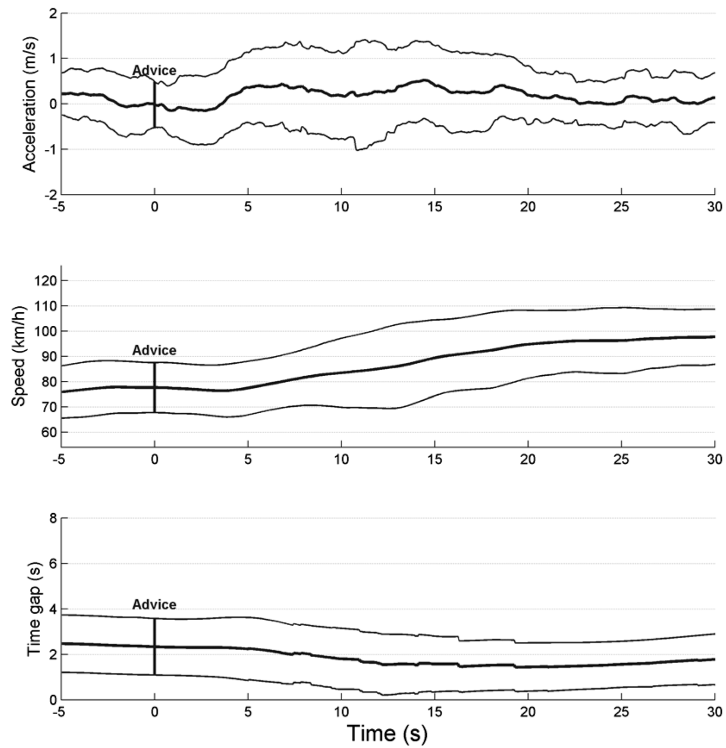
D.12 Speed development after advice

COMBINED speed and lane change advice in the ON-RAMP

Low density



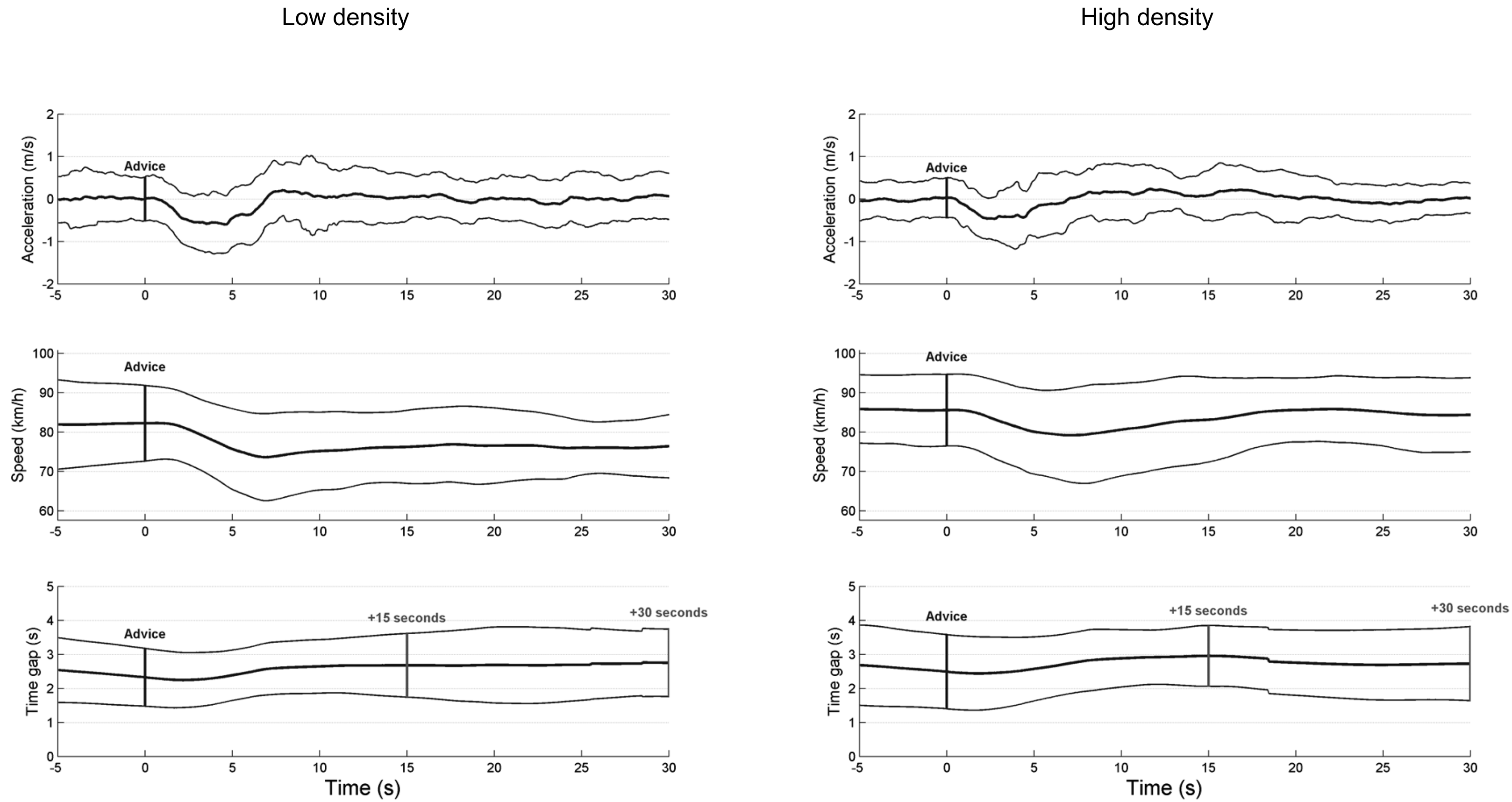
High density



Note. Inner line denotes mean value, outer lines denote standard deviation

D.13 Gap size development after advice

SEPARATE gap and lane change advice in the WEAVING SECTION

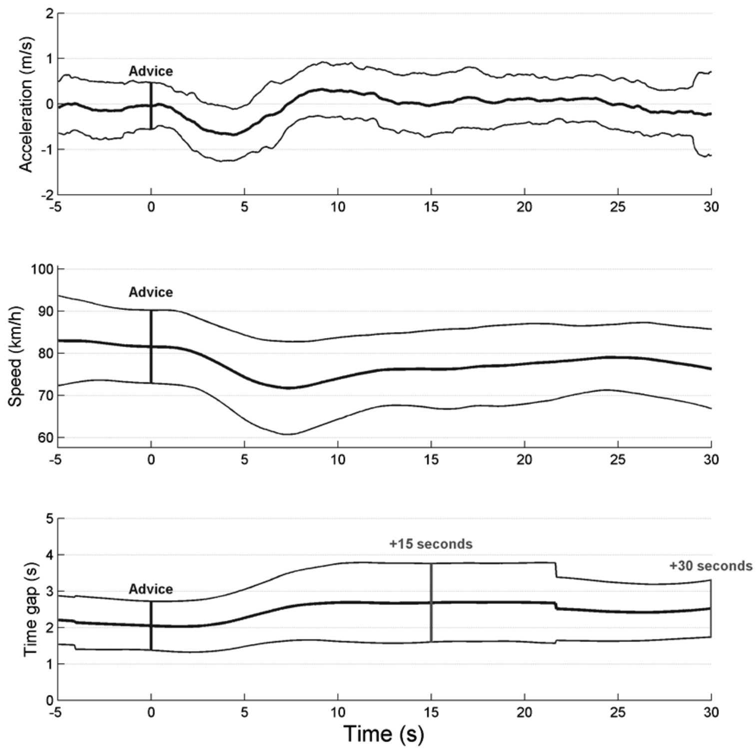


Note. Inner line denotes mean value, outer lines denote standard deviation

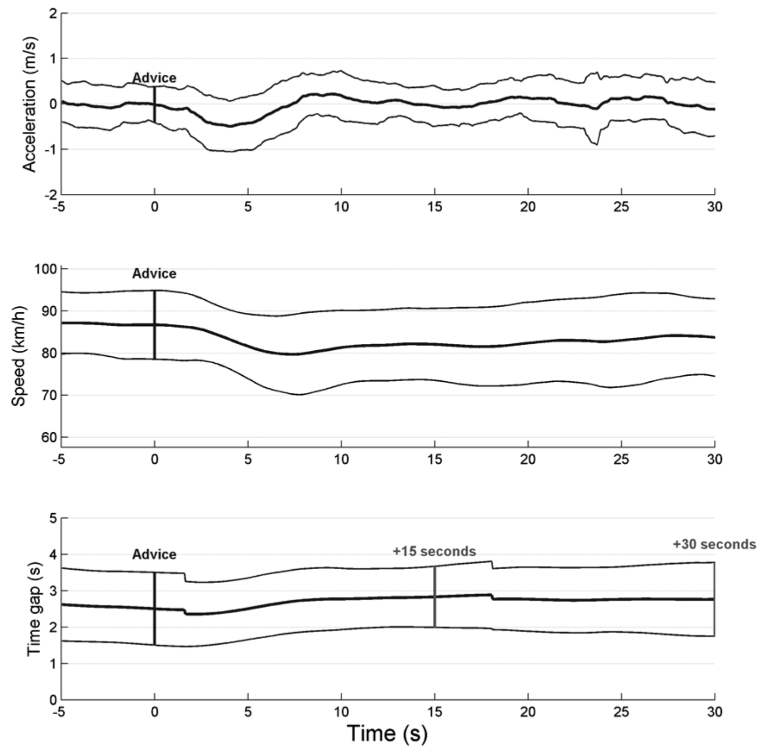
D.13 Gap size development after advice

COMBINED gap and lane change advice in the WEAVING SECTION

Low density



High density



Note. Inner line denotes mean value, outer lines denote standard deviation

E. Compliance and acceptance experiment

E.1 Experimental instructions for compliance estimation and acceptance

Currently a new form of driver support is being developed, whose aim it is to improve traffic flow on motorways during rush hours. Unique about the system is that the driver is at all times fully in control of the vehicle. The system merely gives an advice on the optimal speed, headway and lane that the driver should choose to improve traffic flow and throughput. Of course for the success of the system it is required that drivers are able to follow the given advice.

Additional information only seen in the high info condition

Now, please have a look at the additional information about the advice strategy that is used by the system to improve traffic flow.

The experiment consists of 21 trials that are divided into two blocks of 9 and 12 trials. Between the blocks will be a pause of about 45 minutes.

In the first part of the experiment you will drive in three different locations: a lane drop, an on-ramp and a straight motorway. In each trial, other traffic around you makes use of the system that has been described above and will carry out the advice. The percentage of vehicles that is using the system will vary per trial. After every trial we ask you to estimate the percentage (0% till 100%) of vehicles that, in your view, has been following an advice in that trial. In these trials you are free to choose the lane where you want to drive.

In the second part of the experiment you will be driving in the same locations as in the first part, while receiving an advice from the system. We want to assess the way that advice messages are carried out by the drivers, and also how compliance to advice messages is experienced by drivers. Therefore we will administer questions after every trial as well as at the end of the experiment. During the second block of trials it is important that you stay on your lane and adhere to the starting speed and starting headway until an advice is given. As in real traffic you are also required to adhere to the traffic regulations. During a practice trial you have the change to get used to driving in the simulator.

In case you wish to abort the experiment you can do so at any time. The data of the experiment will be confidential. If you have any remaining questions please ask the experimenter now.

E.2 Questionnaire (Before / Low Info)

Question 1 - A system that stimulates me to adhere to a particular speed, headway and lane to improve traffic flow on the motorway seems to me…

useful	○○○○○	useless
pleasant	○○○○○	unpleasant
bad	○○○○○	good
nice	○○○○○	annoying
effective	○○○○○	superfluous
irritating	○○○○○	likable
assisting	○○○○○	worthless
undesirable	○○○○○	desirable
raising alertness	○○○○○	sleep-inducing

Question 2 – Based on what I now know about the system, I would be inclined to buy one to use for myself?

☐ Yes, and I would pay up to ______ euros for it.
☐ Only if I do not have to pay for it.
☐ I don’t know.
☐ No, because:

E.3 Questionnaire (Before / High Info)

Question 1 - A system that stimulates me to adhere to a particular speed, headway and lane to improve traffic flow on the motorway seems to me…

useful	○○○○○	useless
pleasant	○○○○○	unpleasant
bad	○○○○○	good
nice	○○○○○	annoying
effective	○○○○○	superfluous
irritating	○○○○○	likable
assisting	○○○○○	worthless
undesirable	○○○○○	desirable
raising alertness	○○○○○	sleep-inducing

Question 2 – I think that the chosen advice strategy can have a beneficial effect on traffic flow, given that it is compiled to by a sufficient number of road users…

…at a lane drop:
☐ Yes
☐ Don't know
☐ No, because:

…at an on-ramp:
☐ Yes
☐ Don't know
☐ No, because:

…at a predicted shock wave:
☐ Yes
☐ Don't know
☐ No, because:

Question 3 - Based on what I now know about the system, I would be inclined to buy one to use for myself?

☐ Yes, and I would pay up to ______ euros for it.
☐ Only if I do not have to pay for it.
☐ I don't know.
☐ No, because:

E.4 Questions after each trial

Trial 1 – 9:

How may percent of the other road users have complied to advice messages given by the system in the current trial?

_____%

How sure are you of this estimate?

Very sure ○ ○ ○ ○ ○ Not at all sure

Trial 10-18:

I understand the reason behind the given advice in this situation?

☐ Yes
☐ No

Complying to the advice had advantageous/ disadvantageous consequences for me?

☐ Advantage, because: ______________
____
____

☐ Disadvantage, because: ____________
____
____

☐ Nothing noticed.

E.5 Questionnaire After (same for both groups)

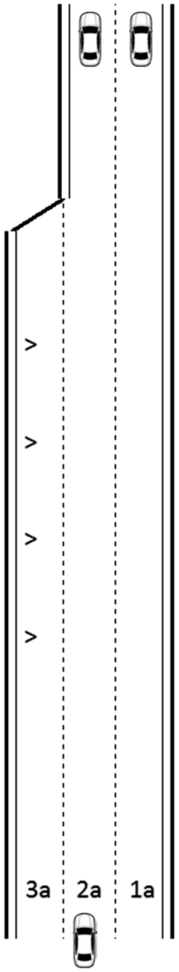
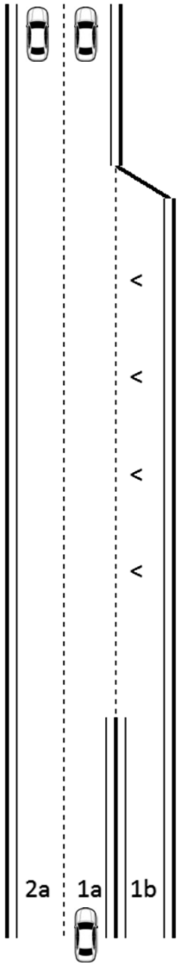
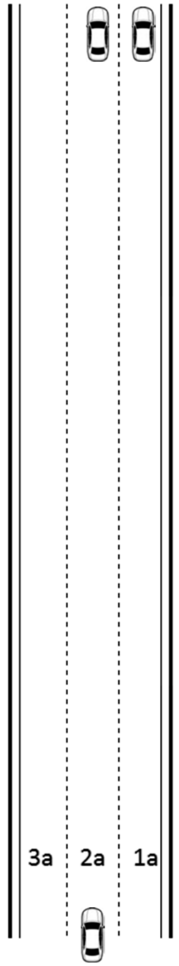
Question 1 - The system that I have just experienced seems to me…

useful	◯◯◯◯◯	useless
pleasant	◯◯◯◯◯	unpleasant
bad	◯◯◯◯◯	good
nice	◯◯◯◯◯	annoying
effective	◯◯◯◯◯	superfluous
irritating	◯◯◯◯◯	likable
assisting	◯◯◯◯◯	worthless
undesirable	◯◯◯◯◯	desirable
raising alertness	◯◯◯◯◯	sleep-inducing

Question 2 – Based on what I now know about the system, I would be inclined to buy one to use for myself?

☐ Yes, and I would pay up to ______ euros for it.
☐ Only if I do not have to pay for it.
☐ I don't know.
☐ No, because:

E.6 Scenario Designs and starting conditions

Lane Drop	On-ramp	Straight motorway
		

Lane	3a	2a	1a	Lane	2a	1a	1b	Lane	3a	2a	1a
Speed [km/h]	120	110	85	**Speed [km/h]**	110	85	85	**Speed [km/h]**	110	100	85
Density [veh/h]	2250	3600	2550	**Density [veh/h]**	3300	1950	1000	**Desnity [veh/h]**	4500	2700	2000
Trucks [%]	0	0	33	**Trucks [%]**	0	27	10	**Trucks [%]**	0	0	30

E.7 Trial list

Trial	Location	Compliance rate	Advice	Starting lane	Target lane
1	Lane drop	low (10%)	No advice	Middle	no target lane
2	Lane drop	medium (50%)	No advice	Middle	no target lane
3	Lane drop	high (90%)	No advice	Middle	no target lane
4	On-ramp	low	No advice	Right	no target lane
5	On-ramp	medium	No advice	Right	no target lane
6	On-ramp	high	No advice	Right	no target lane
7	Straight	low	No advice	Middle	no target lane
8	Straight	medium	No advice	Middle	no target lane
9	Straight	high	No advice	Middle	no target lane
10	Lane drop	medium	Lane change	Middle	Right
11	Lane drop	medium	Lane change	Middle	Right
12	On-ramp	medium	Lane change	Right	Left
13	On-ramp	medium	Lane change	Right	Left
14	Straight	medium	Lane change	Middle	Right
15	Straight	medium	Lane change	Middle	Right
16	Lane drop	medium	Gap	Middle	Middle
17	Lane drop	medium	Gap	Middle	Middle
18	On-ramp	medium	Gap	Right	Right
19	On-ramp	medium	Gap	Right	Right
20	Straight	medium	Gap	Middle	Middle
21	Straight	medium	Gap	Middle	Middle

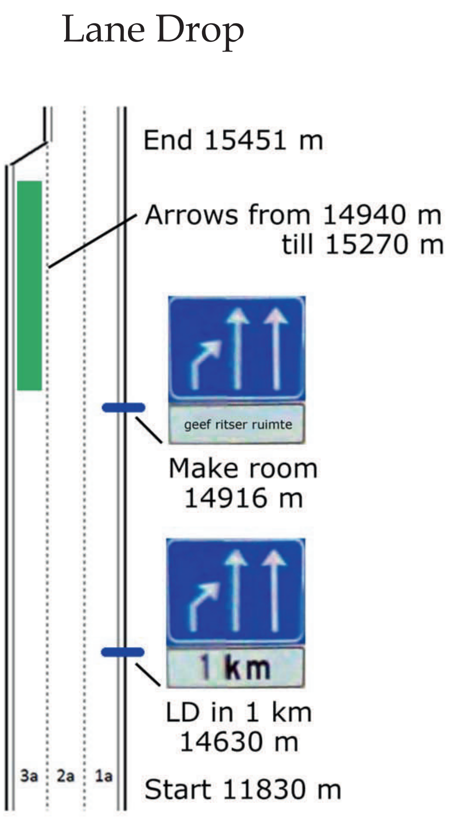
E.8 CIVA penetration rates at the start of a trial

Lane drop	Lane	# Cars	# CIVA-Cars	CIVA Penetration	# Trucks	Truck Fraction
Trial 1	**All**	**76**	**7**	**9%**		
	right	25	1	4%	8	32%
	middle	25	5	20%	0	0%
	left	26	1	4%	0	0%
Trial 2	**All**	**76**	**35**	**46%**		
	right	25	8	32%	8	32%
	middle	25	16	64%	0	0%
	left	26	11	42%	0	0%
Trial 3	**All**	**76**	**66**	**87%**		
	right	25	20	80%	8	32%
	middle	25	24	96%	0	0%
	left	26	22	85%	0	0%
Trial 10, 11, & 16, 17	**All**	**76**	**36**	**47%**		
	right	25	8	32%	8	32%
	middle	25	17	68%	0	0%
	left	26	11	42%	0	0%

On-ramp	Lane	# Cars	# CIVA-Cars	CIVA Penetration	# Trucks	Truck Fraction
Trial 4	**All**	**76**	**7**	**9%**		
	on-ramp	26	1	4%	0	0%
	right	25	5	20%	1	4%
	left	25	1	4%	0	0%
Trial 5	**All**	**76**	**35**	**46%**		
	on-ramp	26	8	31%	0	0%
	right	25	16	64%	1	4%
	left	25	11	44%	0	0%
Trial 6	**All**	**76**	**66**	**87%**		
	on-ramp	26	20	77%	0	0%
	right	25	24	96%	1	4%
	left	25	22	88%	0	0%
Trial 12, 13, & 18, 19	**All**	**76**	**36**	**47%**		
	on-ramp	26	9	35%	0	0%
	right	25	16	64%	1	4%
	left	25	11	44%	0	0%

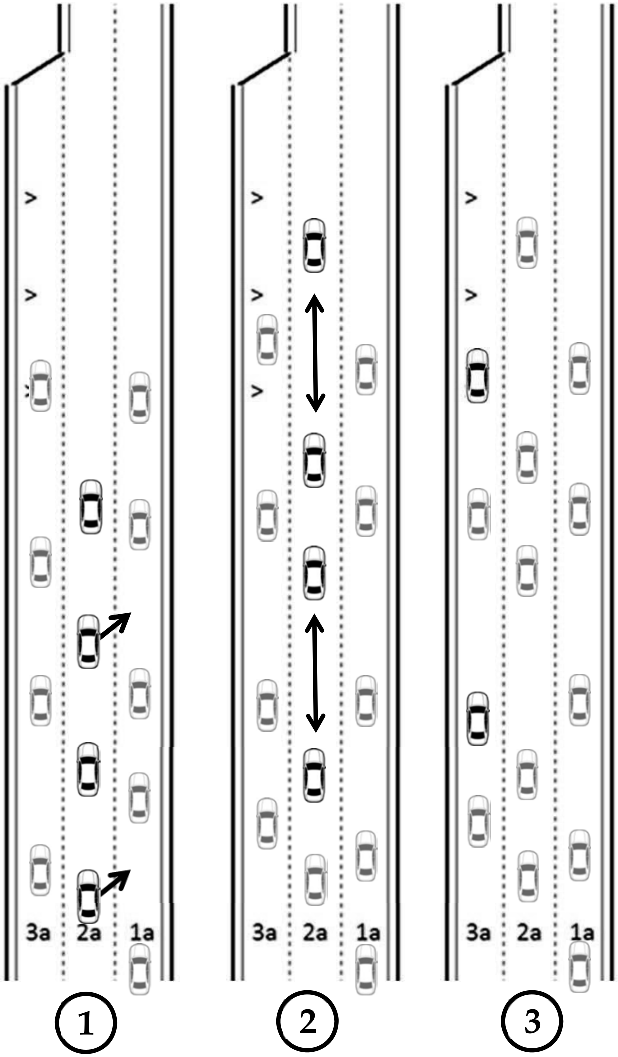
Straight motorway	Lane	# Cars	# CIVA-Cars	CIVA Penetration	# Trucks	Truck Fraction
Trial 7	**All**	**86**	**9**	**10%**		
	right	25	3	12%	8	32%
	middle	20	3	15%	0	0%
	left	41	3	7%	0	0%
Trial 8	**All**	**86**	**33**	**38%**		
	right	25	10	40%	8	32%
	middle	20	9	45%	0	0%
	left	41	14	34%	0	0%
Trial 9	**All**	**86**	**76**	**88%**		
	right	25	22	88%	8	32%
	middle	20	20	100%	0	0%
	left	41	34	83%	0	0%
Trial 14, 15, & 20, 21	**All**	**86**	**41**	**48%**		
	right	25	11	44%	8	32%
	middle	20	10	50%	0	0%
	left	41	20	49%	0	0%

E.9 Distribution of traffic signs in the lane drop location



No road signs were present to the on ramp an straight motorway locations.

E.10 Additional information about the advice strategy



Location: Lane drop

There is no congestion yet, but there is dense traffic on the left and middle lane. The system predicts a bottleneck in connection to the number of vehicles on the left lane and insufficient room on the middle lane. To avoid disturbance in traffic flow the system creates room on the middle lane. This takes place in three steps:

Step 1: A number of vehicles on the middle lane is advised to adapt their speed tot that on the right lane and to change to the right lane. In this way room is created on the middle lane.

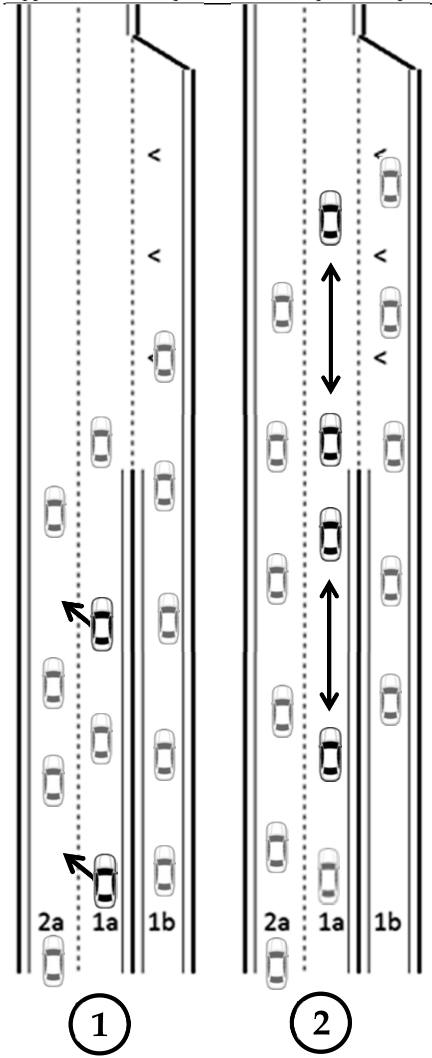
➔ ADVICE: "*Adapt your speed to the speed of the traffic on the right and change to the right lane*"

Step 2: Vehicles that are left on the middle lane are advised to not change lanes and to make room for merging vehicles form the left lane.

➔ ADVICE: "*Stay on your lane and make room for merging traffic from the left*"

Step 3: Vehicles on the left lane are advised to adapt their speed tot hat on the middle lane before they merge onto the middle lane.

➔ ADVICE: "*Before merging, adapt your speed to the speed of the traffic on the middle lane.*"



Location: Dense on-ramp

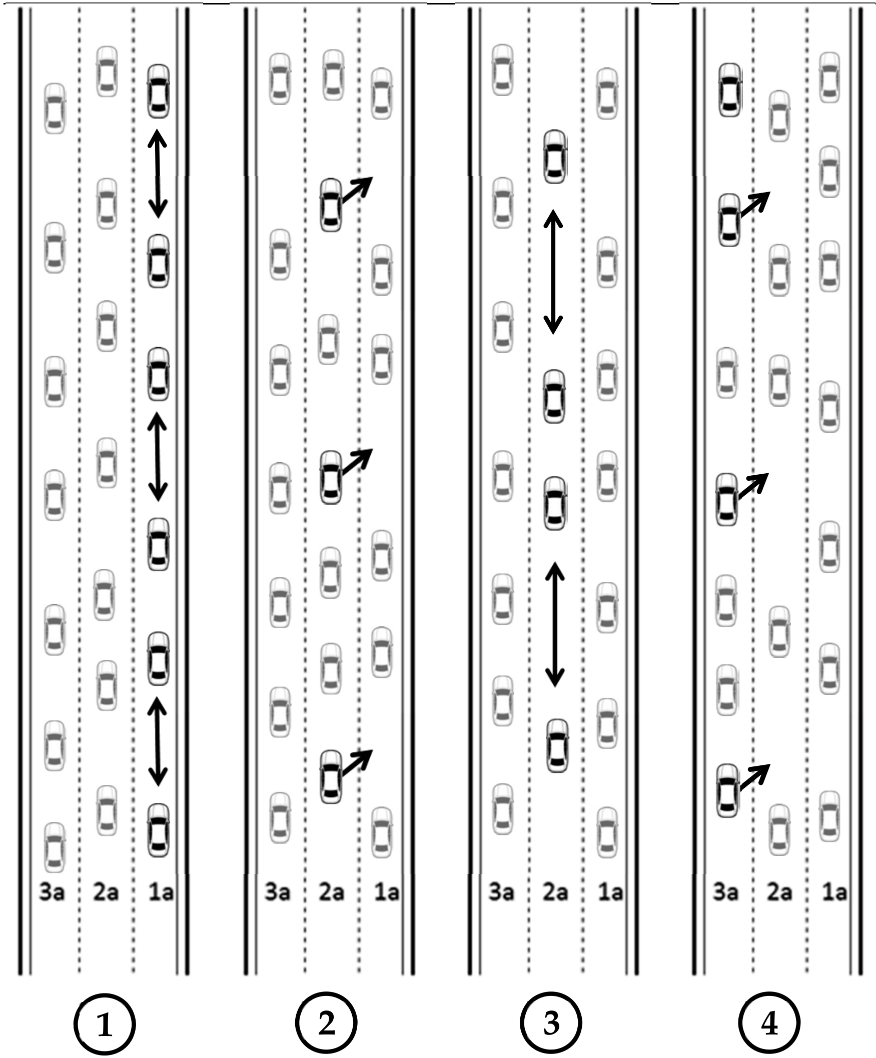
There is no congestion yet, but there is dense traffic on the motorway. The system predicts a bottleneck in connection to the number of vehicles on the on-ramp and insufficient room to merge on the right lane. To avoid disturbances in traffic flow, the system creates room on the right lane. This takes place in two steps:

Step 1: A number of vehicles on the right lane is advised to adapt their speed tot hat on the left lane and to change to the left lane. In this way room is created on the middle lane.

➔ ADVICE: “*Adapt your speed to the speed of the traffic on the left and change to the left lane*”

Step 2: Vehicles that are left on the middle lane are advised to not change lanes and to make room for merging vehicles form the on-ramp.

➔ ADVICE: “*Stay on your lane and make room for merging traffic from the right*”



Location: Straight motorway (shockwave predicted)

There is no congestion yet, but there is dense traffic on the motorway where shockwaves are occurring frequently. The system predicts an overcapacity on the left lane. To avoid shockwaves on the left lane the system distributes vehicles evenly over the driving lanes. This takes place in four steps:

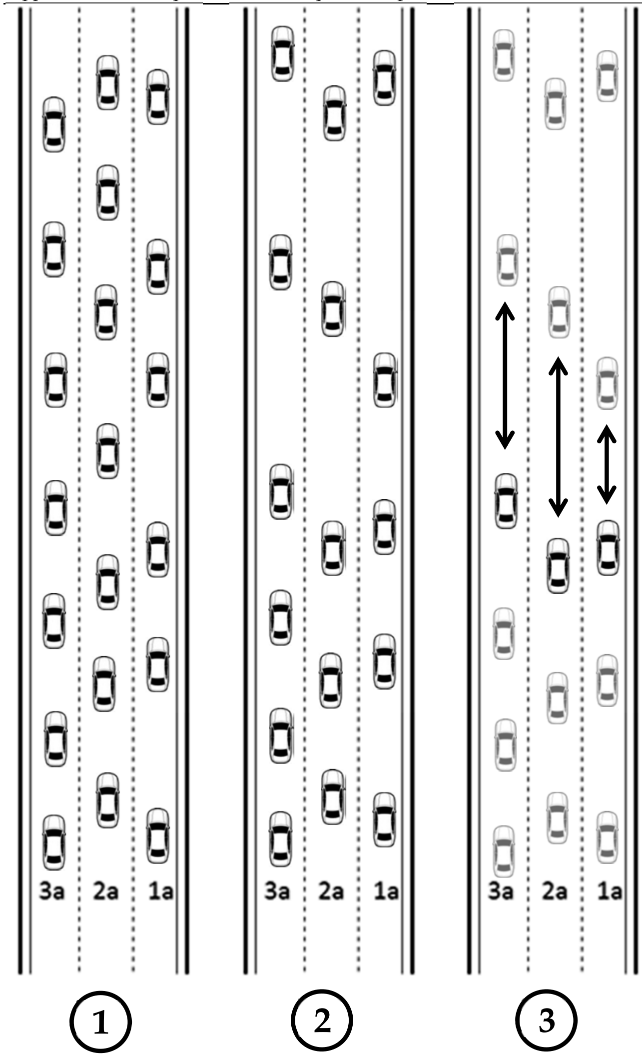
Step 1: Vehicles on the right lane are advised not to change lanes and make room for merging vehicles from the left.

➔ ADVICE: "*Stay on your lane and make room for merging traffic from the left*"

Step 2: A number of vehicles on the middle lane is advised to adapt their speed tot hat on the right lane and to change to the right lane. In this way room is created on the middle lane.

➔ ADVICE: "*Adapt your speed to the speed of the traffic on the right and change to the right lane*"

This procedure is repeated in **step 3 and 4** for the middle and the left lane.



Location: Straight motorway (end of traffic jam)

There is congestion. The system predicts that the congestion will dissolve in the near term and advises drivers to efficiently drive out of the traffic jam. This takes place in three steps:

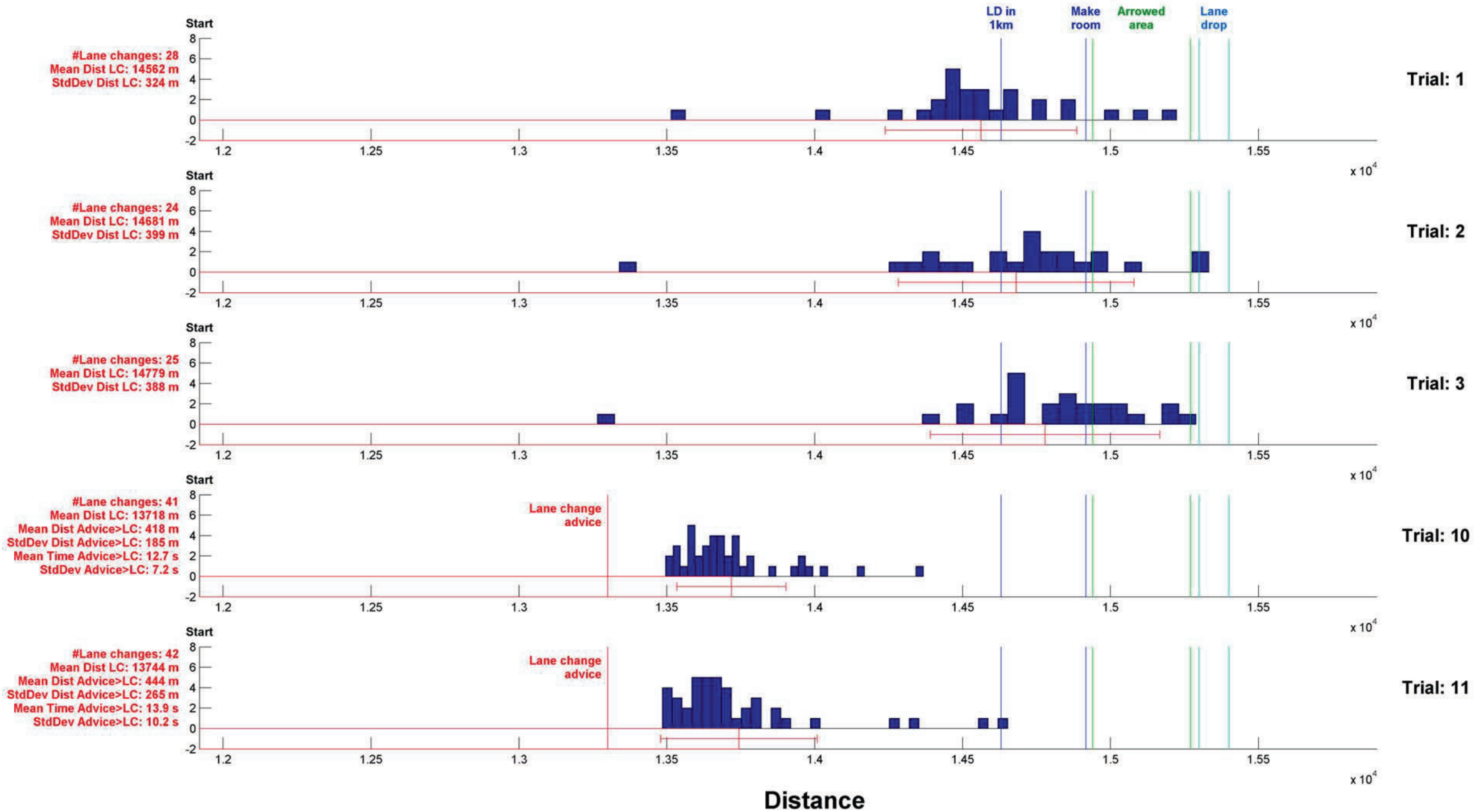
Step 1: Vehicles stand or drive slowly in congestion. The system predicts the end of congestion in the near term.

Step 2: The end of congestion approaches and vehicles begin to accelerate out of congestion. The system does not predict congestion in the near future.

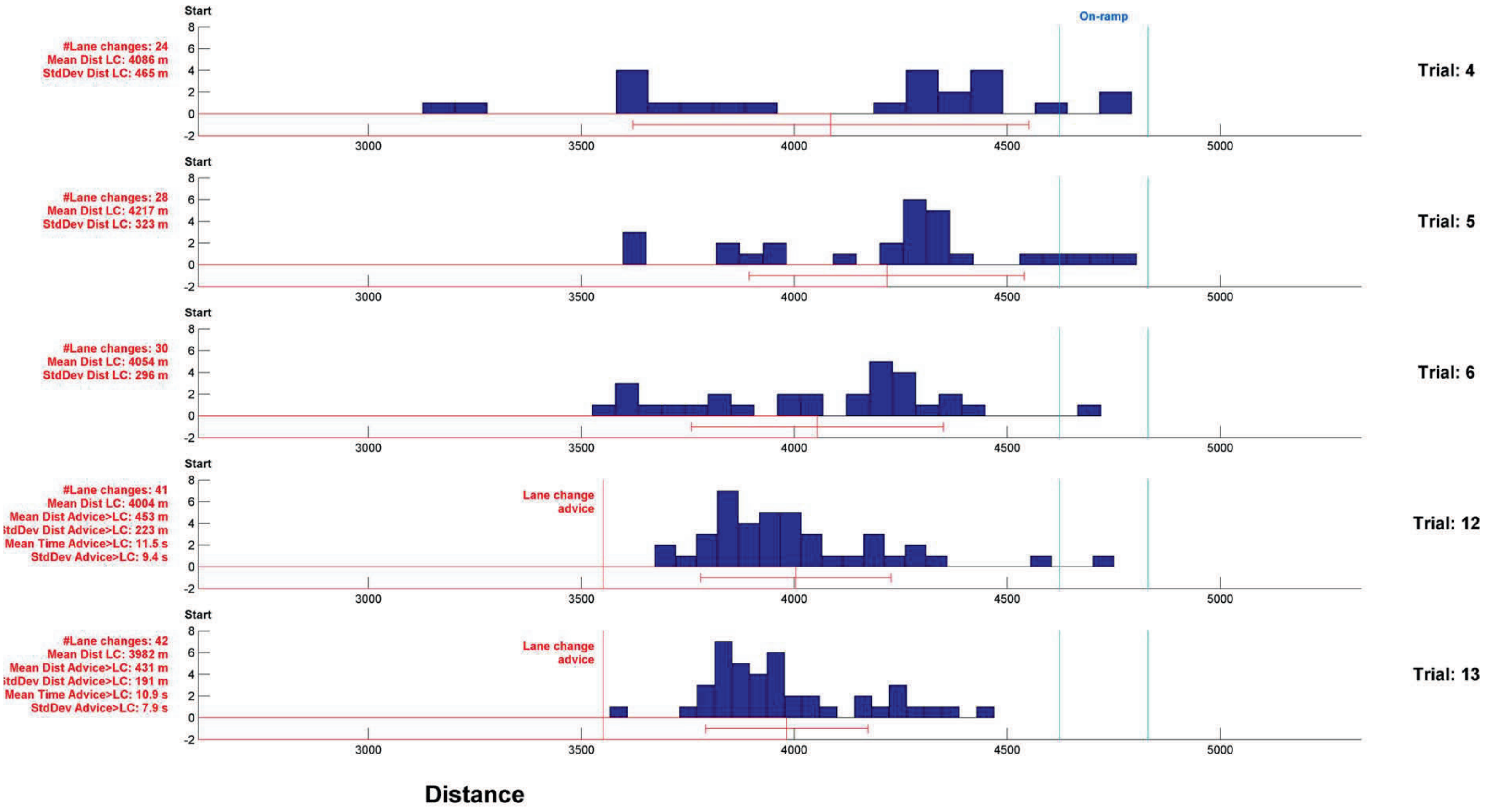
Step 3: Vehicles that approach the head of congestion are advised to keep a short but safe gap to the vehicle in front.

➔ ADVICE: "*Keep a short but safe gap size*"

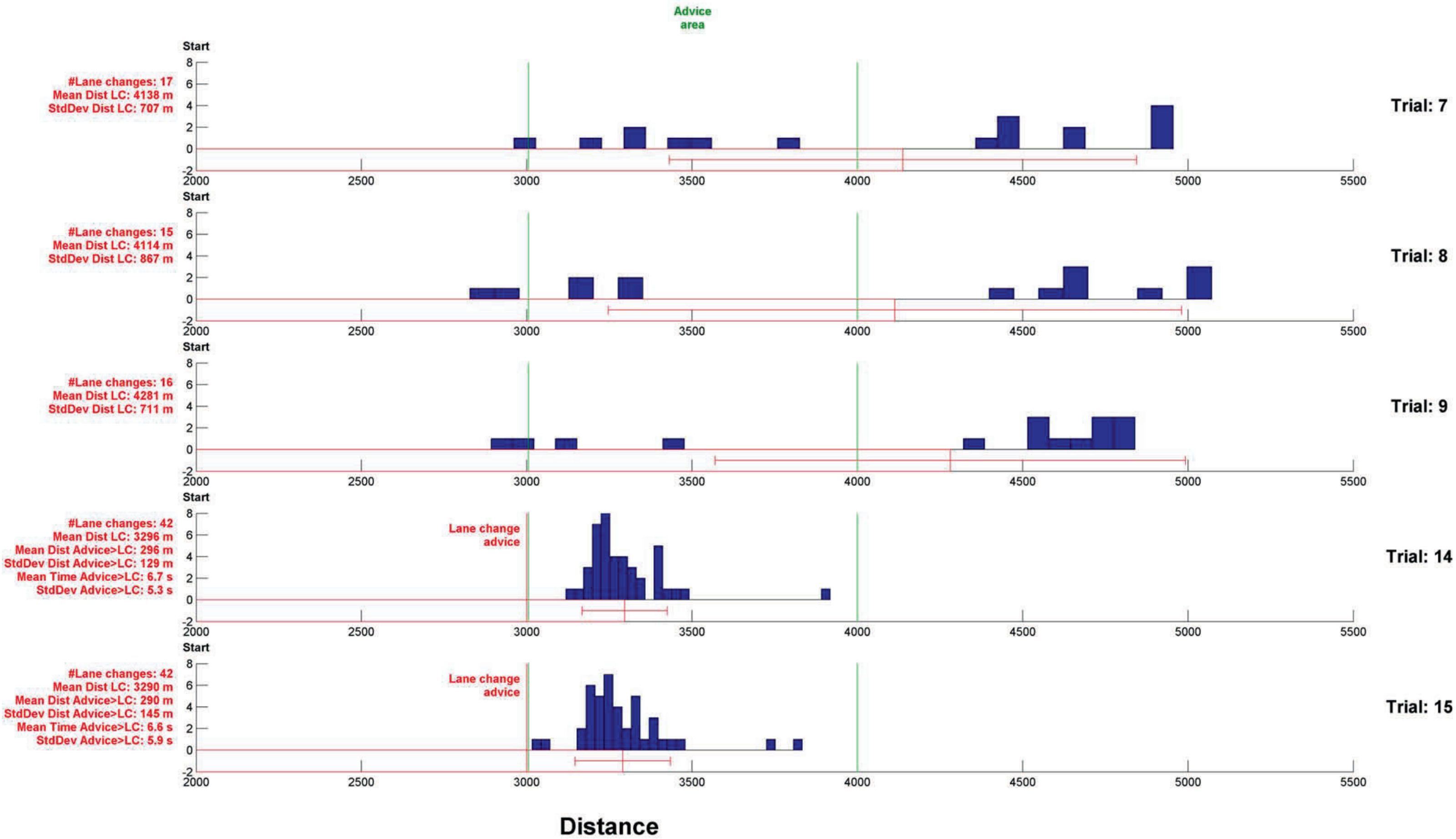
E.11 Lane change distance at LANE DROP



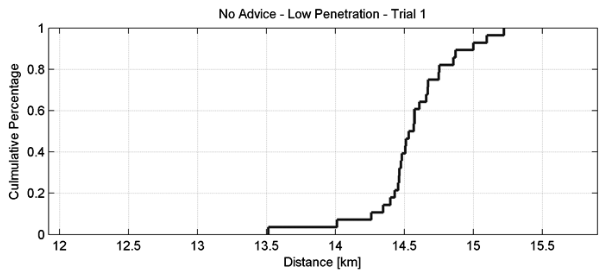
E.11 Lane change distance at ON-RAMP

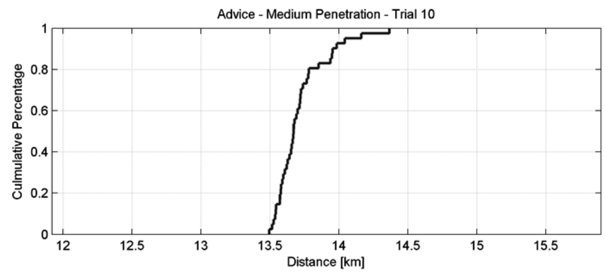


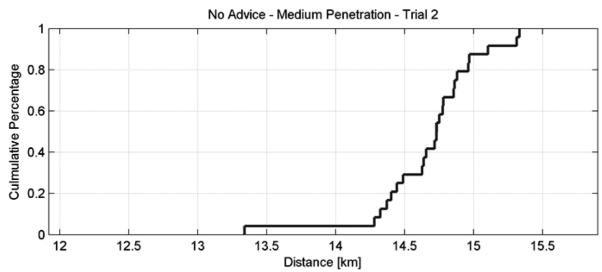
E.11 Lane change distance at STRAIGH MOTORWAY

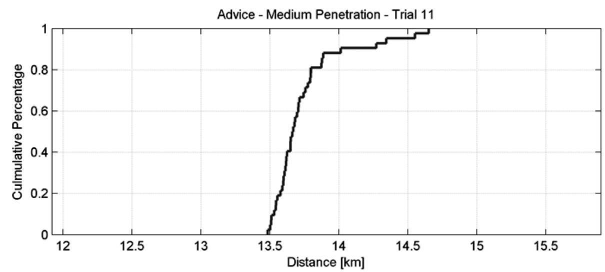


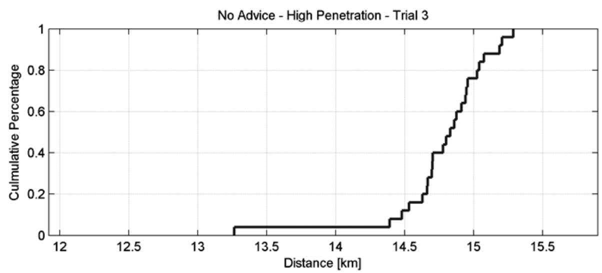
E.12 Cumulative frequency distribution of lane changes at LANE DROP



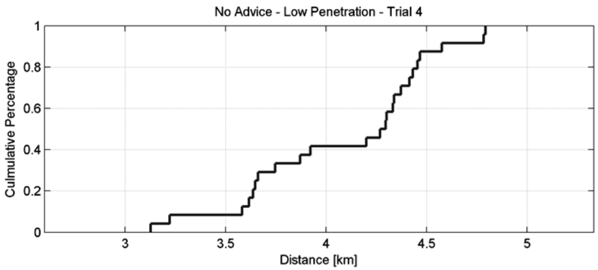


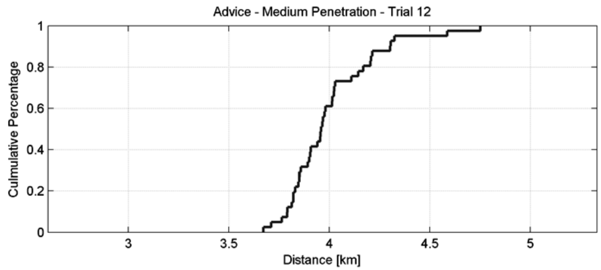


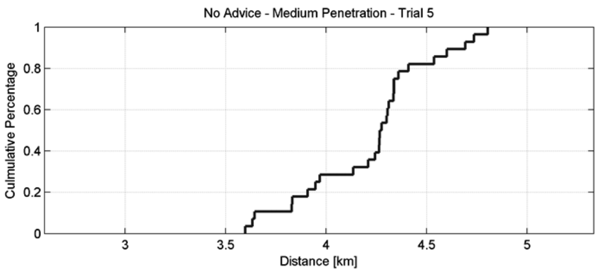


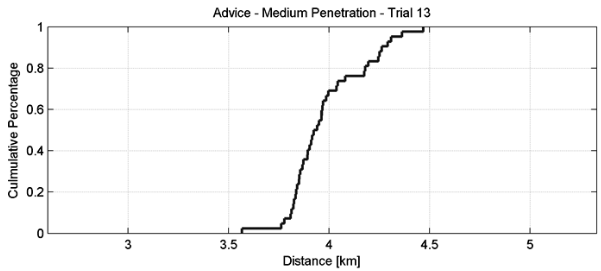


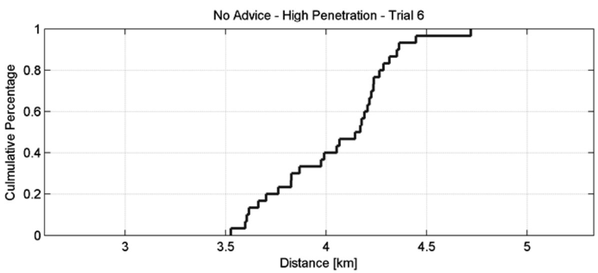
E.12 Cumulative frequency distribution of lane changes at ON-RAMP



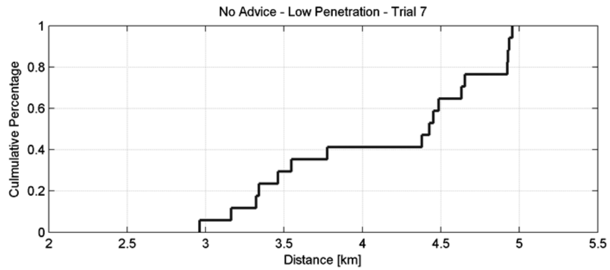


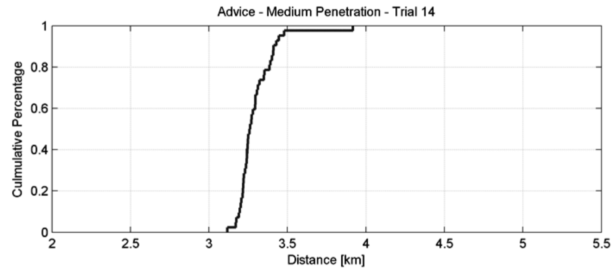


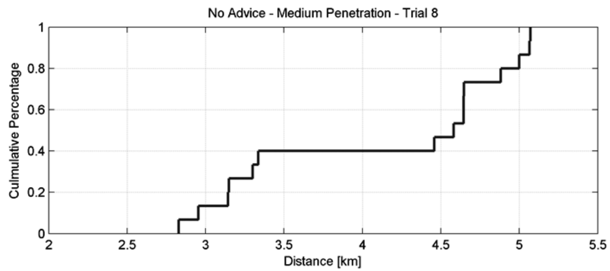


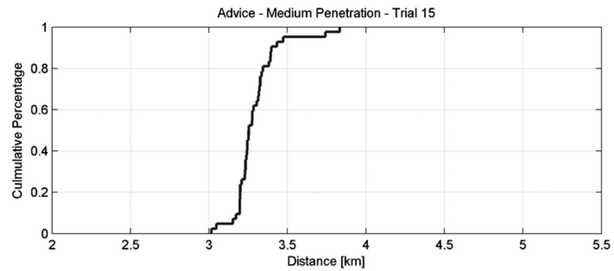


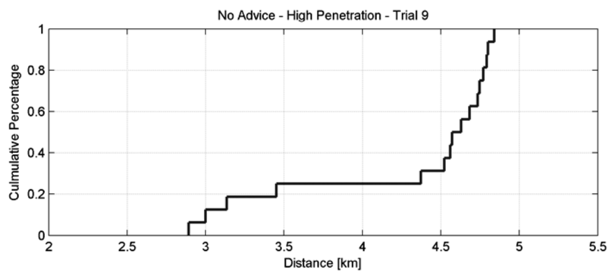
E.12 Cumulative frequency distribution of lane changes at STRAIGH MOTORWAY



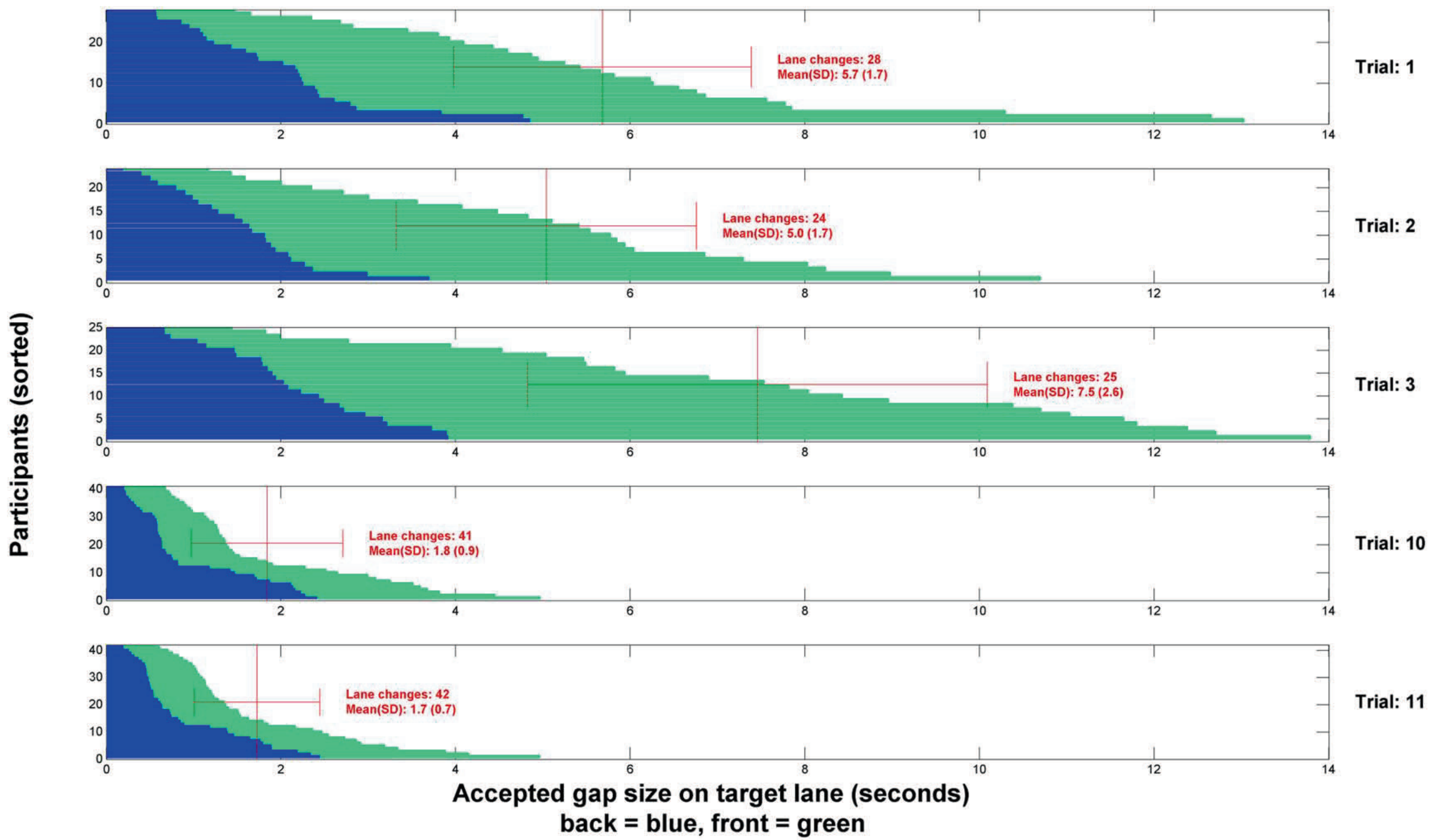




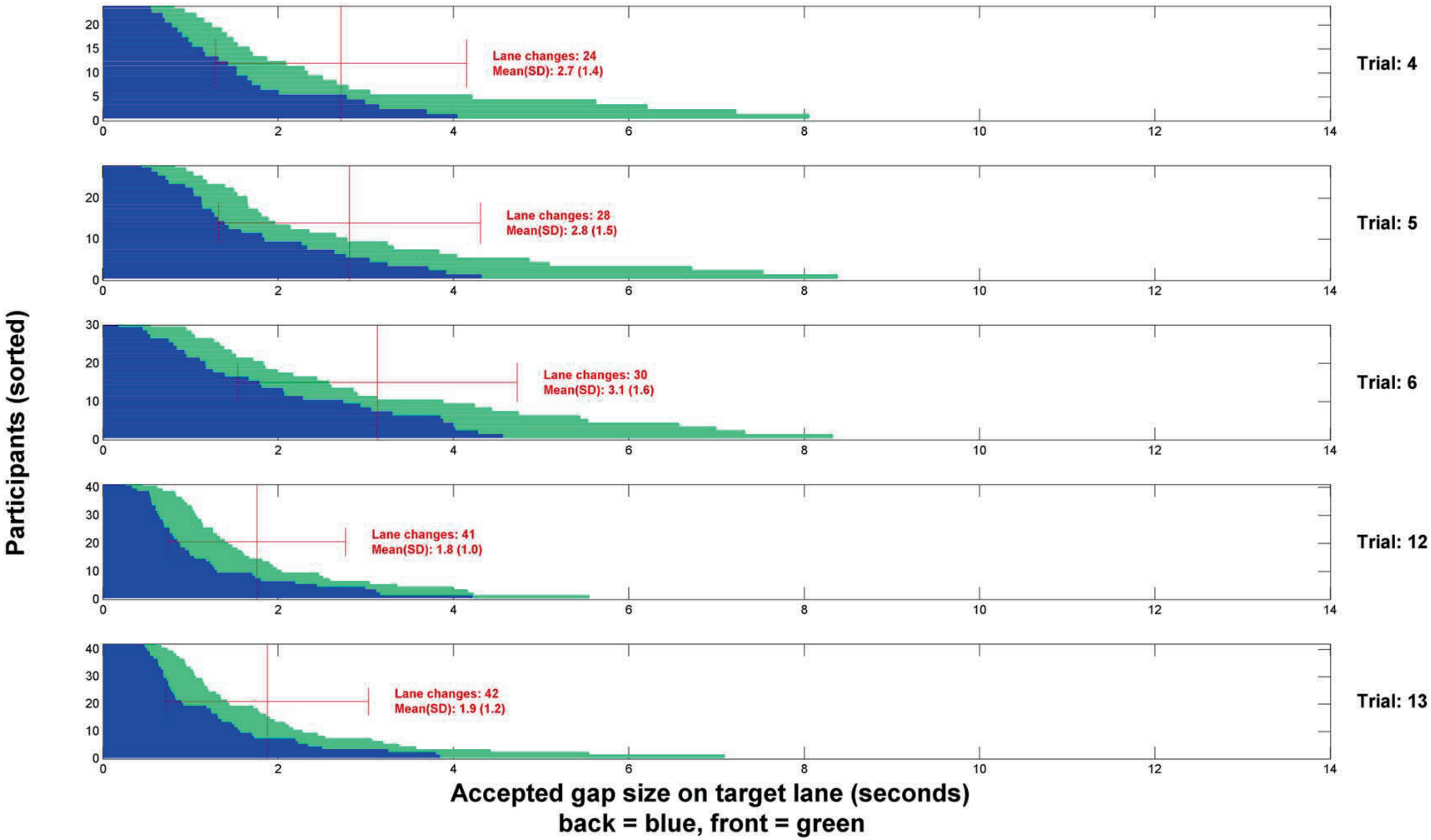




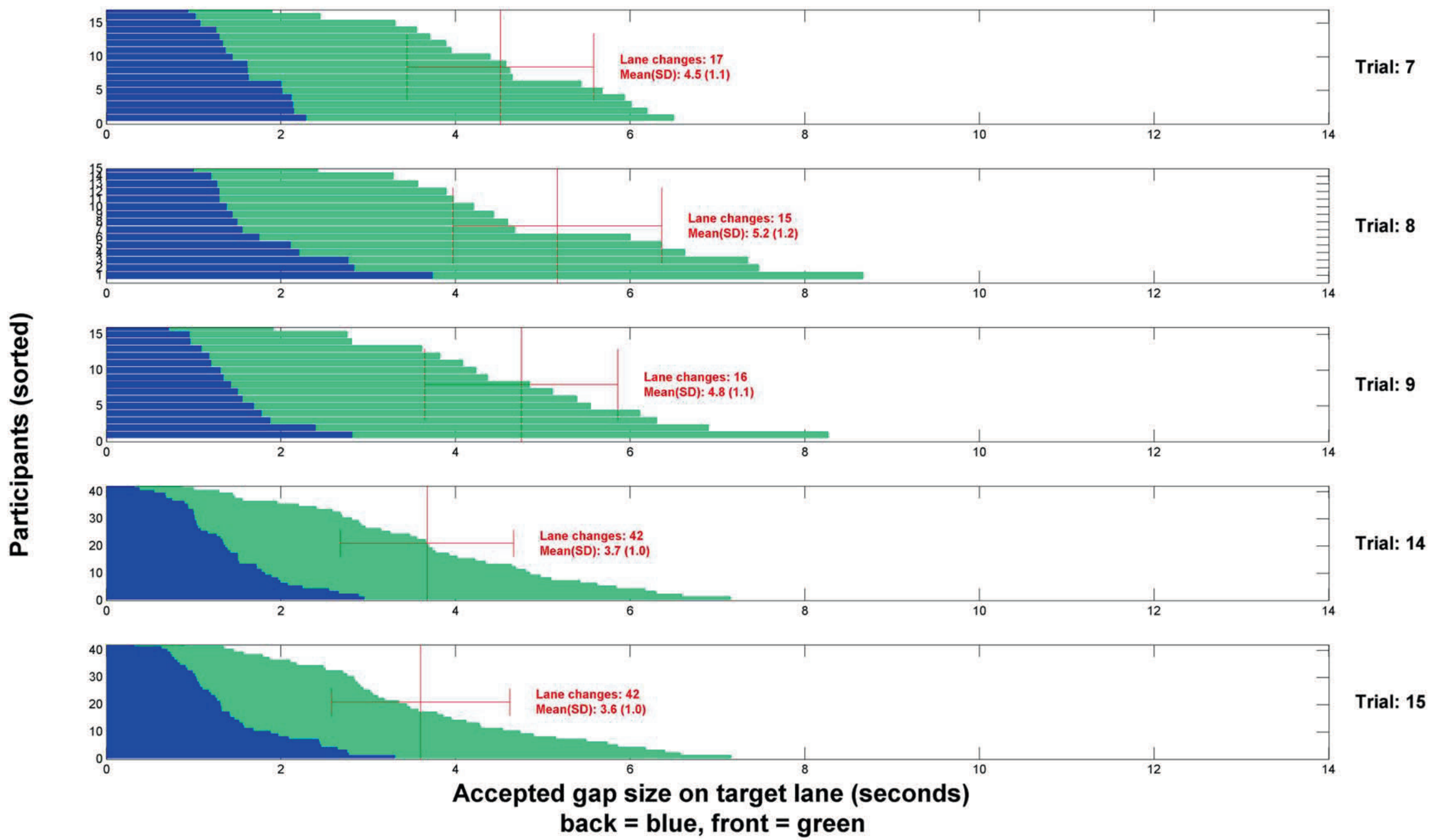
E.13 Gap size on the target lane at the time of line crossing at LANE DROP



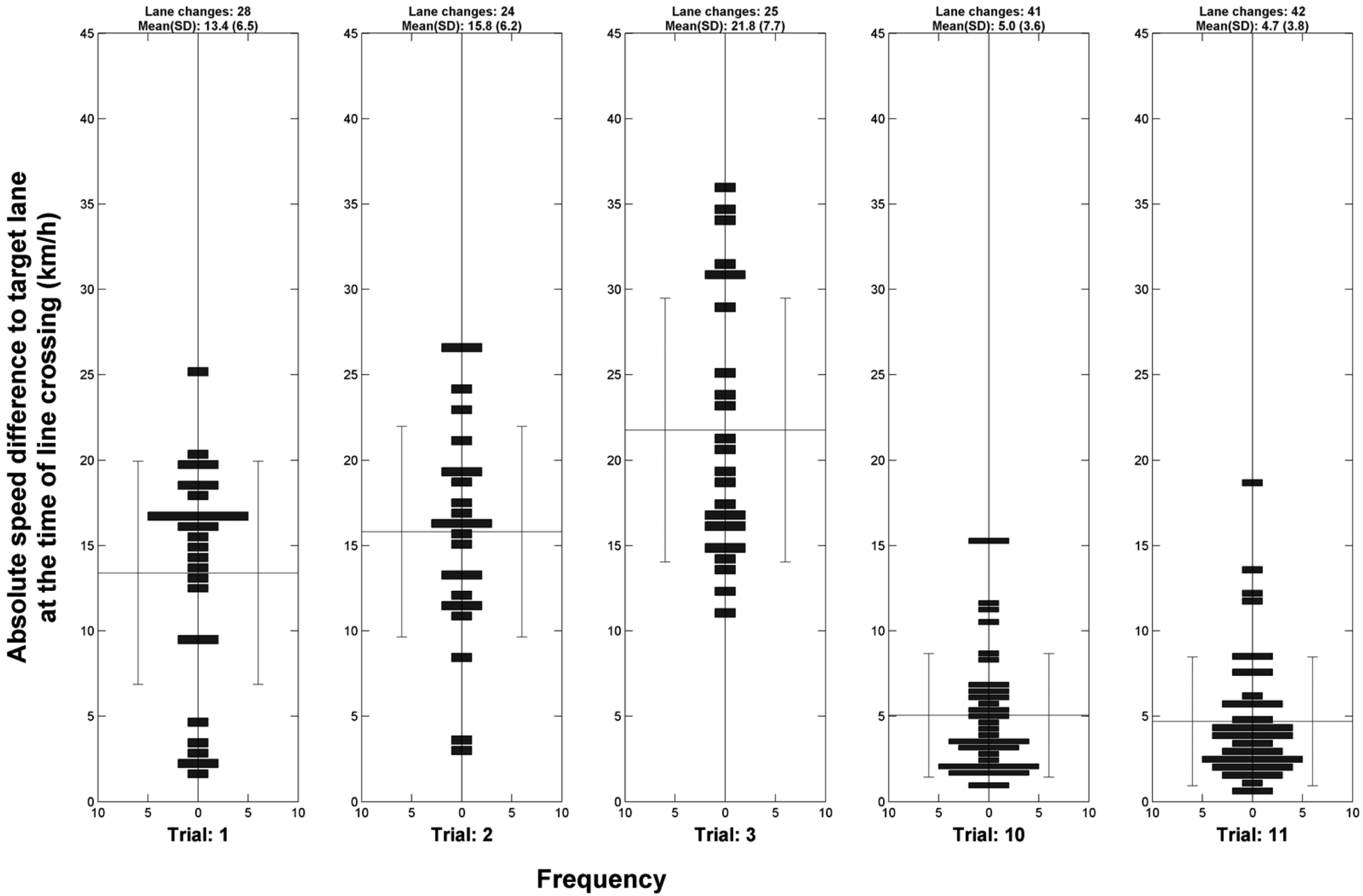
E.13 Gap size on the target lane at the time of line crossing at ON-RAMP



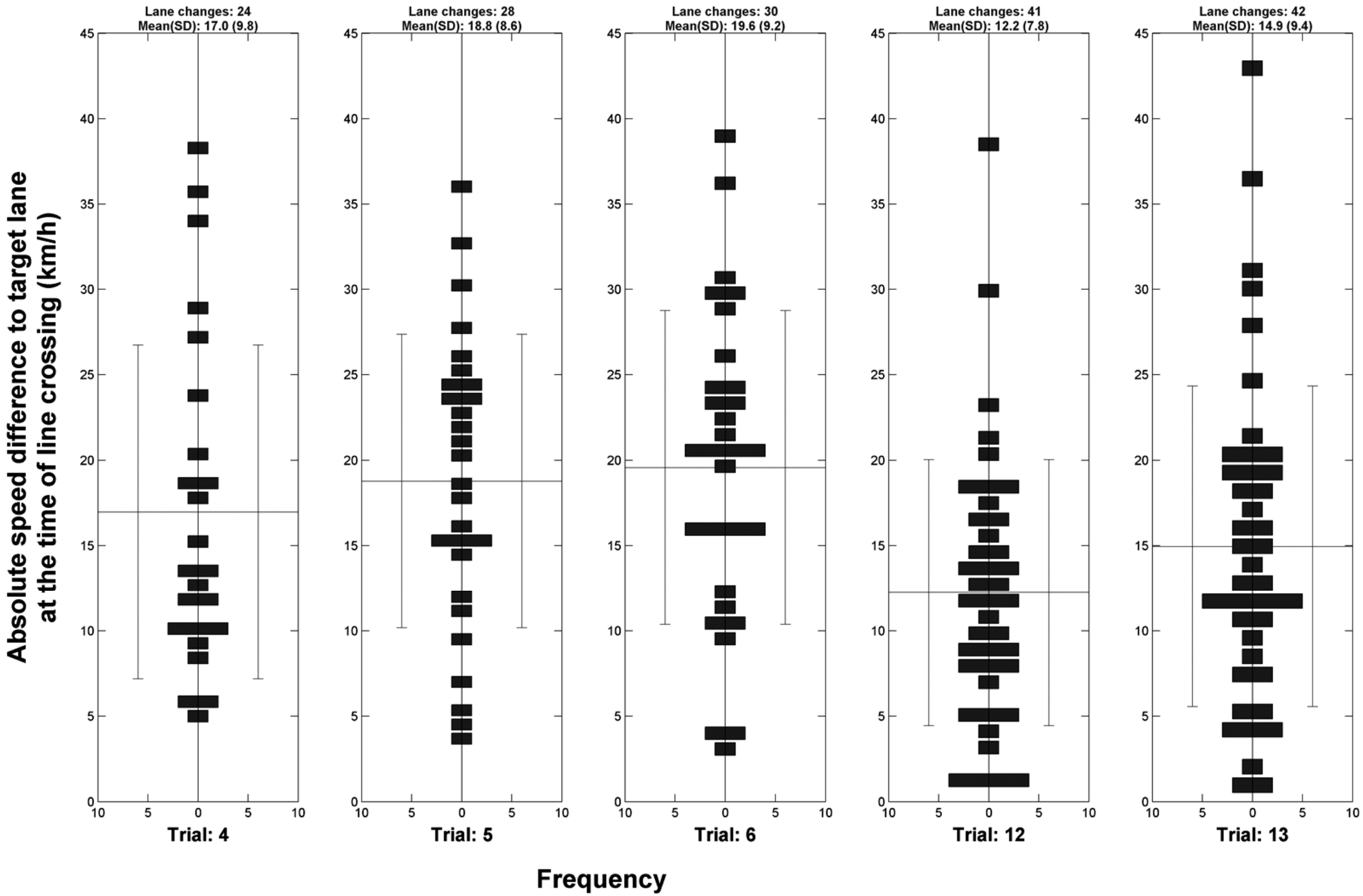
E.13 Gap size on the target lane at the time of line crossing at STRAIGH MOTORWAY



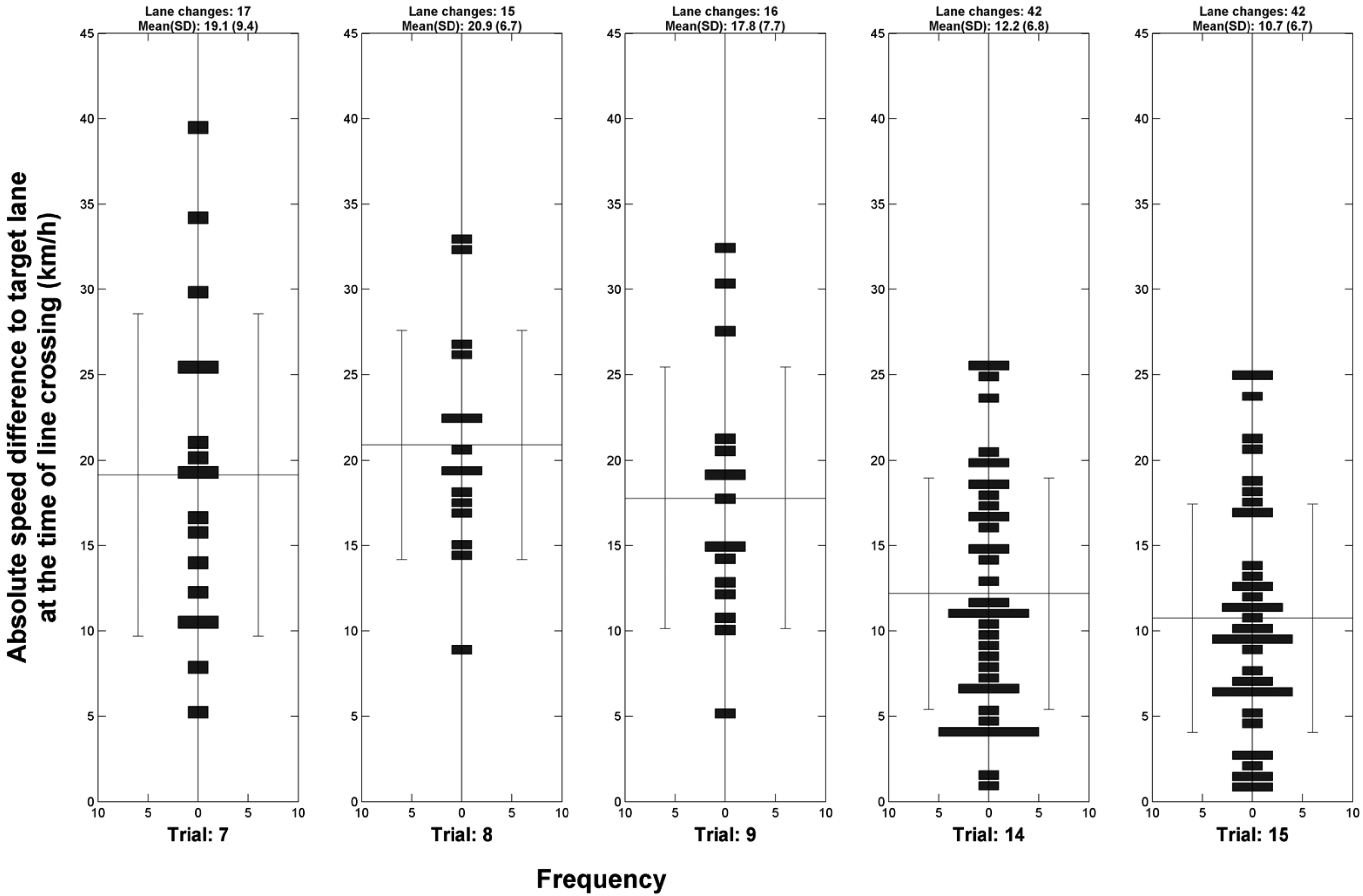
E.14 Speed difference to the target lane at the time of line crossing at LANE DROP



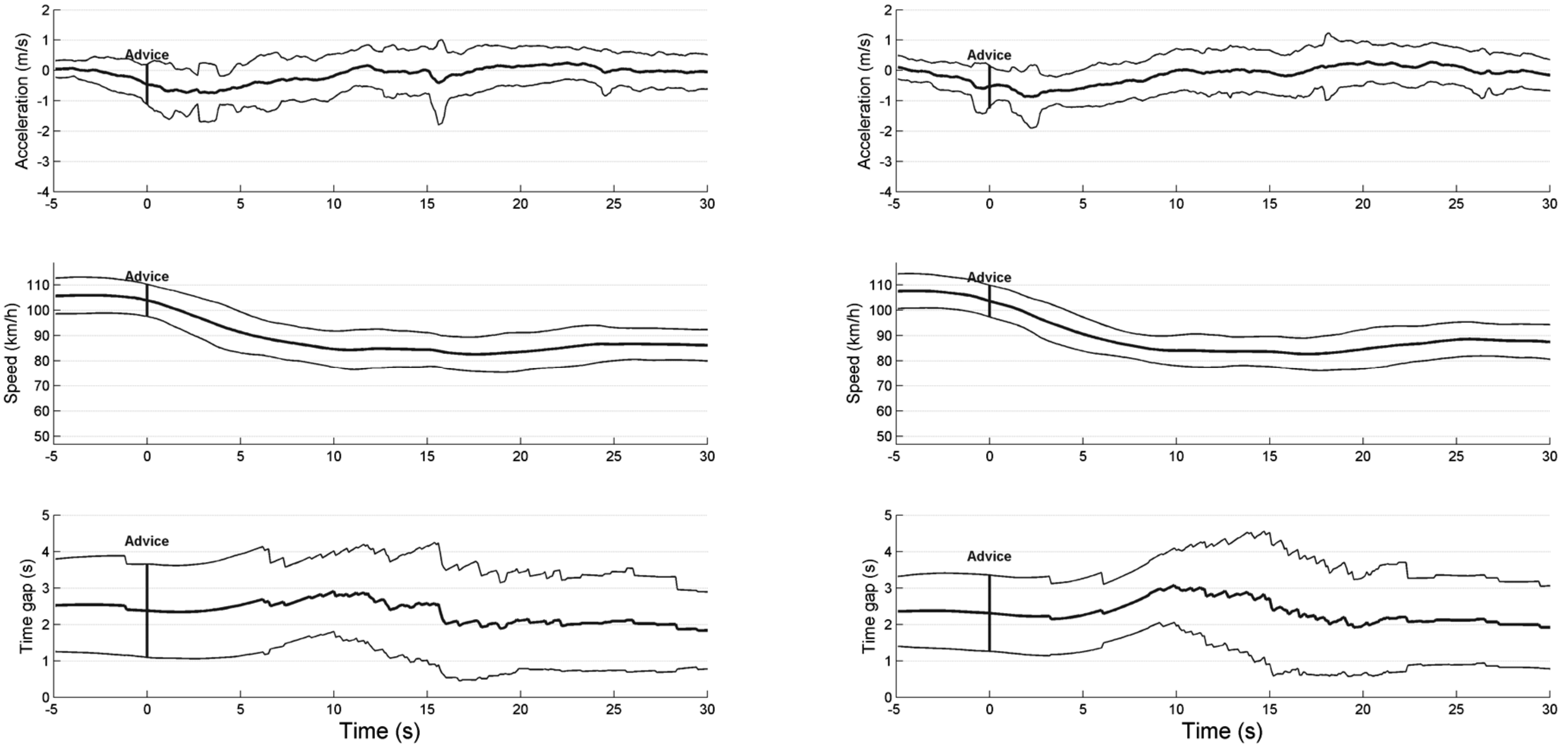
E.14 Speed difference to the target lane at the time of line crossing at ON-RAMP



E.14 Speed difference to the target lane at the time of line crossing at STRAIGH MOTORWAY

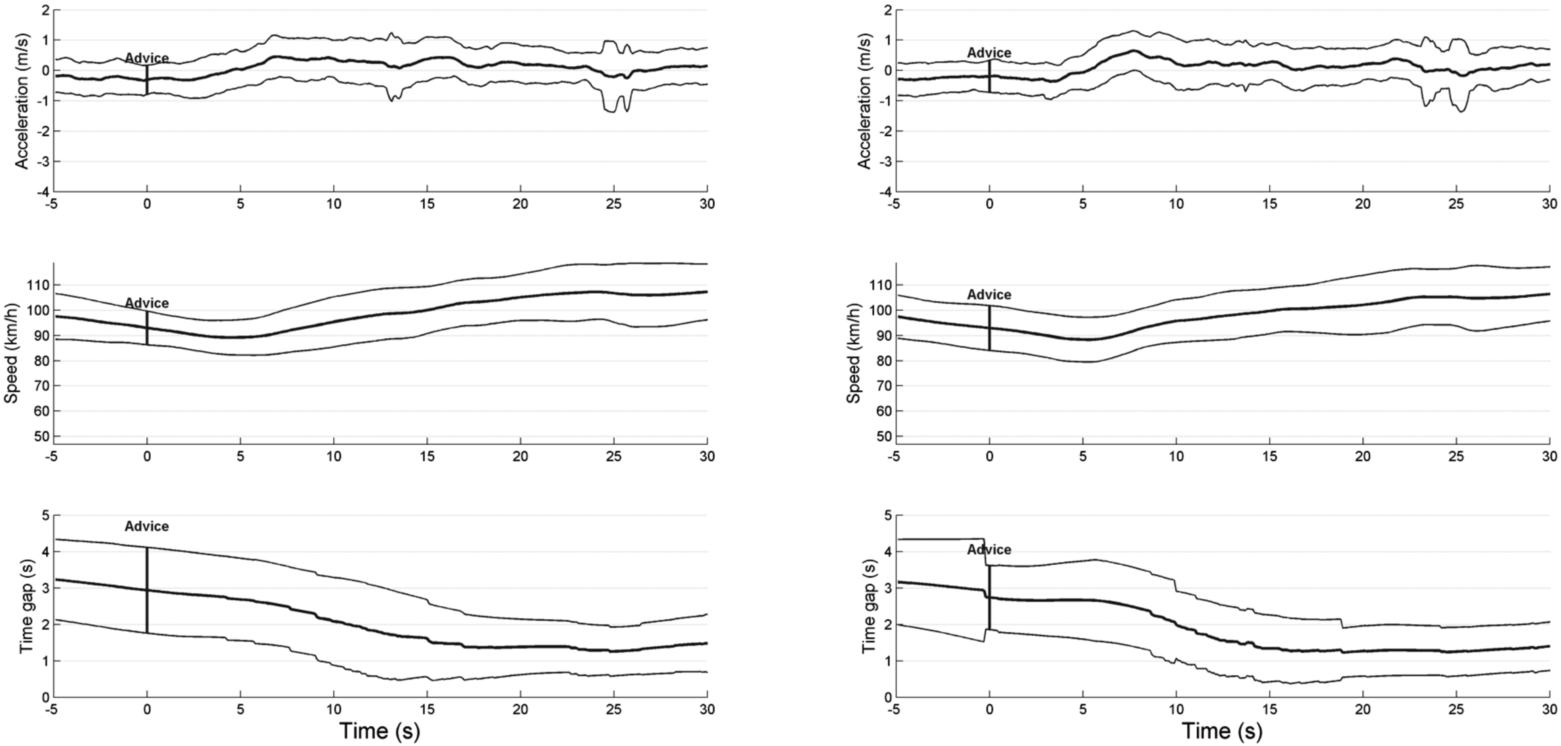


E.15 Speed development after speed advice at LANE DROP



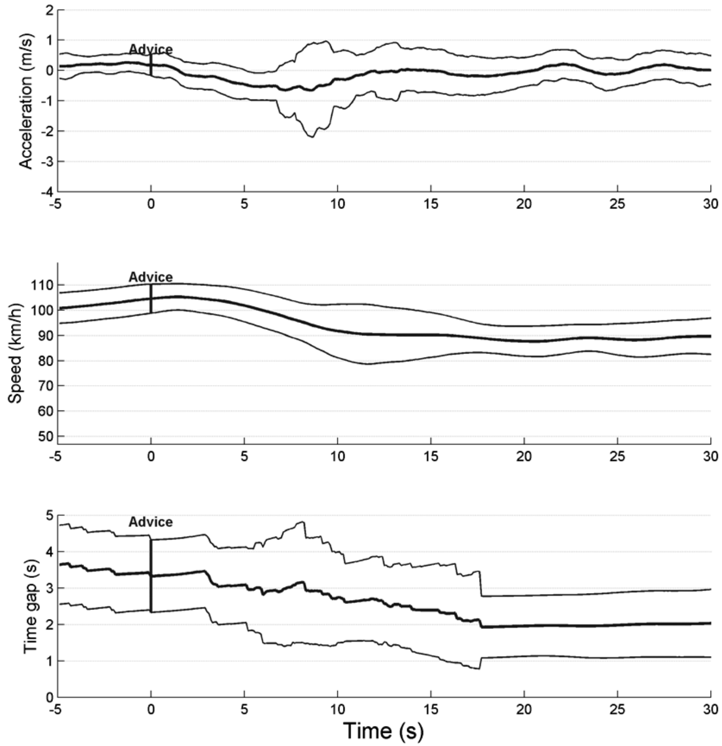
Note. Inner line denotes mean value, outer lines denote standard deviation

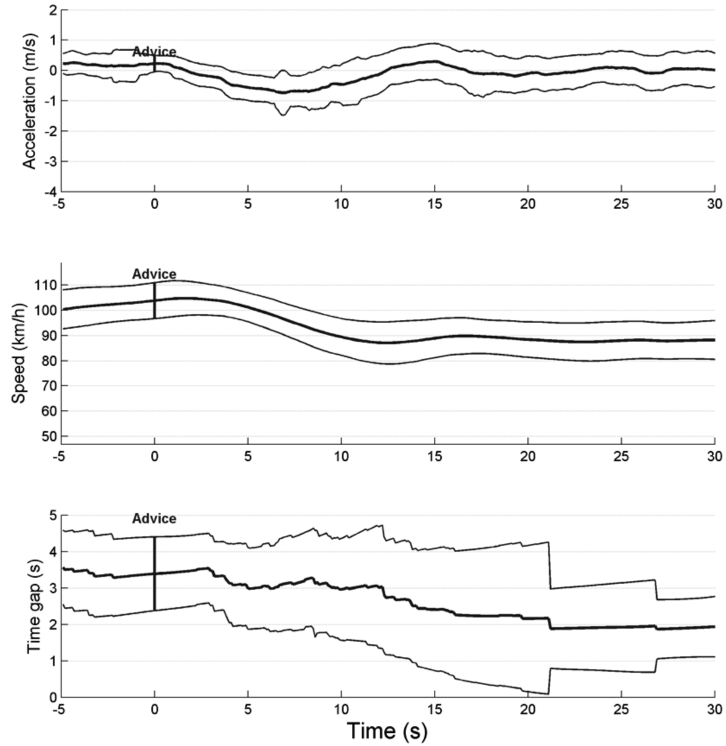
E.15 Speed development after speed advice at ON-RAMP



Note. Inner line denotes mean value, outer lines denote standard deviation

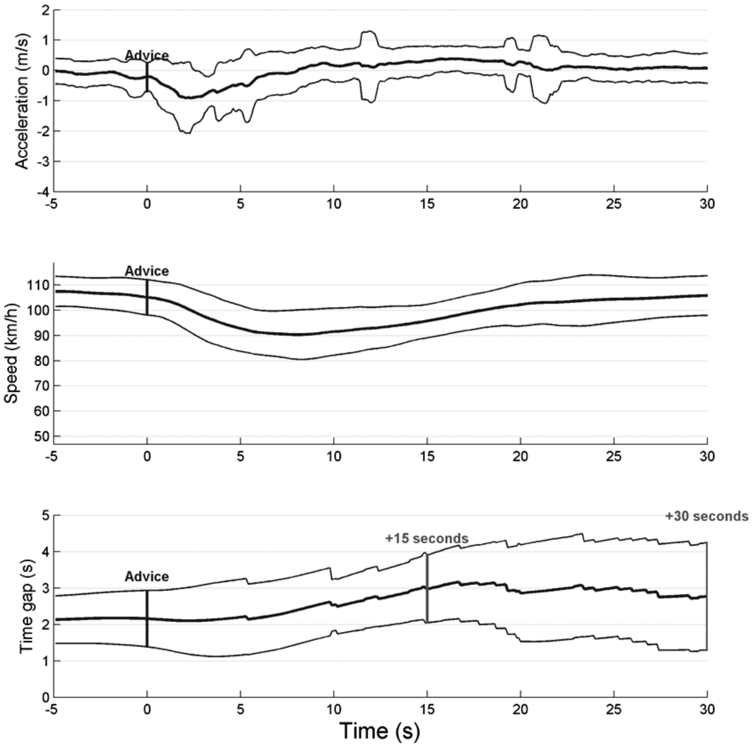
E.15 Speed development after speed advice at STRAIGHT MOTORWAY

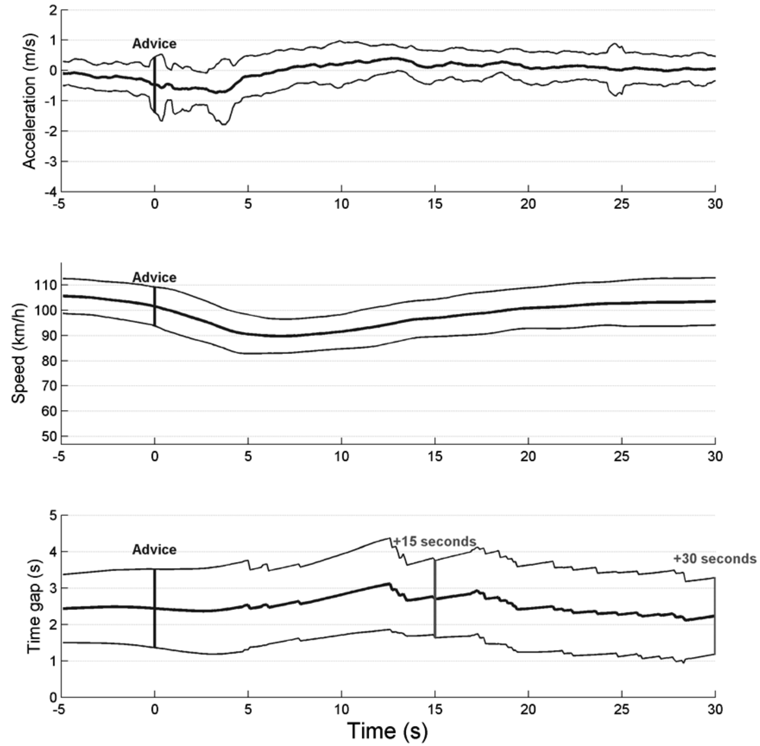




Note. Inner line denotes mean value, outer lines denote standard deviation

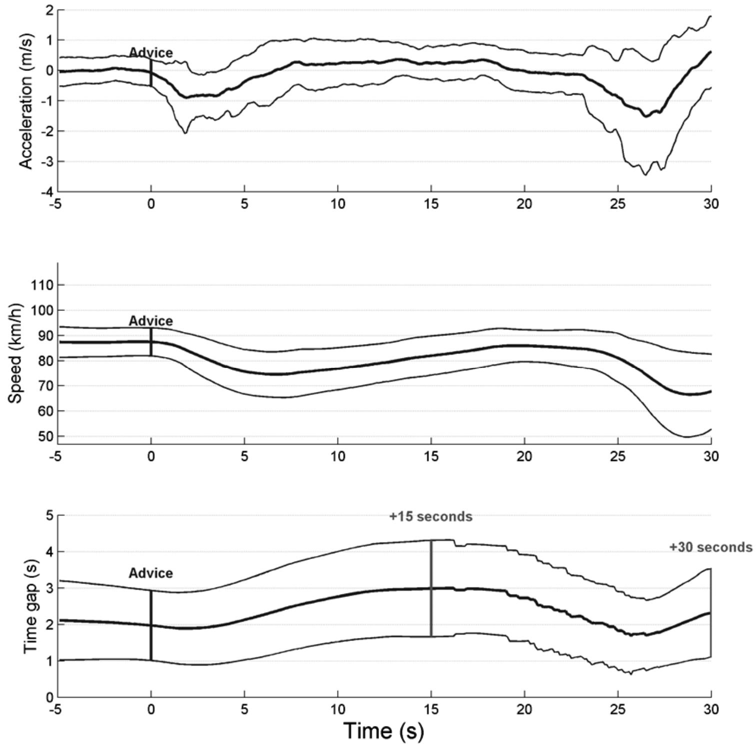
E.16 Gap size development after gap advice at LANE DROP

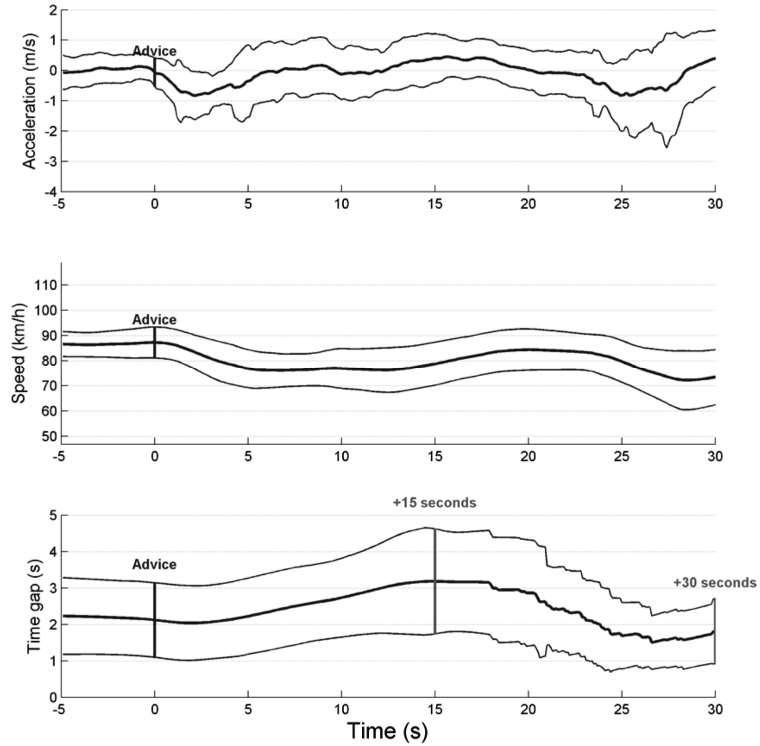




Note. Inner line denotes mean value, outer lines denote standard deviation

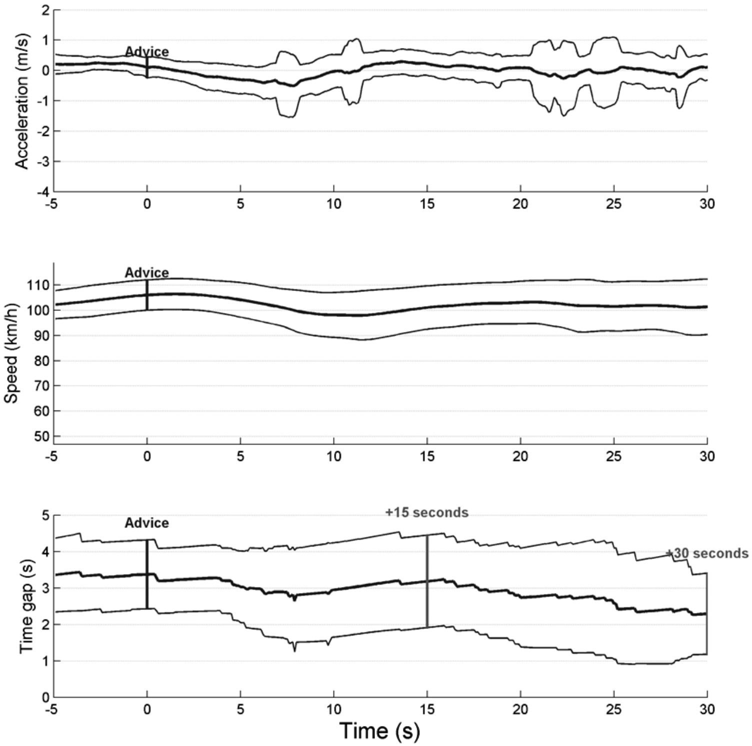
E.16 Gap size development after gap advice at ON-RAMP

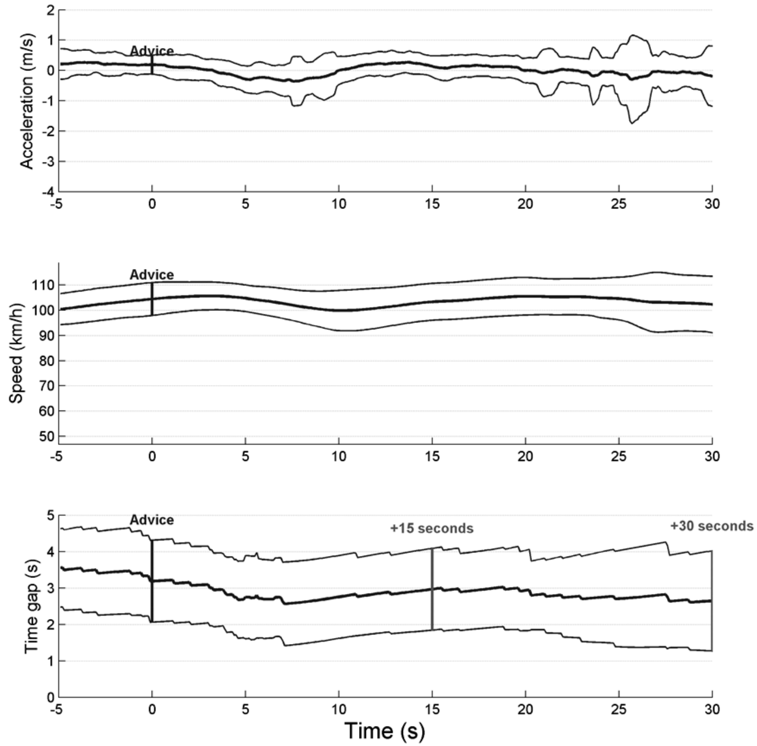




Note. Inner line denotes mean value, outer lines denote standard deviation

E.16 Gap size development after gap advice at STRAIGHT MOTORWAY





Note. Inner line denotes mean value, outer lines denote standard deviation

F. On-road study

F.1 Screener questions for potential participants (on-road experiment)

Thank you for your interest in participating in our experiment. We ask you to answer the following question honestly and to the best of your knowledge.

1. What kind of driver support system do you have in your vehicle. More than one choice is possible.
   - Navigation system
   - Cruise Control
   - Adaptive Cruise Control
   - Blind Spot Warning
   - Lane Departure Warning
2. How many kilometres do you travel annually?
3. How long have you been in possession of a driver's license?
4. What is your motivation to participate in the study?
5. Have you ever participated in a similar study in the past? If so, briefly describe your experience.
6. Do you feel uncomfortable by the thought of having your voice recorded during the experiment? *(please answer with YES or NO)*
7. In what field do you work (e.g. health, security, construction)?
8. May we contact you on a short term if another participant does not show up at the arranged time? *(please answer with YES or NO)*
9. *If you have answered question no. 8 with YES:* Are there days of the week or times in a day where you would prefer to be contacted as a replacement?
10. *If you have answered question no. 9 with YES:* Are there days of the week or times in a day where you would prefer NOT to be contacted as a replacement?
11. May we contact you for future experiments or surveys? *(please answer with YES or NO)*

F.2 Explanation of the on-road experiment

Currently, a new form of driver support is being developed, whose aim it is to improve traffic flow on motorways during rush hours. Unique about the system is that the driver is at all times fully in control of the vehicle. The system merely gives an advice on the optimal speed, headway and lane that the driver should choose to improve traffic flow and throughput. Of course for the success of the system it is required that drivers are able to follow the given advice.

- Now, please have a look at the additional information about the advice strategy that is used by the system to improve traffic flow.

During the experiment you will repeatedly drive a Toyota Prius on the A20 motorway between Gouda and Rotterdam. While driving in the direction of Gouda, you will receive advice messages on your speed, headway and lane. You are free to decide whether to follow the advice or not. You are asked to think aloud about the advice messages that you receive. This includes your thoughts about the information and the advice in the given situation. In case you decide not to follow a given advice, please indicate your reason for that choice.

- Now, please have a look at the additional information regarding the think aloud protocol.

Before and after the experiment your opinion about the system will be assessed in a questionnaire. During the experiment, your statements regarding the advice, as well as the traffic scene in front of you will be recorded with a video camera and a microphone.

The advice messages will be delivered through loudspeakers in the vehicle. In addition, the in vehicle display will show icons that support the comprehension of a given advice message. The advice was designed in a way that reduces distraction from the driving task. However, if you feel that the advice messages hinder proper execution of the driving task please tell the experimenter immediately.

In case you wish to abort the experiment you can do so at any time. The data of the experiment will be confidential. If you have any remaining questions please ask the experimenter now.

F.3 Explanation of the think aloud method

Imagine that you are on your way from Rotterdam to Gouda and you have decided to use the advisory system on that trip. You are not yet familiar with the system and you are curious how it works. During the trip, the system will provide you with a description of a predicted traffic situation further down the road, followed by an advice to adjust you driving behaviour. The description of the situation is intended to provide a motivation for the advice, in a way the reasons why the system is providing you with the advice. We are interested in your reaction to the motivation as well as the advice message.

Try to verbalize every thought that goes through your head after hearing the motivation and advice combination. We are especially interested in your intention to follow or reject the advice. Questions that you may answer are:

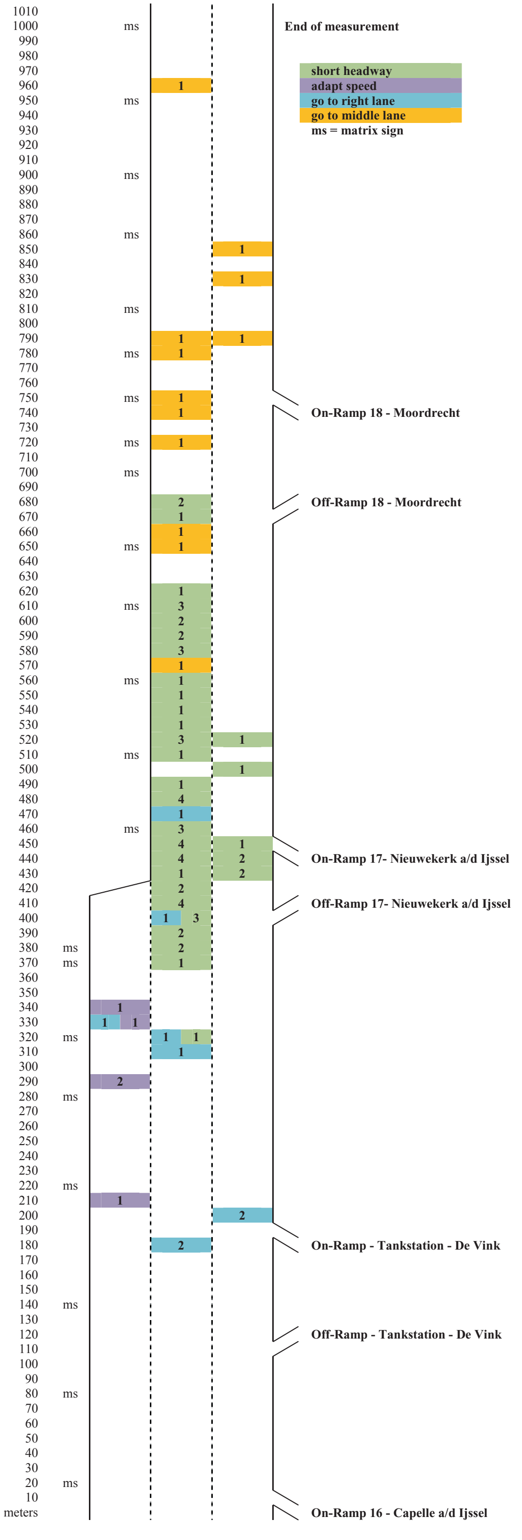
- Do you find it difficult understand the motivation?
- Do you find it difficult to understand the advice?
- Do you understand why you receive the advice in the given situation?
- Do you think that the advised action is suited for the situation that you are approaching?
- What do you think is the effect of following the given advice?
- Do you feel capable to execute the advised action?
- Do you think that following the advice is safe in the given situation?

Please be honest in your opinion about the advice and the information, even if that means criticising the system. An honest reaction helps us more than if you remain silent due to politeness.

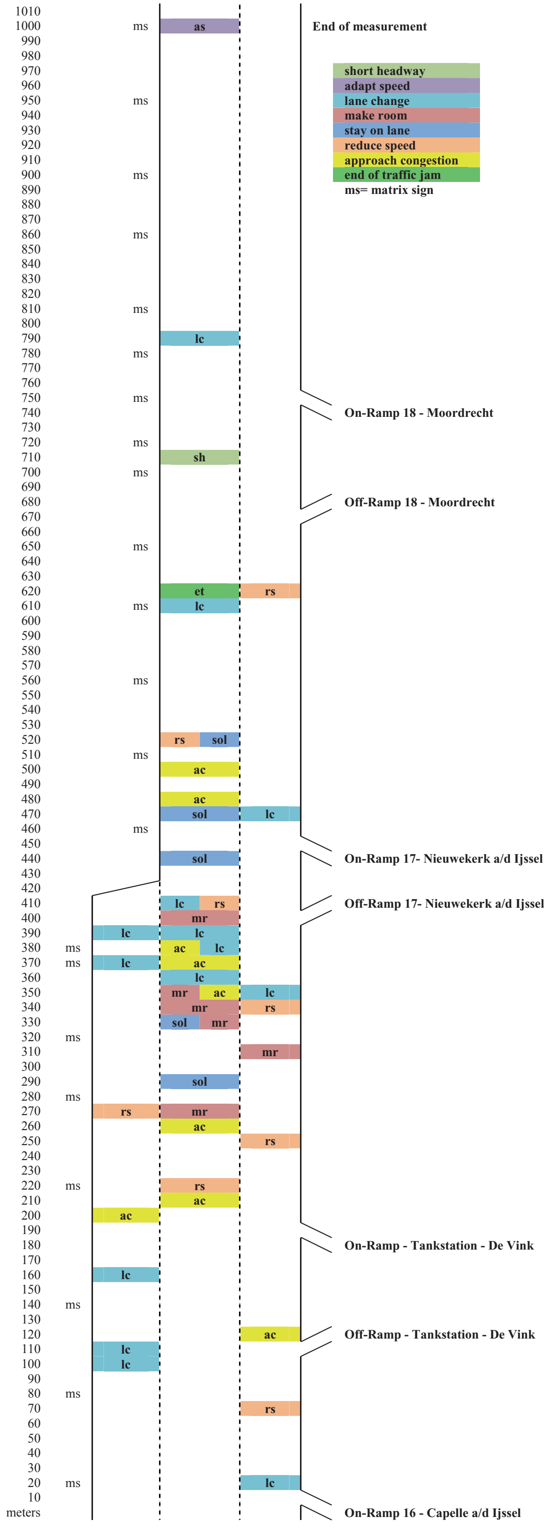
If you do not want to follow the advice, for any reason, please indicate what led to your decision. Do not be afraid that the reason you provide may not justify your decision. Every reason you give is valid and provides us with valuable insight in the drivers' reactions to the advice.

You do not have to state a reason for actions that you initiate without being advised to do so (e.g. overtaking, lane changes or headway adjustment).

F.4 Spatial location of the advice messages



F.5 Spatial location of the request for information and advice



Cooperative In-Vehicle Advice: Summary

Congestion is a major problem in today's society, associated with high economic costs due to lost productivity hours, environmental pollution, higher accident risk, and increased vehicle operating cost (such as wearout and fuel cost). While there are several causes of congestion, it is often the result of traffic demand approaching or exceeding the available road capacity, coupled with disturbances in traffic flow. The behaviour of the human driver influences the onset of congestion by either increasing traffic demand, temporarily reducing road capacity or causing traffic flow disturbances.

Efforts to reduce congestion in the Netherlands range from expanding the road infrastructure to a more efficient use of the existing infrastructure. Here, the development of Intelligent Transport Systems (ITS) plays an essential role in managing traffic more efficiently. Cooperative ITS promise to make road transport more safe, predictable and efficient by sharing information and managing traffic. In this context, cooperative, automated driver support systems are studied in several European projects. These systems aim to make driving more efficient by taking over parts of the driving task from the driver. However, these systems face technical, legal and human factors issues that make their implementation in the near future less likely.

A near term alternative to automated systems are systems that improve driver behaviour by providing information and advice to drivers. The present thesis describes the human factors research during the development of a Cooperative In-Vehicle Advice (CIVA) system, that advises drivers about their tactical driving behaviour (that is speed, gap, and lane choice) in order to improve traffic flow efficiency in motorway near peak hour traffic. Drivers receive individualized advice messages via an in-vehicle, nomadic device. Therefore, the advice is restricted to the visual and auditory modality. Individual messages are adjusted to a drivers' current lane, gap size and speed, the actual speed limit as well as the desired route. The system will not take over control of the vehicle. Therefore, the effect that the system will have on traffic flow will depend on the drivers' ability and willingness to follow the advice messages. The studies in this thesis were developed to provide contributions to answering the following questions:

- Are drivers able to follow CIVA?
- Are drivers willing to follow CIVA?
- Are drivers willing to adopt the CIVA system?

Data to answer these questions was obtained in a survey among potential users, several driving simulator experiments and a study in real world motorway traffic.

User survey among potential users of CIVA

The focus of the survey was on the evaluation of the conceptual CIVA system by potential users. The initial reaction of drivers to a description of the idea behind the system was assessed as well as factors that would influence the adoption and rejection of the system by

users. In order to indicate whether the system targets driver behaviour that is seen as problematic among road users, participants of the survey were asked to state their annoyance with other road users' speed, gap and lane use behaviour.

Factors that would facilitate the adoption of the system include a clear benefit from using the system and the certainty that a sufficient number of other road users would use the system as well. A lack of trust in the system has been identified as a factor that in particular can influence the rejection of CIVA. Furthermore, participants would reject a system that gives advice which conflicts with their own opinion about the optimal behaviour in a given situation.

Among the most annoying forms of driver behaviour were late, aggressive merging at a lane drop, on-ramp or off-ramp, driving left without a cause, hindrance with merging at a lane drop, on-ramp or off-ramp, early merging at a lane drop, motorway entrance or exit and merging with speed differences at a lane drop, on-ramp or off-ramp. These results show that the systems advice targets driver behaviour that is relevant to road users.

The validation of the University of Twente driving simulator

In order to study gap choice behaviour in the driving simulator of the University of Twente the simulator had to be validated for the task. An experiment compared gap choice behaviour in a driving simulator and in an instrumented vehicle. Participants carried out instructions to either change their gap size to a specific value or to choose a gap as they would normally do. The speed of the lead vehicle (80, 100 or 120 km/h) as well as the target gap size (1, 1.5, 2 seconds) were varied between trials. Specific gap instructions were provided in seconds as well as metres. The attained gap sizes were compared between the virtual and the real environment. Results show no significant difference between gap choice in the simulator and on a real road, neither for self-chosen nor for instructed gaps. Therefore, the results provided support for the use of the driving simulator in studies on gap choice.

Drivers' ability to follow specific gap advice

It was proposed to provide gap advice in the terms of a specific target gap size that has to be attained by drivers. An experiment was conducted to assess the ability of drivers to carry out specific gap advice formulated as a distance gap (meters) or time gap (seconds). Results show that drivers were able to follow the instructions of the gap advice to some extent, both for instructed time gap and distance gap. The differences in the chosen gap sizes for advice provided in seconds and to advice in meters was small. However, drivers were not able to attain the exact gap sizes that were advised. This was the case for various speeds and various advised gap sizes.

Furthermore, it was assessed whether some form of support would help drivers in attaining the advised gap size more accurately. Half of the participants received a tone at the time the advised gap size was reached. When participants were advised to reduce their gap to 2 seconds, support increased the accuracy of the attained gap size. However, when participants were advised to increase their gap to 2 seconds, support resulted in a lower accuracy compared to no advice.

Drivers' inability to follow specific gap advice with great accuracy reduced the merit of a specific formulation for gap advice, in favour of a less specific formulation. Less specific gap advice was provided in terms of a manoeuvre that participants had to carry out (i.e. "keep a short but safe gap", "leave room for merging vehicles").

Effect of CIVA advice on driver behaviour

The behavioural response of drivers to the advice was assessed in a driving simulator experiment. The effect of different advice messages on driver behaviour was assessed at three road locations: a lane drop, an on-ramp and a weaving section. The presented advice was a lane change advice, that was either preceded by an advice to adapt the speed to the speed of the target lane before changing lanes (in the lane drop and the on-ramp scenario), or by an advice to increase the gap size to the lead vehicle to 2 seconds (in the weaving section scenario). The experiment had three broader objectives.

First, it was assessed whether advice messages lead to the intended behavioural response. Also, the effect of two specific factors on the behavioural response was assessed:

1. The effect of providing the related advice messages separately or together.
2. The effect of low and high traffic density during compliance.

In addition, participants' self-reported mental effort when following the advice was assessed. Also, acceptance of the system before and after exposure to the advice messages in the driving simulator was measured.

Second, questions were studied that emerged from previous studies. With regard to the survey that was carried out earlier, it was evaluated whether compliance to the advice may lead to driving behaviour that has been deemed annoying by other road users. Furthermore, the experiment on gap choice accuracy indicated that drivers were not able to attain an instructed gap with great accuracy. In this experiment, other vehicles showed a more dynamic driving behaviour (e.g. changing speed and lanes), compared to the first experiment. It was assessed whether gap choice in this traffic environment would lead to similar levels of accuracy compared to the previous experiment.

Third, behavioural response parameters were recorded that can be used to model the behavioural response of virtual drivers in traffic simulations. The following behavioural response parameters were assessed:

- Distance to a physical location (that triggered the lane change advice) at time of lane change
- Time from a lane change advice to a lane change
- Accepted gap on the target lane at the time of a lane change
- Relative speed to the target lane at the time of a lane change

- Gap size to lead vehicle before/after headway advice

Results show that lane change advice led to lane changes taking place in a smaller region just after the advice was given. However, for the weaving section no difference was found between lane change distance with or without a lane change advice. Participants changed lanes as soon as the uninterrupted road marking ended.

It was tested whether drivers would change lanes hastily in order to comply to the advice, thereby accepting smaller gaps. Such behaviour may have caused unsafe situations and irritation. However, accepted gaps following an advice were not smaller, compared to regular driving.

During a lane change, the absolute difference in speed (i.e. higher or lower) to vehicles on the target lane was reduced following the “adjust speed before lane change” advice. However, a speed difference to the target lane remained in the on-ramp scenario. Also in the on-ramp scenario, when there was a time interval of one minute between the speed advice and the lane change advice, the ‘adjust speed to the left lane’ advice tended to result in a premature lane change to the left.

Gap advice led to an increase in gap size , however drivers also increased their gap size in situations where they were already driving at or above the target time gap size of two seconds.

The results indicate that in most cases the advice led to the intended adjustment of driving behaviour. Driver’s self-reported mental workload was not increased by adhering to the advice, compared to unadvised driving. Acceptance of the system was reduced as a result of experiencing the advice in the driving simulator.

Ability to estimate compliance to the system

An experiment was devised to determine whether drivers are able to distinguish between different rates of compliance to the CIVA system and whether the ability was affected by additional information about the advice messages that drivers received in different situations.

Before the experiment half of the participants received additional information about the advice strategy that was used by the system to coordinate traffic in different situations. Then, all participants drove several trials in dense traffic conditions on different road layouts (i.e. lane drop, on-ramp, straight motorway) with varying levels of simulated system compliance of other road users. After each trial, participants were asked to estimate the penetration rate of the system in that trial and their confidence with the estimate.

Results indicate that participants were not able to distinguish between different levels of system penetration. Participants, who had received additional information, systematically underestimated the actual penetration rate.

Effect of information on system acceptance

Another experiment was conducted to assess the effect of information about the advice strategy on the perceived comprehensibility of the advice, the perceived outcome of compliance to the advice as well as acceptance of the system. Furthermore, the second part provided additional parameters of drivers' behavioural response to CIVA. The same information about the advice strategy was used that had already been used in the previous experiment.

All participants received advice while driving several trials at the same locations as in the previous experiment. After each trial, participants indicated whether they understood the reason for the advice as well as whether they thought compliance to the advice had led to an advantageous or disadvantageous situation for them. Overall acceptance of the system before the experiment was compared to acceptance after participants had experienced the advice in the driving simulator.

Participants who had received additional information, reported an improved comprehension of the advice, compared to participants who had not received information. No effect of information was found on the perceived outcome of compliance. Perceived usefulness and satisfaction, after exposure to the advice in the driving simulator, was reduced for participant without additional information. For participants with information no significant difference was found between before or after exposure in terms of usefulness and satisfaction.

The results of this and the previous experiment show a mixed effect of information. While lower perceived penetration rates could make informed drivers less willing to use the system, additional information can be beneficial to improve the acceptance of the system.

Drivers' evaluation of real time information and advice in real traffic

An on-road study with a prototype of the CIVA system was designed to assess the user experience with the first implementation of the prototype system, in real traffic. Two main questions for this study were:

1. What factors play a role in drivers' decisions to follow a given advice?
2. What advice or information is expected from the system in a given situation?

Participants drove in nearly congested traffic on the A20 motorway from Rotterdam to Gouda, while receiving advice that was generated, in real time, by the CIVA system. Participants' verbal response to the given advice were assessed using a think aloud procedure. Their frontal field of view was recorded by a video camera to be able to link participants comments to the traffic situation at that time. Transcripts of the verbal response data, the camera images, and driver behaviour parameters (e.g. speed, gap size, lane) were used in the subsequent analysis. In drivers' verbal response to the advice, reoccurring themes were identified. These represented the basis for the identification of factors that influenced drivers' intentions whether or not to follow the advice. The same procedure was applied to drivers' request for advice and/or information that was not provided by the system during the experimental sessions.

Participants frequently engaged in an active evaluation of the credibility of information that they received. This process included a verification of the information that preceded the advice with information that drivers could perceive at the moment that the advice was given (e.g. variable message signs, the behaviour of traffic, their own speed). However, often this information was not sufficient to immediately verify the provided information as accurate or false. Usually over time, cues were found in the behaviour of other traffic or matrix signs that would deem the information accurate or not. Some participants remained suspicious whether to trust the provided information, especially when they had already received inaccurate information earlier in the experiment. Participants in the experiment had experience with the test track. This led to situations, where drivers did not agree that the advice was the most appropriate reaction to a given situation.

From the requests for advice and information, that participants made during the experimental sessions, it appears that they were often expecting early information about events that they would encounter later on (e.g. information about emerging congestion). This information may provide a value to the driver as a justification for using the system.

Conclusion

The present research has demonstrated that drivers are generally able to follow tactical driver advice that is aimed at improving traffic flow in rush hour motorway traffic. For advising gap sizes a less specific gap advice is more suitable that a specific gap advice. Discrete headway feedback is not recommended in order to support drivers in carrying out a gap advice as it may not always improve the accuracy of the attained gap.

Drivers who receive a combined speed an lane change advice should receive one advice message without a pause in between the speed and lane change advice in order to avoid confusion due to a premature lane change. Lane advice should be formulated as a lane change to the left or right lane rather than a target lane in order to avoid confusion which lane to choose.

Adoption of the CIVA system may be hindered by a social dilemma due to a lack of a perceivable benefit and advantage from using the system. For a successful implementation of the CIVA system it is crucial to obtain a better understanding of the actual personal benefit that is created through the use of the system and to communicate this to drivers to increase the willingness to follow the advice.

The role of the additional information about upcoming traffic situations may be extended from being purely a motivation for a given advice to a general service for system users. Providing such information, even when not followed by an advice, can be of value to drivers and a reason to have the system operating during a trip, thereby increasing penetration rate. Efforts for improving future compliance with the advice may focus on building of trust that the system does have an accurate representation of the situation and that compliance actually improves the situation in case of higher penetration rates.

Before the system is further studied with participants, it is recommended to improve the traffic state prediction and advice algorithms and carry out a thorough technical evaluation of the system in real traffic. Further research should focus on improvements of the advice messages in order to elicit safe driving behaviour that can produce the desired effect on traffic flow efficiency. Also the effects of additional information should be evaluated for its effects on drivers' motivation to comply with an advice and general system acceptance.

Cooperative In-Vehicle Advice: Samenvatting

Congestie is een groot probleem in de huidige maatschappij en wordt geassocieerd met hoge economische kosten als gevolg van verminderde inzetbaarheid, milieuvervuiling, hoger ongevalsrisico, en hogere operationele kosten van voertuigen (zoals slijtage en brandstofkosten). Congestie is vaak het gevolg van een groot verkeersaanbod, dat de beschikbare wegcapaciteit nadert of overschrijdt, in combinatie met stoornissen in de verkeersstroom. Het gedrag van de menselijke bestuurder beïnvloedt het ontstaan van congestie, onder andere door het creëren van verkeersaanbod, het tijdelijk verlagen van de capaciteit van een weg of door het rijgedrag de verkeersstroom te verstoren.

Inspanningen om congestie in Nederland te verminderen variëren van het uitbreiden van de weginfrastructuur tot het efficiënter gebruiken van de bestaande infrastructuur. Intelligente Transport Systemen (ITS) spelen een essentiële rol bij het efficiënter beheren van verkeer. Coöperatieve ITS beloven het wegvervoer veiliger, meer voorspelbaar en efficiënter te maken, door het delen van informatie en het beheren van het verkeer. In deze context worden coöperatieve bestuurdersondersteunende systemen in meerdere Europese projecten onderzocht, waarbij soms delen van de rijtaak worden overgenomen van de bestuurder. Deze systemen hebben echter ook te maken met onopgeloste vraagstukken op technisch, juridisch en human factors gebied die de invoering ervan in de nabije toekomst minder waarschijnlijk maken.

Een alternatief voor geautomatiseerde systemen zijn systemen die het gedrag van de bestuurder beïnvloeden door informatie en advies aan bestuurders te geven. Dit proefschrift beschrijft human factors onderzoek tijdens de ontwikkeling van een *Coöperative In-Vehicle Advice* (CIVA). Het systeem adviseert bestuurders over hun tactisch rijgedrag (met name snelheid, volgafstand en rijstrook) om de doorstroming tijdens spits uren op snelwegen te verbeteren. Bestuurders krijgen geïndividualiseerde adviesboodschappen via een in-voertuig systeem. Het advies is beperkt tot de visuele en auditieve modaliteit. Individuele berichten worden aangepast aan de rijstrook, volgafstand en de snelheid van de bestuurder, de wettelijke snelheidslimiet en de gewenste route. Het systeem zal niet de controle over het voertuig overnemen van de bestuurder. Het effect dat het systeem zal hebben op de doorstroming is daarom afhankelijk van het vermogen en de bereidheid van de bestuurder om de adviesboodschappen op te volgen. Het doel van dit onderzoek was om bij te dragen aan het beantwoorden van de volgende vragen:

- Zijn bestuurders in staat om CIVA op te volgen?
- Zijn bestuurders bereid om CIVA op te volgen?
- Zijn bestuurders bereid om het CIVA systeem te gebruiken?

Gegevens om deze vragen te beantwoorden werden verkregen door middel van een enquête onder potentiële gebruikers, meerdere rijsimulator experimenten en een studie op de snelweg.

Enquête onder potentiële gebruikers van CIVA

De focus van dit onderzoek lag op de evaluatie van het conceptuele CIVA systeem door potentiële gebruikers. De eerste reactie van de bestuurders op een beschrijving van het idee achter het systeem werd onderzocht. Verder werden ook factoren verzameld die de acceptatie van het systeem door de gebruikers zouden beïnvloeden. Hierbij werd gekeken naar de potentie van het systeem om rijgedrag te beïnvloeden dat onder weggebruikers als problematisch bestempeld wordt.

Factoren die bij kunnen dragen aan het draagvlak van het systeem zijn: een duidelijk voordeel van het gebruik van het systeem, en de zekerheid dat een voldoende aantal weggebruikers het systeem ook zou gebruiken. Een gebrek aan vertrouwen in het systeem is geïdentificeerd als een belangrijke factor voor een mogelijk lage acceptatie van CIVA. Bovendien gaven deelnemers aan moeite te hebben met een systeem waarvan de adviezen in strijd zijn met hun eigen mening over het optimale gedrag in een bepaalde verkeerssituatie.

De meest problematische vormen van gedrag van andere weggebruikers die werden genoemd waren het te laat en agressief invoegen bij een afvallende rijstrook, oprit of afrit, links rijden zonder goede reden, hinderen tijdens het invoegen bij een afvallende rijstrook, oprit of afrit, te vroege rijstrookwissel bij een wegversmalling, oprit of afrit, en rijstrookwissels met hoge snelheidsverschillen te opzichte van de doel strook. Deze resultaten laten zien dat het CIVA rijgedrag beïnvloedt dat voor weggebruikers relevant is en er dus potentie is voor een dergelijk systeem.

De validatie van de rijsimulator van de Universiteit Twente

Om de keuze van volgafstanden bij bestuurders in de rijsimulator van de Universiteit Twente te kunnen bestuderen moest de simulator voor deze taak worden gevalideerd. In een experiment werd het keuzegedrag van volgafstanden door bestuurders in een rijsimulator vergleken met het gedrag in een geïnstrumenteerd voertuig op de weg. Deelnemers volgden instructies om hun volgafstand te veranderen naar een specifieke waarde of een volgafstand te kiezen zoals ze dat normaal doen. De snelheid van de voorligger (80, 100 of 120 km/h) en de grootte van de volgafstand (1, 1.5, 2 seconden) werden gevarieerd tussen ritten. Specifieke volgafstandsinstructies werden gegeven in seconden en in meters. De aangehouden volgafstanden werden vergeleken tussen de virtuele en de echte omgeving. De resultaten tonen geen significant verschil tussen de volgafstanden die werden gekozen in een simulator en op de weg, noch voor zelfgekozen volgafstanden noch voor specifieke instructies. Deze resultaten bieden steun voor het gebruik van de UT rijsimulator in studies over volgafstandskeuze.

Bestuurdersvermogen om specifieke volgafstandsadviezen op te volgen

Er werd voorgesteld om volgadviezen te geven in de vorm van een specifieke volgafstand die moet worden aangehouden door bestuurders. Een experiment werd uitgevoerd naar het vermogen van bestuurders om specifieke volgafstandsadviezen op te volgen die zijn geformuleerd in afstand (meters) of tijd (seconden). Resultaten tonen aan dat bestuurders de volgafstandsadviezen enigszins konden volgen, zowel voor geïnstrueerde afstanden als ook voor tijd, waarbij er weinig verschil zat in de gekozen volgmarges voor volgafstandsadviezen in seconden vergleken met adviezen in meters. Echter, bestuurders waren niet in staat om de volgmarge heel nauwkeurig aan te houden. Dit was zowel het geval voor verschillende snelheden en als verschillende geadviseerde volgafstanden of volgtijden.

Verder werd nagegaan of ondersteuning door het systeem bestuurders zou helpen bij het opvolgen van de volgafstandsadviezen. De helft van de deelnemers kreeg een toon te horen op het moment dat de geadviseerde volgmarge werd bereikt. Ondersteuning door middel van auditieve feedback vergrootte de nauwkeurigheid van de gekozen volgafstand wanneer deelnemers werden geadviseerd hun volgafstand te verkleinen. Wanneer deelnemers werden geadviseerd om hun volgafstand te vergroten zorgde steun voor lagere nauwkeurigheid van de gekozen volgmarge vergeleken met geen advies.

Het onvermogen van bestuurders om specifieke volgafstandsadviezen met grote nauwkeurigheid op te volgen verminderde de waarde van deze vorm van advies vergeleken met minder specifieke adviezen zoals een manoeuvre dat bestuurders moesten uitvoeren (bijv. "kies een korte maar veilige volgafstand", "laat ruimte voor invoegers").

Effect van CIVA op het rijgedrag

De gedragsmatige reactie van bestuurders op het advies werd geëvalueerd in een rijsimulator experiment. Het effect van verschillende adviesboodschappen op het rijgedrag van bestuurders werd bekeken op drie stukken snelweg: een stuk snelweg met een afvallende rijstrook (3 naar 2 rijstroken), een oprit en een weefvak. De aangeboden adviesboodschappen bestonden uit een rijstrookwisseladvies, dat voor werd gegaan door ofwel een advies om de snelheid aan te passen aan de snelheid van de doelrijstrook (in de 3 naar 2 situatie en bij de oprit), of door een advies om de volgafstand te vergroten naar 2 seconden ten opzichte van de voorligger (bij het weefvak scenario). Het experiment had drie doelstellingen.

Ten eerste werd beoordeeld of adviesboodschappen tot de beoogde gedragsverandering leiden. Ook het effect van twee factoren op de gedragsmatige respons werd bekeken:

1. Het effect van het afzonderlijk of samen aanbieden van gerelateerde adviesboodschappen.
2. Het effect van lage of hoge verkeersdichtheid tijdens het opvolgen van het advies.

Daarnaast werd de zelf-gerapporteerde mentale inspanning van deelnemers bij het opvolgen van het advies vastgelegd. Ook acceptatie van het systeem voor en na blootstelling aan het advies in de rijsimulator werd gemeten.

Ten tweede werden vragen bestudeerd die zijn voortgekomen uit eerdere studies. Zo werd onderzocht of de naleving van het advies kan leiden tot rijgedrag dat door andere weggebruikers als vervelend wordt geacht. Verder werd onderzocht of de nauwkeurigheid van de gekozen volgafstanden in een meer dynamische verkeerssituatie (bijvoorbeeld veranderde het verkeer van snelheid en rijstrook). vergelijkbaar is met het vorige experiment.

Ten derde werden parameters voor rijgedrag gemeten die kunnen worden gebruikt om de reactie op het advies in verkeerssimulaties te modelleren. De volgende parameters werden vastgelegd:

- Afstand tot een fysieke locatie (die leidde tot het rijstrookwisseladvies) op het moment van de rijstrookwissel
- De tijd tussen een rijstrookwisseladvies en de daadwerkelijke rijstrookwissel
- Het geaccepteerde hiaat op de doelstrook bij een rijstrookwissel
- Relatieve snelheid tot de voertuigen op de doelstrook bij een rijstrookwissel
- Volgmarge tot de voorligger voor en na een volgafstandsadvies

Resultaten laten zien dat rijstrookwisseladvies ertoe leidt dat rijstrookwisselingen plaats vinden in een kleiner gebied, net nadat het advies werd gegeven. Echter, voor het weefvak werd geen verschil gevonden tussen rijstrookwisselingen met of zonder rijstrookwisseladvies. Deelnemers wisselden van rijstrook zodra de ononderbroken rijstrookmarkering eindigde.

Er werd onderzocht of bestuurders haastig van rijstrook zouden wisselen om te voldoen aan het advies en daardoor mogelijk kleinere hiaten zouden accepteren. Dergelijk gedrag kan onveilige situaties en irritatie bij overige weggebruikers veroorzaken. Echter, geaccepteerde hiaten na een advies waren niet kleiner dan bij reguliere rijstrookwisselingen.

Na een "aanpassen snelheid" advies werd het absolute verschil in ten opzichte van voertuigen op de doelrijstrook teruggebracht. Echter, in de opritsituatie bleef een verschil in snelheid ten opzichte van de doelrijstrook bestaan. In de on-ramp locatie, in het scenario met een tijdsinterval van een minuut tussen het snelheidsadvies en het rijstrookwissel advies, resulteerde het snelheidsadvies in een vroegtijdige wissel van rijstrook naar links.

Het advies om de volgafstand uit te breiden naar 2 seconden leidde tot een toename in de volgmarge tussen voertuigen. Echter, bestuurders vergrootten hun volgafstand ook in situaties waarin zij reeds gelijk of boven de beoogde voltijd van 2 twee seconden zaten.

De resultaten geven aan dat in de meeste gevallen het advies leidde tot de beoogde aanpassing van het rijgedrag. De zelf-gerapporteerde mentale werkbelasting van bestuurders werd niet verhoogd door het opvolgen van de adviezen in vergelijking met het rijden zonder advies. Acceptatie van het systeem na het rijden met het systeem in de rijsimulator was lager dan vooraf na het beschrijving van het systeem zelf.

Vermogen om de naleving van het advies in te schatten

Een experiment werd uitgevoerd om te bepalen of bestuurders in staat zijn om onderscheid te maken tussen verschillende maten van naleving van het advies bij andere weggebruikers. Verder werd nagegaan of het vermogen wordt beïnvloed door informatie over het advies dat bestuurders in verschillende situaties ontvangen.

De helft van de deelnemers ontving aanvullende informatie over de adviesstrategie die het systeem gebruikt om het verkeer in verschillende situaties te adviseren. Vervolgens reden alle deelnemers in meerdere trials in druk verkeer in verschillende locaties (van drie naar twee rijstroken, oprit en rechte autosnelweg) met verschillende niveaus van gesimuleerde systeemnaleving van andere weggebruikers. Na elke rit werden de deelnemers gevraagd om een schatting van de naleving van het systeem door andere weggebruikers in de trial te geven en hun zekerheid over deze schatting aan te geven.

De resultaten laten zien dat deelnemers geen onderscheid konden maken tussen verschillende graden van naleving van het advies bij andere weggebruikers. Deelnemers die aanvullende informatie over de werking van het systeem hadden ontvangen lieten een systematische onderschatting van de gesimuleerde naleving zien.

Effect van informatie op de acceptatie van het systeem

Een experiment werd uitgevoerd om het effect van informatie over de adviesstrategie op de waargenomen begrijpelijkheid van het advies, de waargenomen uitkomst van de naleving van het advies, alsmede de acceptatie van het systeem te beoordelen. De aanvullende informatie over de adviesstrategie die werd gebruikt was dezelfde als die in het vorige experiment.

Alle deelnemers ontvingen adviezen tijdens het rijden in meerdere trials in dezelfde wegsituaties als in het vorige experiment. Na elke trial gaven deelnemers aan of zij de reden voor het gegeven advies dachte te begrijpen. Ook werd gevraagd of ze dachten dat de naleving van het advies tot een voor hen gunstige of ongunstige situatie heeft geleid. Algemene acceptatie van het systeem voorafgaand aan het experiment werd vergeleken met de acceptatie nadat de deelnemers het advies in de rijsimulator ervaren hadden.

Deelnemers die aanvullende informatie hadden gekregen, rapporteerden vaker dat zij de reden voor het advies begrepen, in vergelijking met deelnemers die geen informatie hadden ontvangen. Er werd geen effect van de aanvullende informatie gevonden op de waargenomen naleving van het advies. Waargenomen nut en genoegen, na blootstelling aan het advies in de rijsimulator, was lager voor deelnemer zonder aanvullende informatie. Voor deelnemers met informatie werd geen significant verschil gevonden tussen voor en na blootstelling aan het advies.

De resultaten van deze experimenten tonen een gemengd effect van aanvullende informatie. Terwijl de informatie kan leiden tot een lagere waargenomen naleving bij andere weggebruikers, hetgeen bij bestuurders de bereidheid kan verlagen om het systeem zelf te gebruiken, kan aanvullende informatie gunstig zijn voor het verbeteren van de waargenomen nut van het systeem.

Bestuurders evaluatie van de real-time informatie en advies in het echte verkeer

Een on-road studie werd uitgevoerd om de gebruikerservaring met de eerste uitvoering van het prototype CIVA systeem in een echte verkeerssituatie te bestuderen. Twee hoofdvragen van dit onderzoek waren:

1. Welke factoren spelen een rol in de besluitvorming van bestuurders om een gegeven advies op te volgen?
2. Wat voor advies of informatie wordt in een bepaalde situatie van het systeem verwacht?

Deelnemers reden in druk verkeer op de A20 van Rotterdam naar Gouda, terwijl zij advies boodschappen ontvingen die in real-time werden gegenereerd door het CIVA systeem. Verbale reacties van de deelnemers op de gegeven adviesboodschappen werden opgenomen in een hardop denken procedure. Het frontale gezichtsveld werd opgenomen op video zodat achteraf duidelijk zou zijn in welke situatie proefpersonen welk commentaar leverden. De verbale reacties, de camerabeelden, en het gedrag van de bestuurders (zoals snelheid, volgafstand, rijstrook) werden gebruikt in de verdere analyse. In verbale reacties van bestuurders op het advies, werden terugkerende thema's geïdentificeerd. Deze staan aan de basis voor het identificeren van de factoren die de geneigdheid van bestuurders beïnvloeden om al dan niet het advies op te volgen. Dezelfde procedure werd toegepast op verzoeken van deelnemers om advies en/of informatie, welke tijdens de experimentele sessies niet werd verstrekt door het systeem.

Deelnemers deden vaak pogingen om de geloofwaardigheid van de informatie die zij ontvingen te beoordelen. Dit proces omvatte een verificatie van de informatie, die het advies was voorafgegaan, met informatie die de deelnemer, op het moment dat het advies werd gegeven, zelf konden waarnemen (zoals AID, het gedrag van het verkeer, zijn eigen snelheid). Echter, deze informatie was vaak niet voldoende om de informatie van het systeem onmiddellijk te verifiëren. Meestal werden met de tijd tekens in het gedrag van het verkeer of van matrixborden gevonden, die wel of niet overeen kwamen met de informatie die door het systeem was verstrekt. Sommige deelnemers bleken de verstrekte informatie niet te vertrouwen, vooral als ze eerder in het experiment al onjuiste informatie hadden ontvangen. Deelnemers in het experiment hadden ervaring met de weg waarop de testen werden afgenomen. Dit leidde tot situaties waarin deelnemers het niet eens waren met de geschiktheid van het geadviseerde gedrag als een reactie op de waargenomen situatie.

Deelnemers geven tijdens de experimentele sessies aan dat ze vaak verwachten vroegtijdige informatie over gebeurtenissen te ontvangen welke zich later zullen voordoen (zoals informatie over opkomende congestie). Hoewel het systeem deze informatie voor een deel al verstrekt zou de frequentie en de bandbreedte van mogelijke informatieboodschappen kunnen worden uitgebreid. De informatie heeft een waarde voor bestuurders en het verkrijgen van deze informatie kan gezien worden als een reden voor het gebruik van het systeem.

Conclusie

Het hier opgevoerde onderzoek heeft aangetoond dat bestuurders over het algemeen redelijk in staat zijn om tactische advies op te volgen dat is gericht op het verbeteren van de doorstroming op snelwegen in de spits.

Voor het adviseren van volgafstanden is een minder specifiek volgafstandsadvies meer geschikt dan een specifiek advies. Discrete feedback op gekozen volgmarges wordt niet aanbevolen om bestuurders te ondersteunen bij het uitvoeren van volgafstandsadviezen omdat het soms tot een verslechtering van de nauwkeurigheid van het gekozen volgmarge leidt. Voor bestuurders die een gecombineerde snelheid en rijstrookwisseladvies ontvangen wordt aanbevolen deze zonder een pauze tussen de twee adviezen te geven om verwarring door vroegtijdige rijstrookwissels te voorkomen. Het wordt ook aanbevolen om rijstrookadvies te formuleren als een gewenste verandering van rijstrook naar links of rechts in plaats van een doel rijstrook om verwarring te voorkomen welke rijstrook gekozen moet worden.

Draagvlak van het CIVA kan worden belemmerd door een sociaal dilemma, te wijten aan een gebrek aan waarneembaar voordeel van het gebruik van het systeem. Voor een succesvolle implementatie van het CIVA systeem is het cruciaal om een beter begrip van de werkelijke persoonlijk voordeel te hebben, dat wordt gecreëerd door het gebruik van het systeem en om deze te communiceren aan de bestuurders.

Het wordt aanbevolen om aanvullende informatie over opkomende verkeerssituaties uit te breiden van een motivatie voor een gegeven advies naar een algemene informatie voor de gebruikers van het systeem. Het verstrekken van dergelijke informatie, zelfs als deze niet gevolgd wordt door een advies, wordt door bestuurders als waardevol ervaren, en kan een reden zijn om het systeem tijdens een reis te gebruiken met als gevolg een verhoging van de penetratiegraad. Inspanningen ter verbetering van de toekomstige naleving van het advies kunnen zich richten op het opbouwen van vertrouwen dat het systeem een accurate weergave van de situatie heeft en dat naleving van het advies de situatie daadwerkelijk verbetert (in geval van voldoende hoge penetratiegraad).

Voordat het systeem verder experimenteel wordt bestudeerd is het raadzaam om de voorspelling van verkeerssituaties en de advies algoritmes te verbeteren en een grondige technische evaluatie van het systeem in het echte verkeer uit te voeren. Verder onderzoek moet zich richten op verbetering van de adviesboodschappen om veilig rijgedrag uit te lokken dat het gewenste effect op de doorstroming heeft. Ook dient het aanbeveling om de effecten van aanvullende informatie op de motivatie van bestuurders om het advies daadwerkelijk op te volgen en de algemene acceptatie van een verder ontwikkeld systeem nader te onderzoeken onderzocht.

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About the author

Malte was born in Göttingen, Germany, on November 21 1983. In 2005 he moved to Enschede in the Netherlands to study Psychology at the University of Twente, where he earned a his Master's degree (MSc) in Cognition, Media and Ergonomics in 2010. His thesis, studying factors that influence trust in Wikipedia, using an eye-tracking methodology, was one of five theses nominated for the dissertation award 2010 of the Research Institute for Social Sciences and Technology (CTIT).

A curiosity for the interaction between humans and technology led him to pursue a PhD at the Center for Transport Studies (CTS) at the University of Twente. There he conducted research on the human factors aspects of a cooperative, advisory, driver support system that aims to improve traffic flow efficiency on motorways during peak hour traffic. During this research he explored topics regarding the direct human-machine interaction as well as the broader social psychological aspects of traffic flow improvement.

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Summary

Motorway traffic congestion is a problem in today's society. Driver behaviour is a factor that can deteriorate traffic flow in nearly congested traffic. Traffic flow efficiency may be improved by an in-vehicle system that advises drivers on their speed, gap, and lane choice. The system's effect depends on its penetration rate and drivers' compliance with the advice. This thesis describes a user-survey, driving simulator experiments and a real road study to assess drivers' ability and willingness to use the system and follow advice messages. Results show a general ability to follow given advice messages. Factors are identified that may reduce drivers' willingness to follow the advice and adopt the system.

About the Author

Malte holds a Master's degree in Psychology from the University of Twente. He performed his doctoral research at the Centre for Transport Studies within the Research Institute for Social Sciences and Technology of the University of Twente, in cooperation with the Dutch Organisation for Applied Scientific Research.

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