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Master thesis

Roadside versus in-car speed support for a green wave: a driving simulator study

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Preface

This Master thesis report is the final part of my graduation project in the master Civil Engineering and Management at the University of Twente, with main subject Traffic and Transport. The thesis was part of the Applications of Integrated Driver Assistance knowledge centre (AIDA) and was performed at TNO Human Factors in Soesterberg from July 2006 till April 2007. AIDA is realised by TNO and the University of Twente. This study is part of the TNO SUMMITS Network Manager research project. SUMMITS is an acronym for SUstainable Mobility Methodologies for Intelligent Transport Systems.

When I started my search for an assignment I was (and still am) interested in driving behaviour and Intelligent Transport Systems. So TNO Human Factors was the place to be. When starting my research plan I intended to investigate too many interesting aspects. Over time, I learned to make choices and stay focussed on my research questions. And I learned to be patient and to make a new planning when the old one did not fit anymore.

The thing I liked the most was to get to know all aspects of a driving behaviour study. At the start, it was exciting to me because it was the first time I performed such a study. However, there were a lot more challenges in the assignment that sometimes asked for much perseverance.

I would like to take this opportunity to thank my supervisors. I would like to thank Bart van Arem for creating the possibility to perform my Master thesis at TNO and all the tips, advices and support. Also I would like to thank Nina Schaap for the useful feedback and for keeping me on track in the beginning by asking: ‘what were your research questions about?’ And also for working together on the experiment which I really enjoyed. I would like to thank Richard van der Horst for all the facilities at TNO, support and the opportunity to have a look in the world of driving behaviour. During my stay at TNO I was lucky to have a fourth supervisor. I would like to thank Philippus Feenstra for all his feedback and support. And I want to thank all the other people at TNO, especially Antoon Wennemers, Wytze Hoekstra, Ingmar Stel and Jeroen Hogema, for all their help. Finally, I would like to the Traffic behaviour group, who made my stay to a really great time.

Next, I would like to thank Jeroen Pouwels for his support and for having faith in a happy ending.

Last but not least I would like to thank my parents and brother for all their love, support and faith in me. It was a tough time but I did it!

Kirsten Duivenvoorden
Zeist, May 2007

Summary

A green wave on a road with a series of coupled signalised intersections enables a driver to pass each traffic light at green light. So he/she does not have to stop. A green wave is an advantage for drivers, through-put and safety on the road network and the environment. At coupled signalised intersections, the driver will get green light at the intersections driving a given speed. Therefore, the driver needs information about the speed he/she has to drive. Variable message signs are already used for giving drivers a speed advice for a green wave. The use of an in-car display for a green wave is new. The given green wave speed advice is adjusted to the current status of the traffic lights. In this study, two systems providing the driver a green wave advice were investigated. These two systems were variable message signs at the roadside and an in-car display.

A driving simulator study was conducted to measure the effects of a green wave advice using these two systems for providing the advice to drivers. Using the fixed-base driving simulator of TNO, this experiment investigated the effects on driving behaviour, workload and user acceptance. Fifty subjects participated in the experiment in the driving simulator. Each subject completed three experiment runs, two containing either one system (variable message signs/in-car display) and one baseline run. A road with signalised intersections in the Netherlands was used to examine the effects of a green wave.

The results for driving behaviour showed that speed support for a green wave resulted in a change in driving behaviour compared to the baseline condition. The subjects responded to the green wave advice by driving a speed closer to the advice. Using the in-car display, subjects drove slower but more the same speed compared to the baseline condition. Subjects were also more able to continue driving using the in-car display than the variable message signs because of the smaller amount of stops.

For workload, the results showed that speed support using the variable message signs resulted in a higher workload for the drivers compared to when no system was used. Compared to the baseline condition, using the in-car display did not result in a higher workload.

After experiencing both systems for the green wave speed support, both systems were found less useful and satisfying as the systems were expected to be. The variable message signs were found more satisfying than the in-car display. The green wave speed advice on in-car display was experienced as more personal than the ones shown on the variable message signs. However, most of subjects preferred the variable message signs. Reasons for this were the easy realisation and the accessibility for all drivers. Subjects said to follow the green wave advice because fuel could be saved and it was pleasant to be benefit from the green wave.

In conclusions, the subjects responded to speed support for a green wave. Using an in-car display and variable message signs, the subjects adhered to the given advisory speed. Comparing the variable message signs and the in-car display applied in this experiment, the following significant differences were found. The results of this study showed that subjects drove more comfortably using the in-car display because they drove more the same speed and they made less stops during the trip. The in-car display caused less distraction to the subjects. But the subjects accepted the variable message

signs more. In this study, it was possible to influence driving behaviour by using speed support for a green wave. It can be seen that the objective measurements of driving behaviour and workload differ from the subjective measurement of user acceptance.

Based on the findings of this driving simulator experiment, the best system for green wave support in terms of *comfort*, *distraction* and *acceptance* was the in-car display. An in-car display is a promising system for green wave speed support because it has potential advantages for the through-put and safety on the road network. However, determining the best system should be done with care because the in-car display and the variable message signs do not differ very much from each other.

Samenvatting

Een groene golf op een weg met verkeerslichten geregelde kruispunten zorgt ervoor dat de een bestuurder bij elk verkeerslicht groen licht krijgt. Hij/zij hoeft dus niet te stoppen. Een groene golf is een voordeel voor zowel bestuurders, de doorstroming en veiligheid op het wegennetwerk en het milieu. Bij gekoppelde met verkeerslichten geregelde kruispunten kan de groene golf worden behaald door een bepaalde snelheid te rijden. De bestuurder heeft echter informatie nodig over de te rijden snelheid. Dynamische borden langs de kant van de weg worden al gebruikt om bestuurders een adviessnelheid voor de groene golf te geven. Het gebruik van een in-voertuig display voor een groene golf is nieuw. De gegeven adviessnelheid is afgestemd op de huidige status van de verkeerslichten. In deze studie zijn twee systemen onderzocht die de bestuurder een groene golf adviessnelheid geven. Het eerste systeem bestaat uit dynamische borden langs de kant van de weg en het tweede is een display dat in het voertuig is gemonteerd.

Een rijsimulator studie was uitgevoerd om de effecten van de groene golf adviessnelheid weergegeven op dynamische borden en een in-voertuig display te onderzoeken. De fixed-base rijsimulator van TNO werd gebruikt om de effecten op rijgedrag, werkbelasting en gebruikersacceptatie te bepalen. Vijftig proefpersonen namen deel aan dit simulatorexperiment. Elke proefpersoon reed drie ritten, twee daarvan met een systeem (dynamische borden/in-voertuig display) en één rit zonder systeem. Een provinciale weg in Nederland diende als basis om de effecten van de groene golf te onderzoeken.

De resultaten voor rijgedrag laten zien dat snelheidsondersteuning voor de groene golf resulteerde in een verandering in rijgedrag vergeleken met de conditie waarin geen systeem werd gebruikt voor snelheidsondersteuning. De proefpersonen reageerden op de groene golf door een snelheid te rijden die dichterbij de adviessnelheid lag. Bij het gebruik van een in-voertuig display reden de proefpersonen langzamer maar wel meer dezelfde snelheid ten opzichte van de situatie zonder systeem. En ze konden beter doorrijden omdat ze minder vaak stopten dan bij het gebruik van dynamische borden.

Voor werkbelasting resulteerde de snelheidsondersteuning op de dynamische borden in een hogere werkbelasting voor de proefpersonen vergeleken met de situatie zonder systeem. De in-voertuig display resulteerde niet in een hogere werkbelasting vergeleken met de situatie waarin geen systeem werd gebruikt.

Proefpersonen waren minder tevreden over beide systemen na gebruik ervan. En de systemen werden ook minder nuttig gevonden dan dat ze vooraf werden ingeschat. De proefpersonen waren meer tevreden over de dynamische borden dan over de in-voertuig display. De adviessnelheden getoond op de in-voertuig display werd persoonlijker gevonden dan die op de dynamische borden. Toch gaven de meeste proefpersonen de voorkeur aan de dynamische borden. De gemakkelijke realisatie en de toegankelijkheid voor alle bestuurders werden als redenen gegeven. Proefpersonen zeiden de groene golf adviessnelheid op te volgen zodat ze daarmee brandstof konden uitsparen en ze zeiden het prettig te vinden om te profiteren van de groene golf.

De resultaten van dit onderzoek laten zien bestuurders reageerden op de groene golf. Bij het gebruik van de dynamische borden en de in-voertuig display reden de proefpersonen

een snelheid die in de buurt kwam van de gegeven adviessnelheid. Bij het vergelijken van beide systemen werden de volgende significante verschillen gevonden. Uit de resultaten blijkt dat proefpersonen comfortabeler reden bij het gebruiken van de in-voertuig display ten opzichte van de dynamische borden. Daarbij waren ze ook minder afgeleid, maar de dynamische borden langs de kant van de weg werden meer geaccepteerd. Uit dit onderzoek blijkt dat het mogelijk is om het rijgedrag te beïnvloeden door het gebruik van snelheidsondersteuning voor de groene golf. Daarbij valt op dat de objectieve maten van rijgedrag en subjectieve maten van werkbelasting en gebruikersacceptatie van elkaar verschillen.

Op basis van de resultaten uit dit onderzoek kan worden gezegd dat een in-voertuig display het beste systeem voor de groene golf snelheidsondersteuning is in termen van *comfort*, *afleiding* en *acceptatie*. De in-voertuig display is een veel belovend systeem voor groene golf snelheidsondersteuning omdat het voordelen heeft voor de doorstroming en veiligheid op het netwerk. Echter moet het bepalen van het beste systeem met enige terughoudendheid worden gedaan omdat beide systemen niet heel veel van elkaar verschillen.

Contents

	Preface	**2**
	Summary	**3**
	Samenvatting	**5**
1	**Introduction**	**10**
2	**Background**	**11**
2.1	Measuring driving behaviour	11
2.2	Measuring workload	14
2.3	Measuring user acceptance	15
3	**Method**	**17**
3.1	Research plan	17
3.2	Green wave	17
3.3	Databases and scenarios	21
3.4	Experiment design	22
3.5	Driving simulator	24
3.6	Peripheral Detection Task	26
3.7	Subjects	27
3.8	Procedure	28
3.9	Data registration	29
4	**Data analysis**	**33**
4.1	Driving behaviour and workload	33
4.2	User acceptance	34
4.3	Outliers	35
5	**Results**	**36**
5.1	General	36
5.2	Driving behaviour	36
5.3	Workload	48
5.4	User acceptance	52
5.5	Remarks of the subjects	56
5.6	Summary of the results	58
6	**Discussion**	**61**
6.1	The experiment	61
6.2	Driving behaviour	62
6.3	Workload	62
6.4	User acceptance	63
7	**Conclusions and recommendations**	**64**
7.1	Conclusions	64
7.2	Recommendations	65
8	**References**	**66**
	Appendices	**69**

List of figures

Figure 1 The variable message signs ... 19
Figure 2 The in-car display and the head mounted Peripheral Detection Task (PDT) ... 20
Figure 3 The traffic signs for ‘green wave’ and for ‘no green wave’ ... 20
Figure 4 The Kruithuisweg (Source: www.routenet.nl) ... 21
Figure 5 The TNO fixed-base driving simulator ... 25
Figure 6 The screens and the mock up ... 25
Figure 7 The LED of the PDT ... 26
Figure 8 The micro switch of the PDT ... 27
Figure 9 The eastern driving direction ... 31
Figure 10 The western driving direction ... 31
Figure 11 Travel time as a function of 'reference speed' ... 37
Figure 12 Travel time as a function of ‘reference speed’ and ‘system’ ... 38
Figure 13 Average speed as a function of ‘reference speed’ ... 39
Figure 14 Average speed as a function of ‘system’ ... 39
Figure 15 Average speed as a function of ‘reference speed’ and ‘system’ ... 40
Figure 16 Standard deviation of average speed as a function of ‘reference speed’ ... 41
Figure 17 Standard deviation of average speed as a function of ‘system’ ... 42
Figure 18 Standard deviation of average speed as a function of ‘reference speed’ and ‘system’ ... 43
Figure 19 RMS of the driven speed as a function of ‘reference speed’ ... 44
Figure 20 RMS of the driven speed as a function of ‘system’ ... 44
Figure 21 RMS of the driven speed as a function of ‘system’ and ‘reference speed’ ... 45
Figure 22 Average PDT reaction time as a function of ‘system’ ... 49
Figure 23 Average PDT reaction time as a function of ‘system’ and ‘reference speed’ ... 49
Figure 24 Percentage missed PDT signals as a function of ‘reference speed’ ... 50
Figure 25 Percentage missed PDT signals as a function of ‘system’ ... 51
Figure 26 Percentage missed PDT signals as a function of ‘system’ and ‘reference speed’ ... 51
Figure 27 Usefulness as a function of ‘measurement’ ... 53
Figure 28 Satisfying as a function of ‘measurement’ ... 53
Figure 29 Satisfying as a function of ‘measurement’ ... 54
Figure 30 Satisfying as a function of ‘measurement’ ... 55
Figure 31 Overview of the scores for the three conditions ... 56

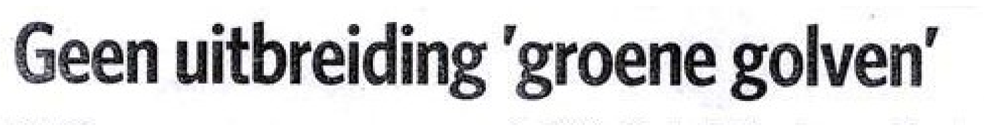
List of tables

Table 1 The nine items of the Van der Laan questionnaire ... 15
Table 2 Six trials of the experiment ... 23
Table 3 Combination of the runs of the SUMMITS and TRANSUMO experiment ... 24
Table 4 Results (α values) of the reliability analysis (U = usefulness, S = satisfying) ... 34
Table 5 Statistical results on travel time ... 36
Table 6 Statistical results on average speed ... 38
Table 7 Statistical results on standard deviation of average speed ... 41
Table 8 Statistical results on RMS of the driven speed ... 43
Table 9 Results of the analysis of the Student´s t-Test ... 46
Table 10 Frequency table of the number of stops ... 46
Table 11 Frequency table of the number of yellow light runners ... 46
Table 12 Frequency table of the number of red light runners ... 47
Table 13 Frequency table of the number of had or should have stopped ... 47
Table 14 Statistical results on average PDT reaction time ... 48
Table 15 Statistical results on percentage missed signals ... 50
Table 16 Usefulness scores (U) and satisfying scores (S) for both study parts ... 52
Table 17 Statistical results on usefulness and satisfying for baseline first ... 52
Table 18 Statistical results on usefulness and satisfying for system first ... 54
Table 19 Usefulness scores and satisfying scores for both study parts together ... 54
Table 20 Statistical results on usefulness and satisfying for both study parts together ... 55

1 Introduction

A green wave on a road with coupled signalised intersections enables a driver to pass each traffic light at green light. Drivers will benefit from a green wave. A green wave also has advantages for the environment, the through-put and safety on the road network. In the Netherlands several green waves are implemented on roads with coupled signalised intersections. A green wave was experienced differently.

In January 2007, a Dutch newspaper (Algemeen Dagblad, 2007) headlined the following sentence:


Geen uitbreiding 'groene golven'

In English: ‘no increases in the number of green waves’. In the article the city council of the city of Delft decided to not increase the number of green waves. The decision of the city council was based on research which discovered that the objections against a green wave were bigger than the benefits.

Despite the newspaper article, it is to be expected that drivers, the environment and the road network benefit from a green wave. The driving simulator experiment presented in this report examined two systems for speed support for a green wave, namely variable message signs and an in-car display. Drivers received an advisory speed for a green wave. When following this advice, a green wave was guaranteed. The objective of the study is to determine the effects on driving behaviour, workload and user acceptance of speed support for a green wave. The main research question is: how will drivers respond to speed support for a green wave, by using an in-car display and variable message signs?

The driving simulator research which is presented in this report, is part of the Network Manager project which is part of TNO’s research program SUMMITS. SUMMITS is the acronym for SUstainable Mobility Methodologies for Intelligent Transport Systems. One of the objectives of the SUMMITS program is to develop concepts and systems for the interaction between the infrastructure and vehicles, known as co-operative road-vehicle systems (CRVS) (Baart et al, 2004). Improving traffic safety and efficiency and reducing the environmental impact or road traffic are also of interest (Van Arem, 2007). The aim of the Network Manager project is ‘to develop and study new concepts that support the traffic manager in striving after the optimum network efficiency and maximum comfort and safety for road users (TNO, 2007). Such a concept is the provision of speed support for a green wave by an in-car system.

This report presents the results of a driving simulator study which investigated the effects of speed support for a green wave. Chapter 2 gives the background of the research. The method of the conducted driving simulator experiment is described in Chapter 3. Chapter 4 contains the method of the performed data analysis. Results of the experiment can be found in Chapter 5. Chapter 6 describes the discussion. Conclusions and recommendations can be found in Chapter 7.

2 Background

A green wave on a road with a series of coupled signalised intersections enables a driver to pass each traffic light at green light. Facing a red light can be annoying because it takes more time to arrive at the destination. When cars continue driving the emissions and noise will decrease which is an advantage for the environment. For a driver, facing green lights is an advantage. A green wave also has advantages for the environment, the through-put and safety on the road network. But how to benefit from a green wave? Speed support for a green wave can be useful. But what is the best way to give this speed support? Static traffic signs can show a advisory speed. Driving this advisory speed will make the driver benefit from a green wave. At vehicle-actuated traffic lights the control strategy of the traffic lights is adjusted to the amount of traffic. At these traffic lights static traffic signs are useless. Dynamic roadside or in-car messages can be used for a green wave speed advice adjusted to the current status of the traffic lights. Therefore, variable message signs and in-car displays can be used for giving a speed advice to drivers. Will this have impact on driving behaviour? And, if so, what kind of impact? And what effects will this speed support have on workload for the driver and on user acceptance?

2.1 Measuring driving behaviour

Characteristics of driving behaviour can be measured in different ways. According to Akamatsu (2002), there are three methods to measure driving behaviour, namely:

- With a driver style questionnaire (DSQ). The aim of this questionnaire is to quantify the attitudes of drivers that may affect driving behaviour;
- With an equipped car in a real environment. Sensing devices in the car will measure behaviour of the driver, such as which direction the driver is looking or which pedal the driver has his foot on;
- With a driving simulator. A driving simulator is a fully instrumented car cabin that is placed on a (motion) platform. A visual database projects a virtual environment in which the driver can drive. Instruments contained in the simulator measures driver’s behaviour, such as head movement or eye movement. There are two types of driving simulators. The first one is the fixed-base driving simulator and the second one is the moving-base driving simulator.

Performing driver style questionnaires is easily done for data collection. However, drivers’ attitudes are only assessed by the drivers themselves. The equipped car can collect data about natural driving behaviour in a real environment, but the accuracy is not high enough. The extraction of data is also very intense for the experimenter. Driving with an equipped car has limitations because of the lack of controllability over the traffic situation. According to Akamatsu (2002) driving simulators have great advantages in sensing accuracy and safety. By designing good experiments it is possible to measure natural driving behaviour. Simulation in a driving simulator will save engineering time and costs according to Kemeny & Panerai (2002). That is a reason why driving simulators are used more and more in studies of road and traffic safety. Another great advantage of a driving simulator is the control of the traffic situation and road environment. Also measuring driving behaviour itself is less difficult than in a real road environment. An example is determining the precise position of the car. Another advantage of using the simulator might be that it can be easier to obtain all the needed measurements (Akamatsu et al, 2001).

For the experiment presented in the current report, the fixed-base driving simulator of TNO Human Factors was used. In the virtual environment, it was possible to create the needed features for the green wave speed support. By using the driving simulator, it was possible to control the traffic situation during each run in order to let each subject drive under the same conditions. And the technical aspects of the in-car display were relatively easy to realise in the simulator compared to an equipped car. The fixed-base simulator was used because of the low costs and its availability. Because driving behaviour is a small part of this study, there was no need for a moving-base driving simulator. Besides driving behaviour, the user acceptance and workload of the green wave speed support were measured.

A field experiment of the ODYSA pilot project was conducted for green wave speed support (DTV Consultants, 2004). Variable message signs were used on the N282 near Rijen, a provincial road between Tilburg and Breda. ODYSA is short for traffic flow optimisation through variable speed advice (in Dutch: Optimalisatie Doorstroming door dYnamische SnelheidsAdvisering). Variable message signs at the right side of the road give an advisory speed to each passing vehicle in order to get a green wave for the oncoming traffic lights. A ‘green wave’-sign is displayed to make the driver understand the aim of the advisory speed. Through-traffic will face green light at the signalised intersections when driving the advisory speed. Sometimes a green wave cannot be guaranteed so a ‘no green wave’-sign is shown to the driver. The objective of the pilot project is to determine the improvement of traffic safety, level of service and driving comfort by ODYSA. Driver opinion is also examined. The pilot project resulted in a reduced amount of stops and decreased travel time during rush hour. Driving comfort and traffic safety benefit from ODYSA. During other periods travel time increased a little. There were no big disadvantages for other traffic. The opinion of the drivers from through-traffic is a little bit more positive than the opinion of destination traffic. These are the results of the DTV Consultants evaluation report of the pilot project ODYSA. Police reports showed several positive effects of the ODYSA project: the amount of rear-end collisions, the length of waiting lines in front of the traffic lights and speeding is decreased (Vialis Verkeer en Mobiliteit, 2003).

In an explorative study of Van der Horst and Godthelp (1982), the red light discipline of drivers was examined. During the beginning of the red phase, the most red light offences took place. A driver has to decide at the end of the green phase or at the beginning of the yellow phase to stop or continue driving across the intersection. Several factors play a role taking that decision:

- An estimation of the consequences of continuing driving. For example, the consequences of red light running or a fine;
- An estimation of the consequences of stopping. For example, traffic coming from behind;
- The predictability of the traffic situation;
- The behaviour of other traffic.

A prolongation of the yellow phase by one second may reduce the number of red light offences. In a second study, Van der Horst et al (1985) conducted a field experiment for one year to examine the long term influence of the prolongation of the yellow phase on the decision behaviour of drivers. The result was a decrease of 50% of the number of red light offences.

Besides information sources outside the car, it is also possible to use in-car systems for providing information to drivers. According to Vrancken et al (2003), this is a relatively new but attractive technique where a traffic management system is built into the car. For controlling traffic there are several benefits of an in-car system, such as:

- Coverage of the complete road network instead of parts of the motorway network;
- Drivers will only receive relevant information signals;
- In-vehicle signals are more flexible than variable message signs;
- The scope of the information is bigger.

According to Vrancken et al (2003), an in-car system is an attractive way to supply drivers with information but there are many hurdles to be overcome in its realisation. One of the important issues is user acceptance because the vehicle is considered as an extension of the private domain of the driver. In-car systems can be assessed in several ways, for example by a field study or using a driving simulator (Carsten & Brookhuis, 2005b). Both options have advantages and disadvantages. Field studies are more valid and are more similar to the reality. A driving simulator is efficient and allows for reproducible conditions. For each research it is important to choose the correct way for evaluating the in-car system.

In the research of Boyle & Mannering (2004) the effects on driving behaviour using an in-car system and variable message signs were examined. Both systems were applied to give drivers advisory information about adverse weather conditions and incident conditions. Three messages displayed to the drivers were about fog ahead, curvy road and snow-plough ahead. The experiment was conducted in a full-size fixed-base driving simulator. The four experiment conditions of passing the information were:

- In-car messages;
- Variable message signs messages;
- Both message types;
- Without any messages.

It was expected that the messages would support drivers avoiding collisions and other dangerous situations and that this would show in their driving behaviour. Drivers decreased their speed significantly when a message was displayed. But they compensated this behaviour by increasing their speed afterwards, probably to compensate for the loss of time (Boyle & Mannering, 2004).

In the field experiment with an instrumented vehicle of Luoma & Rämä (2002), drivers faced driving problems using an in-car system. The drivers reported unintentional speed decreases and late detection of other road users, vehicles or obstacles on the road. This is possibly due to a potential disadvantage of in-car systems, namely that the driver is overloaded with information (Carsten & Brookhuis, 2005a). This can counteract the positive effect that the information should give to the driver.

According to Carsten & Brookhuis (2005a) information overload on drivers can be minimised and information provision can be advantageous if traffic information is easily accessible, carefully timed, understandable and matched the user’s needs. Distraction caused by using an in-vehicle information system is a momentary risk

(Carsten & Brookhuis, 2005b). In order to predict the risk of a distraction, it is important to know the duration of the distraction. However, there is no obvious and immediate answer to this question because it depends on the traffic context in which the distraction occurs.

Dangerous situations can arise when the driver is distracted by the user interface of an in-car system (also called Human-Machine Interface) by speech, blinks or beeps (Andrade et al, 2007). According to Andrade et al (2007) there is need for basic ergonomics and principles when designing a system. Nowadays, information is provided to the driver automatically which means that the driver cannot decide when the information is given. The preferred moment is when the information will not cause distraction and when the primary driving task has a sufficiently low workload. And at the same time, not all information is equally essential. Therefore, a checklist is given for designing a system. For example, an in-car display:

- Should not obstruct the driver’s view of the road scene;
- Should be positioned as close as practical to the driver’s normal line of sight.

Van Winsum et al. (1999) suggested that visually displayed messages should not force drivers to look at the display. Therefore, information should be presented for a sufficient amount of time. A visual display should not present messages that requires an immediate response or action. Information displayed to the driver should be presented in such a way that a small number of glances of short duration are required.

2.2 Measuring workload

Giving information to drivers by using variable message signs and in-car systems can be useful for several goals. As mentioned before, an important issue is the distraction from driving or the increase in workload for the driver when interacting with such systems. However, not all driver support systems will result in an increase in workload. To measure workload, three methods for measurements can be applied (Winsum et al, 1999):

- Self-report measurements. This is a subjective way for measuring workload by applying rating scales;
- Physiological measurements. For example, measuring the driver’s heart rate;
- Task performance measurements. A secondary task is used to measure the remaining capacity while driving. When the workload is high, performance on driving and the secondary task will get worse. For example, the second task can be the Peripheral Detection Task (PDT) in which the driver has to respond to a presented red light as soon as possible. The concept of the PDT was developed by TNO.

According to Van Winsum et al. (1999) self-report and physiological measurements are unable to detect short-lasting variations in workload. The PDT is sensitive for small variations in cognitive load, which is also shown in a study of Van Winsum & Hoedemaeker (2000). The idea behind the PDT is that when the functional visual field decreases, the reaction time increases. The functional visual field decreases because of an increasing complexity of the driving task. The PDT measures the reaction time to a visual stimulus which is presented in the visual periphery. While driving, the drivers have to wear a headband with a small red Light Emitting Diode (LED) above their left eye. On the dominant hand of the subject a micro switch was attached to the index finger.

During one second, the stimulus (the LED) is presented to the subjects. Subjects are instructed to press the micro switch as soon as the red light was detected. If the subjects do not respond within two seconds after the onset of the stimulus, it is counted as a missed signal. The interval between the stimuli is a uniform random distribution with a variation between three and five seconds. On average each four seconds a stimulus was presented. The average reaction time and the percentage missed signals are used as workload indicators. In the current experiment, the Peripheral Detection Task (PDT) is used for measuring workload.

2.3 Measuring user acceptance

Another issue is the acceptance of the system by the users. Luoma & Rämä (2002) examined the user acceptance of traffic signs displayed on an in-car system. The traffic sign information was about a symbolic children sign, a symbolic cyclist sign and a speed limit sign. In a field study, four message conditions were examined:

- Visual sign. The traffic sign was shown;
- Visual sign and spoken message about the sign.
- Visual sign and spoken feedback was based on driving behaviour;
- Visual sign and a complete instruction when a sign was passed.

The results showed that drivers did accept the information about the traffic signs. They preferred the message condition where only the traffic sign was displayed. A speech message was not appreciated. A disadvantage suggested by drivers was that they unintentionally decreased their speed and that other vehicles or objects were detected late. According to the research this is a promising system but further research is needed to examine the former mentioned disadvantage.

As mentioned earlier, the use of in-car systems is relatively new (Vrancken et al, 2003). Therefore, Van der Laan et al (1997) developed a procedure for the assessment of driver acceptance of a new technology. It is a simple technique for measuring attitudes towards new systems by using nine items on a 5-point rating scale. Five items address usefulness and the other four satisfaction. An overview of the items is shown in Table 1. Subjects have to tick a box on every line, the 5-point rating scale is not displayed in the questionnaires. Items 1, 2, 4, 5, 7 and 9 are scored from +2 to -2, the other items (3, 6 and 8) are scored from -2 to +2 because the items are mirrored.

Table 1 The nine items of the Van der Laan questionnaire

Item number	Dimension	Items	Items in Dutch
1	Usefulness	Useful/useless	Nuttig/zinloos
2	Satisfying	Pleasant/unpleasant	Plezierig/onplezierig
3	Usefulness	Bad/good	Slecht/goed
4	Satisfying	Nice/annoying	Leuk/vervelend
5	Usefulness	Effective/superfluous	Effectief/onnodig
6	Satisfying	Irritating/likeable	Irritant/aangenaam
7	Usefulness	Assisting/worthless	Behulpzaam/waardeloos
8	Satisfying	Undesirable/desirable	Ongewenst/gewenst
9	Usefulness	Raising alertness/ sleep-inducing	Waakzaamheidverhogend/ Slaapverwekkend

Averaging the scores of the usefulness items over all subjects result in the end-score for usefulness. Averaging the scores of the satisfying items results in the end-score for satisfying. This method for measuring user acceptance can be applied to obtain scores for usefulness and satisfying in a before measurement and an after measurement. In the before measurement, subjects have to judge a system before experiencing this system. After experiencing the system, the subjects had to judge it again. This way, it can be shown whether the subject's opinion shifted.

3 Method

3.1 Research plan

By influencing by the way an advisory speed for a green wave is presented, the effects of coupled signalised intersections on driving behaviour, workload and user acceptance are examined in this Master thesis research project. An in-car system and a roadside system were used to give drivers speed support for a green wave. When the driver decided to adhere to the advisory speed he/she benefited from a green wave at signalised intersections. As mentioned before, variable message signs were already in use for giving drivers a speed advice for a green wave. The use of an in-car display for a green wave was new. Both systems were compared with a baseline condition where drivers drove without a speed support system to be able to determine the effects of a green wave.

It was to be expected that the green wave speed support using the in-car display would have a better effect on driving behaviour compared to the variable message signs. The in-car display showed the green wave advice all the time. However, this could result in a higher workload compared to variable message signs at the roadside because drivers could monitor the display all the time. Despite this possibly increase in workload, it was to be expected that the user acceptance of the in-car display was higher because the speed advice was displayed continuously.

Objective
The objective of this research was to determine the effects on driving behaviour, workload and user acceptance of two systems for speed support for a green wave. The two systems which give the drivers speed support, were 1) an in-car display and 2) variable message signs at the roadside.

Main research question
How will drivers respond to speed support for a green wave, by using an in-car display and variable message signs?

Minor research questions
1. What kind of effects does speed support for a green wave via variable message signs have on driving behaviour, workload and user acceptance?
2. What kind of effects does an advisory speed via an in-car display have on driving behaviour, workload and user acceptance?
3. Which system has the greatest user acceptance?
4. What is the attitude of the subjects on the two systems for the green wave speed support?

3.2 Green wave

A green wave is a term for when drivers get green light at coupled signalised intersections so a continuous traffic flow occurs. Drivers in a green wave will not have to stop for red light at signalised intersections. In order to make use of a green wave the driver has to drive a given speed. This can be a fixed speed or a variable speed. With a fixed speed one is able to make use of a green wave driving always the same speed.

This speed can be given to the drivers by traffic signs at the roadside. The variable speed can depend on vehicle-actuated traffic lights where the control strategy of the traffic lights is adjusted to the amount of traffic.

Not all traffic will always be able to get a green wave because the green phase is not infinite. So it is possible that drivers do have to wait. A green wave can reduce noise emission and also energy consumption because of less need for acceleration and deceleration. The environment and the safety and through-put on the road network will also benefit from a green wave. A green wave can be disturbed by slow traffic of traffic speeding.

In this experiment two systems were examined for presenting the subjects a green wave speed to benefit from a green wave at signalised intersections. The first system consisted of variable message signs at the roadside and the second one was an in-car display.

Green wave speed

The variable message signs and the in-car display were applied to give the subject a green wave speed. This was an advisory speed so the subject could decide if he/she wanted to adopt this speed. When driving this speed, the subject faced green light at the signalised intersections. Theoretically it was possible to give the subject different speed values. However in this experiment the values of the advisory speed varied between 60 km/h and 80 km/h. The maximum of the green wave speed (80 km/h) equalled the speed limit on the Kruithuisweg. The minimum was 60 km/h because it could be dangerous driving slower than other traffic on the provincial road. When the green wave speed was lower than 60 km/h or higher than 80 km/h, there was no speed value shown to the subject but the sign ‘no green wave’ was displayed.

The advisory speed given to the subjects was calculated by the time left to the start of the green phase and the distance to a traffic light. The calculated green wave speed for the variable message signs was displayed at the signs when the subject was at thirty metres to the signs. For the in-car display the calculation was done continuously so the in-car display showed the green wave speed continuously. For a subject it was hard to drive at a constant speed of for example 63 km/h or 78 km/h. It was less hard to drive a speed of 65 km/h or 80 km/h. The scale of the speedometer was not that precise. Hence the calculated speeds were rounded at 5 km/h.

Variable message signs

The first system for giving the subject the green wave speed consisted of variable message signs at the side of the road. For each signalised intersection two pairs of variable message signs were placed at the roadside. The first pair of signs, one sign at the right side of the road and one at the left side of the road, was placed at a distance of 100 metres after the intersection and is about 300 to 350 metres in front of the next intersection. Accordingly, subjects had time for adjusting their speed after passing the last intersection if they choose to act on the advice. There was a sign at each side of the road because the road has two lanes. Each subject had the chance to have a good view on a sign independent of the lane he/she was driving in. Figure 1 shows the variable message signs as used in the experiment.

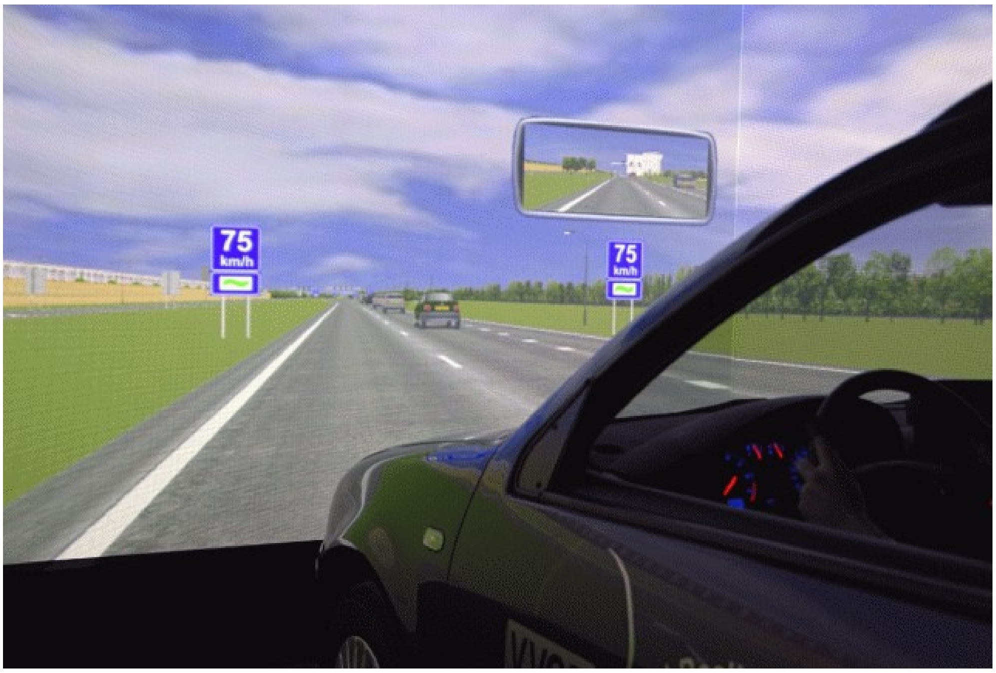


Figure 1 The variable message signs

The second pair, also one sign at the right and one at the left side of the road, was placed 150 metres ahead of the traffic light of the next intersection. This second pair was meant to inform the subject to adapt their speed to the one displayed on the signs. The distance between the signalised intersections on the experiment differed from intersection to intersection. The distance in between the two pairs of signs was about 150-200 meter. The distance between the intersections was too short for adding an additional pair of signs.

In-car display

The second system was an in-car display. The display was a Newision NW-819 VT TFT-LCD 8 inch screen with size 206mm (l) x 163mm (w) x 39.5mm (h) and pixel resolution 640 (h) x 480 (v). The subjects did not have to interact with the in-car display. The in-car display in the simulator was positioned at the right side of the steering wheel. The location close to the steering wheel required the least movement of the head in a horizontal way. The in-car display was also placed as high as possible to minimise the movement of the head in a vertical way but the in-car display was not in the field of view of the road. The location of the in-car display was chosen with respect to safety because of distraction from the road. It was important that the subject had an unblocked view on the road (Andrade et al, 2007), so the in-car display was not allowed to block the field of view on the road. The vertical and horizontal position of the chair in the simulator could be adjusted. Therefore, subjects were instructed to lift the chair when the in-car display blocked the view on the road. Figure 2 shows the used in-car display.

Figure 2 The in-car display and the head mounted Peripheral Detection Task (PDT)

The green wave speed on the in-car display was shown continuously to give the subject the most current advice. The in-car display only gave a visual message. No sound or light effects were used and the sign displayed on the in-car display was the same as the one on the variable message signs. Otherwise an additional factor would have been created which could lead to difficulties in comparing both systems. The last speed advice was given to the subjects at 80 metres in front of the intersections so the subjects could concentrate on the oncoming intersection.

The traffic sign

The traffic sign displayed on the variable message signs and the in-car display was similar. The traffic sign consisted of two parts. The sign lay-out of the upper half was according to the existing traffic sign A4 for an advisory speed in the Dutch Traffic Code 2006 (Ministry of Transport, Public Works and Water Management, 2006).

The lower part showed a green wave symbol (~) (see Figure 3). This part showed that the subject could benefit from a green wave. This existing sign was already in use or was used in green wave areas in the Netherlands.

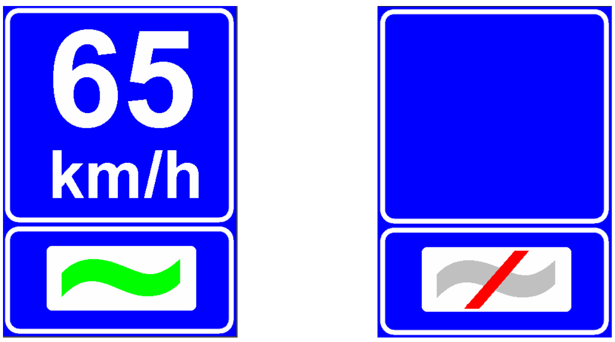


Figure 3 The traffic signs for ‘green wave’ and for ‘no green wave’

The sign 'no green wave'

It was not always possible for the subject to catch a green wave. When a green wave could not be guaranteed, a grey wave symbol with a red line symbol (/) was shown instead of a green wave symbol with an advisory speed (see Figure 3). In this case no advisory speed was shown on the variable message signs or the in-car display.

3.3 Databases and scenarios

South of the city Delft the Kruithuisweg (N470) connects two highways, the A4 on the eastside and the A13 on the westside (see Figure 4). The Kruithuisweg is a rural road with two separate driving carriageways with each two lanes. Four signalised intersections are located at the Kruithuisweg. The speed limit is different at different locations. Close to the intersections the speed limit is 50 km/h in combination with speed humps. On other parts of the road the limit is 70 km/h or 80 km/h. The length of the Kruithuisweg is around 3.5 kilometres, without access and entry ramps. There are four viaducts for crossing a railway and a river and two other roads. The last two viaducts are connected with elevated access and entry ramps. Three of the four intersections are used in the green wave experiment.

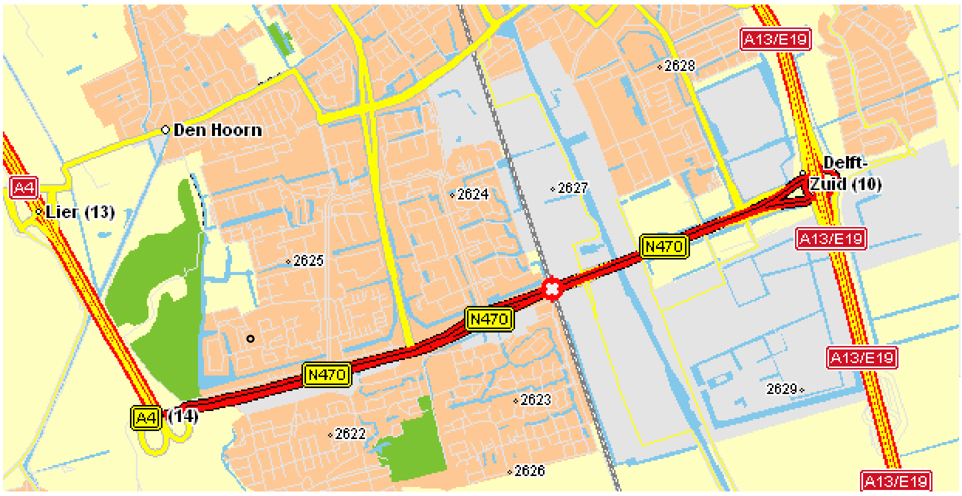


Figure 4 The Kruithuisweg (Source: www.routenet.nl)

A database of the Kruithuisweg was used for presenting the Kruithuisweg in the virtual environment. STRoadDesign of ST Software was used to make a 2D database which was transformed into a 3D database for projection on the screens.

In the experiment, the subjects drove at the Kruithuisweg in both directions (from west to east and vice versa). Driving both directions, the subjects were given time to experience the variable message signs and the in-car display for the green wave advice. To let the subjects drive both directions at the Kruithuisweg a loop was created to enable the subject drive in the opposite direction. The loop was not much curved to prevent subjects from getting motion sick. The loop was designed as a non-existing highway. In the real situation drivers, largely through traffic, entered the Kruithuisweg via the highways A4 or A13. Including a highway in the run made driving more varied.
The Kruithuisweg as used in the test road environment consisted of two driving lanes without shoulders. A strip of grass separated the eastern direction from the western direction. Four signalised intersections were present at the mainly straight road. The eastern intersection closest to the A4 entry was left out of a green wave, as this

intersection was considered too small. The highway had two driving lanes with shoulders.

The Kruithuisweg in the database differed from the real Kruithuisweg due to practical and technical reasons. The appearance of the eastern and western direction in the database was almost similar. It is assumed that this did not affect the results. Technically, it was not possible in STRoadDesign to copy every element of the Kruithuisweg into the database. For example, the several elevated parts of the Kruithuisweg and the speed humps could not be made in the database. Therefore, two viaducts, two access and entry ramps were left outside the database. The length of curved lanes at the intersections did not equal the form and length of the real intersections. Some adjustments had to be made on the length and form of the lanes at intersections because of software-technical reasons. For example, when the length of the access ramp was designed too short it would give problems for traffic entering the road. The traffic regulation installations at the intersections were not equal to the one at the real intersections. On the real Kruithuisweg, there was no green wave. Therefore, the setup of the traffic lights was made as coupled signalised intersections for a green wave. Driving the green wave advisory speed, the subject faced green light at the signalised intersections.

Each run started from still standing position on the highway on the west side. The subject had to start the car by himself. After the start on the highway, the subject entered the Kruithuisweg and passed four signalised intersections driving from west to east. Leaving the Kruithuisweg, the subject drove at the highway. After leaving the highway, the same four signalised intersections were passed but now in western direction. Passing the last intersection, the subject was instructed to stop after which the run ended.

At the start of the run ten programmed cars started from behind the subject and drove the same route as the subject. It was possible to get rid of these cars by driving much faster or passing traffic lights in time where the other cars had to stop because they faced red. It was made impossible for the others cars to pass a red sign. At intersections traffic from the other directions entered the Kruithuisweg and left the Kruithuisweg at the next intersection. Only the ten mentioned cars drove the same road as the subjects did. Including the ten cars driving along with the subject, the other traffic in the experiment did not react on the green wave advice. It is assumed that this did not influence the subjects to a large extent. Subjects were able to overtake the other traffic. A run lasted about ten minutes. With respect to driver fatigue, it is important for a run not to last too long. Driver fatigue was not of interest for this study and should therefore be avoided.

3.4 Experiment design

The effects on driving behaviour were measured with three experiment conditions. These conditions varied in the system used for presenting the green wave speed to subjects:

1. Baseline condition. This condition was without a system for giving the subject a green wave speed. In the baseline condition the setup of the traffic lights was similar to the other conditions. For subjects it was possible to make use of a green wave but they did not receive a green wave speed advice;

2. Variable message signs condition. Variable message signs at the roadside were used for giving the subject the advisory speed about a green wave;
3. In-car system condition. Here an in-car display was used for presenting the green wave speed.

The design of the experiment was a within-subject design, which meant that in each condition the same subjects were tested. This gave a reduction in error variance associated with individual differences. A within subject design is also called a repeated measurement. This design had more statistical power and took fewer subjects. With the within-subject design it was possible to compare driving behaviour, workload and user acceptance between the three different conditions. A comparison between ‘without system’ and ‘with system’ could be made but also a comparison between both systems. A disadvantage of a within-subject design was that subjects could learn over time which could result in undesirable learning effects. Therefore, the sequence of the runs was counterbalanced because of these learning effects. In Appendix A the experiment design of the runs for each subject is given.

Two green wave conditions were introduced in order to avoid learning effects on the green wave speed. These two conditions were:

1. The low reference speed condition 65 km/h;
2. The high reference speed condition 75 km/h.

Driving the low reference speed condition meant that a green wave was guaranteed when driving with an average speed of 65 km/h in the low reference speed condition and 75 km/h in the high reference speed condition. The setup of the traffic lights was adjusted to achieve this. The reference speed condition in the eastern direction was not the same as the reference speed condition in the western direction. When a subject drove the eastern direction in the low reference speed condition, he/she had to drive the western direction in the high reference speed condition and vice versa.

In total, each subject completed three runs in the driving simulator corresponding to the three system conditions of the experiment. A run contained two reference speed conditions by driving the eastern and western direction on the Kruithuisweg. This resulted in six trials, two trials in each run, which are shown in Table 2.

Table 2 Six trials of the experiment

Run	**Trial**	**System**	**Reference speed**
1	1	Without system	Low reference speed 65 km/h
	2	Without system	High reference speed 75 km/h
2	3	Variable message signs	Low reference speed 65 km/h
	4	Variable message signs	High reference speed 75 km/h
3	5	In-car display	Low reference speed 65 km/h
	6	In-car display	High reference speed 75 km/h

The average speed in the two reference speed conditions was lower than the speed limit. When the advisory speed equalled the speed limit it would be impossible to see whether the subject acted on the advice or on the speed limit. The value of 75 km/h was very close to the speed limit, the value of 65 km/h was not. These two speed values could be used to examine the effects of a bigger difference between the speed limit and advisory speed. The subjects were not informed about these two green wave conditions, so they could not anticipate on this. They were only instructed that they could receive an advisory speed for a green wave on the Kruithuisweg. For more information about the instruction given to the subjects see section 3.8 Procedure.

When the speed advice for the next traffic light was for example 65 km/h, this meant that driving with an average speed of 65 km/h resulted in green light. A bandwidth of 3 km/h was made round this advice, so driving with an average speed between 62 and 68 km/h resulted in green.

The TRANSUMO experiment

The experiment of the current project was combined with the experiment of the TRANSUMO project Intelligent Vehicles by PhD student Nina Schaap (Schaap, 2006). TRANSUMO stands for TRANsitions towards SUstainable MObility. The same subjects were used for both the experiments. In each run the subjects were instructed to drive like they normally did. The three runs from the current experiment were combined with the four runs of the TRANSUMO experiment. In each run of the TRANSUMO experiment, subjects drove a couple of non-signalised intersections in an urban environment (Schaap et al, 2007). This combination of both experiments had the advantage that the subjects did not get used too much to the two runs of both experiments (see Table 3). It is to be expected that the TRANSUMO experiment had no influence on the current experiment.

Table 3 Combination of the runs of the SUMMITS and TRANSUMO experiment

Run	Experiment	Details
0	-	Introduction
1	TRANSUMO	Run 1
2	SUMMITS	Run 1
3	TRANSUMO	Run 2
4	SUMMITS	Run 2
5	TRANSUMO	Run 3
6	SUMMITS	Run 3
7	TRANSUMO	Run 4

3.5 Driving simulator

The experiment was conducted in the fixed-base driving simulator of TNO Human Factors. In this driving simulator the subjects were seated in a Volkswagen Golf 4 mock-up. The mock-up had manual transmission, left seated driver and normal controls. Feedback of steering forces was given to the subject by means of an electrical torque engine. The subject watched the road and traffic environment, which was projected on three large screens (225cm (h) x 300 cm (w)) with a total viewing angle of 180°. Also the sound (engine, wind) of the car a subject was driving were presented. The experimenter was seated in the same room close to the mock-up, where he/she had access to the control system and could watch the mock-up; communication with the subject was possible by means of an intercom. Figure 5 shows the driving simulator.

Figure 5 The TNO fixed-base driving simulator

The outside visual consisted of a projected image on three plane screens in front of the mock-up. The right and left screen are placed with an angle of 120° compared to the screen in the middle. Figure 6 shows the setup of screens and the mock up. The mirror images were projected on the screens as well. The images were projected by means of three Liesegang dv 245 projectors (800 x 600 dpi, 1400 ANSI Lumen). The total horizontal field of view is 180° and the total vertical field of view is 45°.

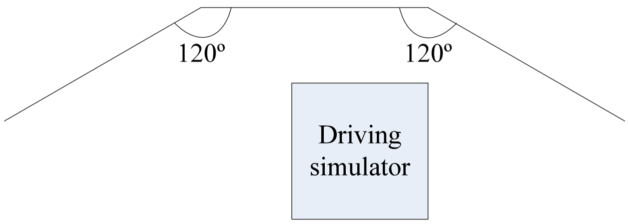


Figure 6 The screens and the mock up

The computer generated image system was a PC based visual system (Dimension 8400, P4 3.0 GHz P4 HT, 1.0 GB DDR2). It consisted of a processor desktop with NVIDIA GeForce 5600 GT graphic cards that generated real-time images at a refresh frequency of 30 Hz.

The controller computer (Dimension 9100, P4 3.0 GHz, 1.0 GB DDR2) managed the communication between the experimenter and the other subsystems, the control and monitoring of the experiment, data storage, the control of the behaviour of other traffic. The sound of the own vehicle (engine, wind) was generated in the cabin itself and was generated by two speakers which were mounted in the mock-up.

3.6 Peripheral Detection Task

The Peripheral Detection Task (PDT) was used to measure workload during driving. The subject had to wear a headband with a small red LED (see Figure 7) above the left eye and on the left hand of the subject, a micro switch (see Figure 8) was attached to the index finger.

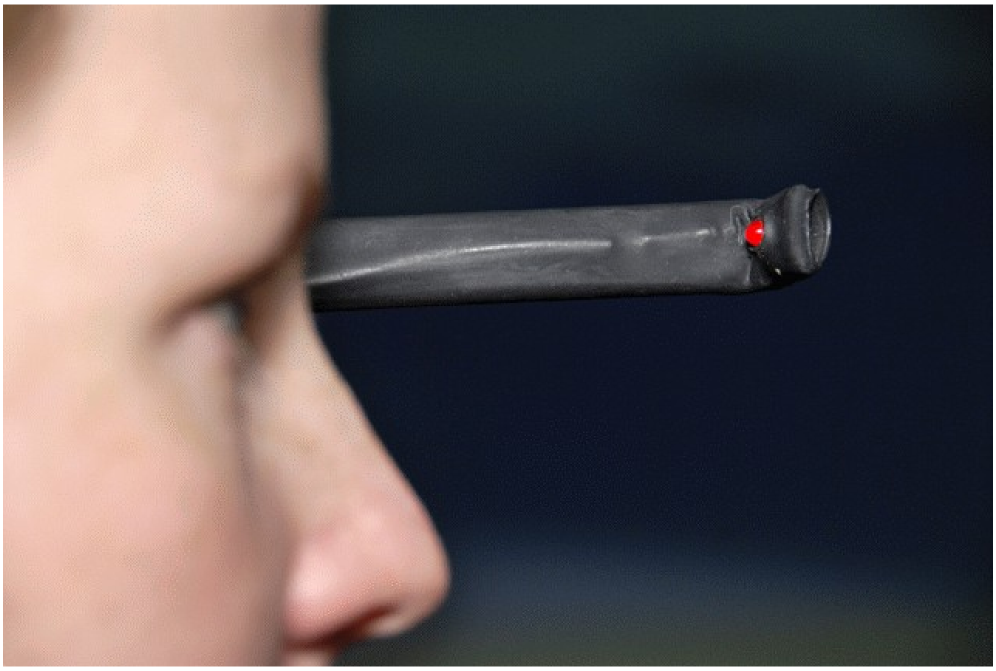


Figure 7 The LED of the PDT

Instead of the dominant hand, the left hand had to be used because of the manual transmission of the driving simulator. Because of the within-subject design, it was assumed this had no influence on the results of workload. Driving the car safely had priority; using the PDT was the second task. Subjects were instructed to press the micro switch as soon as they detected the red light. However, driving safely had priority and therefore subjects were instructed to neglect the PDT when necessary.

Figure 8 The micro switch of the PDT

3.7 Subjects

As mentioned before, there were three system conditions (without system, variable message signs and in-car display) and two reference speed conditions (low and high). Six (2 x 3) groups of subjects were made. To obtain significant results, it was important to have a sufficient number of subjects. In total sixty subjects were planned to take part in the experiment, for each group ten subjects (with a minimum of eight subject for each group and 48 in total). More subjects were planned, considered the possibility of a few subjects getting motion sick or not showing up for any reason. To select subjects from the TNO subject database the following section criteria were applied:

- Age between 23 and 60 years;
- Having a driving license five years or more;
- Driving around 7,000 kilometres a year or more;
- Not experiencing motion sickness in fairground attractions, in a real car and in a simulator.

In the experiment a total of 58 subjects took part, but only fifty (35 male and 15 female) subjects completed the experiment. Eight subjects got motion sick and were left out of the data set. Five out of 40 (12.5%) male subjects and three out of 18 (16.7%) female subjects got motion sick. They did not complete the experiment and were sent home. The average age of the fifty subjects was 44 years (standard deviation 12.9 and range 24-64). Two subjects were older than 60 years (namely 61 and 64 years) but they were still active drivers so it was allowed for them to participate in the experiment. All the subjects had their driving license for more than five years. All subjects, even the motion sick ones, were thanked and paid for their participation.

3.8 Procedure

The experiments were lead by an experimenter, whose task it was (amongst others) to take care of the wellbeing of the subjects and to instruct them. All instructions and forms were in Dutch.

Before the start of the experiment, several introductions were given:
- A written introduction to the experiment, after which subjects were given the opportunity to ask questions;
- A short introduction to the driving simulator including an introduction run. The introduction run was designed to get used to the simulator because it felt different compared to driving in a real car.

Subjects were instructed:
- To sign a form of informed consent, which stated amongst others that both parties could end the experiment anytime without giving a reason;
- Not to ask questions or to talk about the experiment with the other subject (two subjects were performing the experiments in the same time frame) during the experiment because that could influence the results of the experiment;
- Not to drink coffee during the experiment because drinking coffee could increase the chance of getting motion sick.

Motion sickness could influence the results which was not desirable. The subjects were told if they started feeling uncomfortable during the experiment, a short break would be made after which they could continue. In fact this was not true. Possible next runs were not performed as well. Apparently, subjects were more willing to take a break when they knew they could finish the experiment after the break. Subjects might continue driving since they did not want to disappoint the experimenter or they did want to admit they could not complete the experiment because it felt like failing. After the break the subjects did understand that the false information was given because of the experiment results.

After the introduction run the experiment runs started. Here the subjects drove alone in the simulator. Before each run the subjects read an instruction form about the run on the Kruithuisweg in Delft where the speed limit was 80 km/h (on the highway the speed limit was 120 km/h). The instruction explained what a green wave is and gave information about the variable message signs and the in-car display. There was also a short instruction about the PDT (see section 3.6) which was going to be used. Subjects were asked to drive like they normally did.

After each run, the subjects had to fill out a questionnaire. After experiencing both systems, the subjects were asked to evaluate both systems on usefulness and satisfying. Therefore, the procedure of Van der Laan et al (1997) was used. Appendix B shows the questionnaires according to the Van der Laan method as applied in this present study. The subjects had to score nine items on a 5-point rating scale from -2 to +2. An extra question was added to the questionnaire, namely the subjects had to judge if they found the green wave speed advice personal (specially meant for you) or common (meant for everyone). Here, also a 5-point rating scale was used (-2 for common to +2 for personal). Remarks about the experiment could be written down on the questionnaires.

After the last run had been finished and the last questionnaires had been filled out, the subjects were thanked and paid for their participation. The whole experiment for each subject lasted for almost four hours. The experiment was conducted from November 9, 2006 till January 11, 2007.

3.9 Data registration

Registered variables

Thirteen variables were registered with a frequency of 10 Hz during the experiment. Each run gave three data files, one for the data variables of driving (such as speed and acceleration), one for the PDT reaction time and one for the event codes. So for each subject, there were nine data files which gave in total 450 data files for all subjects. The following variables were registered:

1. Time (s);
2. Path number;
3. Distance to intersection (m);
4. Velocity (m/s);
5. Acceleration (m/s^2);
6. Lateral position (m);
7. Lateral velocity (m/s);
8. Stopping distance (m);
9. Time headway (s);
10. Distance lead vehicle (m);
11. Velocity lead vehicle (m/s);
12. PDT reaction time (ms);
13. Advisory speed shown on the variable message signs and the in-car display (km/h).

Variables 6, 7, 8 and 11 were registered for further data analysis in other prospective studies.

The best system

The research questions were about how drivers will react on variable message signs and an in-car display giving an advisory speed for a green wave. Therefore, effects on driving behaviour, workload and user acceptance were measured. Which system was the best for giving the drivers an advisory speed in order to benefit from a green wave? But what will make a system the best system? Therefore, the best system was defined by the following terms:

- Driving behaviour. An advantage of a green wave for the driver is to continue driving at the signalised intersections. This is also an advantage for the traffic flow. A good traffic flow will result in a decreased travel time for the driver and in a smaller acceleration. For measuring if the subjects followed the green wave advice, the average speed had to be compared with the given advice. The standard deviation of speed gives an indication of the variance in speed of all the subjects. The best system in terms of driving behaviour is a system that increases the level of *comfort* of a trip by a decreased travel time, the continuous driving and the smaller maximum of accelerating;
- Workload. Giving the driver a green wave speed is a way of driver support. With respect to traffic safety it is important that the driver is not distracted from driving. So the system may not cause much distraction from driving. From the

workload point of view the best system caused not much *distraction*. For measuring workload the Peripheral Detection Task was used;
- User acceptance. The working of a green wave depends on the user acceptance. If drivers do not accept a system for a green wave it will be useless. The driver has to accept the system and also has to drive the green wave speed. So the best system was a system with a high level of user *acceptance*. The opinion of the driver was measured using the dimensions usefulness and satisfying (Van der Laan et al, 1997). These terms originated from the original paper.

The terms *comfort*, *distraction* and *acceptance* were described using variables which were deducted from the registered variables which resulted in the following variables for each term:

- Comfort:
  - Travel time. The time it took the subject to drive each direction;
  - Average speed. The driven speed was averaged over time in each direction;
  - Standard deviation of speed which was also averaged over time in each direction;
  - Maximum acceleration. The maximum value of acceleration in each direction;
  - Minimum acceleration. The minimum value of acceleration in each direction, which was equal to the maximum value of deceleration;
  - Root Mean Square of the driven speed (RMS). The RMS is a statistical measure to determine the difference between the driven speed and the green wave advice speed in each direction. The RMS was used as a measure to see how much the subject acted on the green wave speed. By applying the following formula, the RMS was computed:

$$RMS = \sqrt{\frac{(v_{driven} - v_{advice})^2}{T}}$$

  Over time (T) the difference between the driven speed by the subject (v_{driven}) and the green wave advice displayed on the variable message signs and the in-car display (v_{advice}) was computed;
- Distraction:
  - Average PDT reaction time. This was computed by averaging all PDT reaction time values smaller than two seconds for each direction;
  - Percentage PDT missed signals. The amount of missed signals out of the total presented signals in each direction. A reaction time of more than 2 seconds was counted as a missed signal;
- Acceptance:
  - User acceptance score. Per run, the end-scores for the dimensions usefulness were computed by averaging the scores on the items for usefulness and satisfying, respectively. The items for usefulness were useful/useless, bad/good/, effective/superfluous, assisting/worthless and raising alertness/sleep-inducing. For satisfying the items were pleasant/unpleasant, nice/annoying, irritating/likeable and undesirable/desirable (see Table 1 in Chapter 2 for the Dutch words).

The effects of the speed support for a green wave at coupled signalised intersections at the Kruithuisweg were of interest for this study. Both driving directions contained three coupled signalised intersections for a green wave. The parts that were of interest were from intersection 0 to intersection 3 for the eastern direction and from the highway to intersection 6 for the western direction. Figure 9 and Figure 10 show the eastern and the western driving directions at the Kruithuisweg, respectively. Variables of driving behaviour and workload were measured for each trial (see Table 2 in Chapter 3).

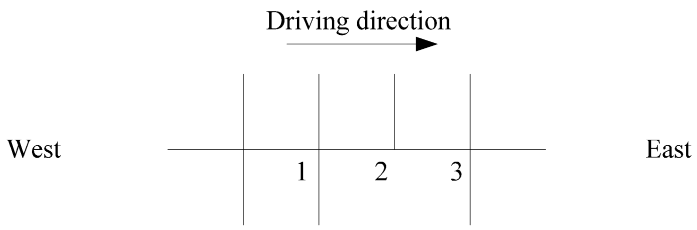


Figure 9 The eastern driving direction

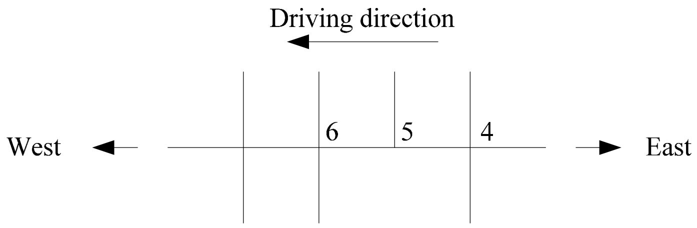


Figure 10 The western driving direction

The highway was also left out of the analysis because this was not of interest for this study. There were no traffic lights and therefore no green wave. Intersection 0 of the real Kruithuisweg was a small intersection with not much traffic. Therefore, intersection 0 was also left out of the analysis.

Frequency tables

From the data set several counts of events were made in order to make frequency tables. These frequency tables gave more information about the runs the subjects completed. The frequency tables are about the number of times the subjects stopped for the traffic lights, ran the red light, ran the yellow light and had or should have stopped:

- Number of stops. For each intersection this count gave information whether the subject had to stop or could continue driving. An interval of hundred metres in front of the traffic lights was analysed. Stopping was defined as a certain decrease in speed so subjects could not continue driving in a smooth move. Therefore, the Speed Reversal Rate (SRR) was applied to determine if a subject had to stop. The SRR is a variant of the Steering Reversal Rate. The Steering Reversal Rate is the number of times the steering wheel is reversed through a certain gap of angle and is used to count the number of steering reversals (Hogema & Verschuren, 2001). Instead of counting the number of steering reversals, the number of speed reversals was counted in an interval of hundred metres in front of the traffic lights. The gap size of the SRR was 8.3 m/s (30 km/h) which meant that a decrease in speed of 8.3 m/s was defined as a stop. See also Appendix C about the SRR;
- Number of red light runners. When a subject passed the stop line when the light was red;
- Number of yellow light runners. A subject passed the stop line when the light was yellow;

- Number of had or should have stopped: the stopping count and the red light running count are added which resulted in a count for the number of times the subject actually had stopped or should have stopped (but violated the red light).

4 Data analysis

4.1 Driving behaviour and workload

Normal distribution

Before performing data analysis, the variables were checked for being normally distributed by making a histogram for each variable. The following variables were normally distributed:

- Travel time;
- Average speed;
- Standard deviation of average speed;
- RMS of the driven speed;
- Average PDT reaction time;
- PDT percentage missed signals.

The following variables were not normally distributed and therefore no analysis of variance could be performed:

- Maximum acceleration;
- Minimum acceleration.

Analysis of variance

The experiment contained three system conditions. The effects of the three system conditions were measured. Also the effects of the two reference speed conditions on driving behaviour and workload were measured, although this was no research question. To see whether there was any statistically significant difference in driving behaviour, workload and user acceptance between these conditions ANalysis Of VAriance (ANOVA) was conducted. In statistics, a result is significant when it is unlikely that this result occurred by chance. A statistically significant difference means there is statistical evidence of a difference between conditions. In analysis of variance the value of the p-level (statistical significance level) is an important index for the reliability of a result. The lower the p-level, the more one can say the result is reliable. The p-level in the analysis is 5%. When the p-level is lower than .05 there is less than 5% chance that the relation found between results is not valid.

The analysis of variance checks if there is statistically significant difference for within-subject factors. These within-subject factors represent the conditions of the experiment runs. The within-subject factors are for driving behaviour and workload:

- ‘Reference speed’. The factor ‘reference speed’ contains the two reference speed conditions, namely the low reference speed condition (65 km/h) and high reference speed condition (75 km/h);
- ‘System’. The factor ‘system’ contains the three system conditions, namely the conditions without system (baseline condition), variable message signs and in-car display.

The within-subject factor for user acceptance, is called ‘measurement’ and contains the three conditions without system (baseline condition), variable message signs and in-car display. The without system condition is a before measurement. In the before measurement, the subjects had to judge a system for the green wave advice by using the questionnaires of Van der Laan et al (1997) before experiencing this system. The variable message signs condition and the in-car display condition were after measurements. In the after measurement the subjects had to judge the variable message signs and the in-car display after having experienced them.

In ANOVAs, two types of effects can be found, namely main effects and interaction effects. The main effect represents the average effect of a single within-subject factor (‘system’ or ‘reference speed’). The interaction effect represents interaction between the two within-subject factors, namely the effect of a factor averaged over another factor.

For analyzing the data, the data analysis software system Statistica version 7.1 from StatSoft Inc. was used.

Post hoc test
When in the analysis of variance a significant result was found for a within-subject factor, a post hoc test was performed. A post hoc test was applied to determine the significant differences between the conditions in a factor. For example, when there is found a statistical significant results for the within-subject factor ‘system’ it is unknown which conditions significant differed from each other. A post hoc test was performed to examine the significant difference between the baseline condition, the variable message signs condition or the in-car display. Here, the Bonferroni test was applied. The Bonferroni test determines the significant differences between group means (Statistica Electronic Manual, keyword “Bonferroni”).

Frequency tables
In the frequency tables the number of stops, the number of red light runners, the number of yellow light runners and the number of times subjects had or should have stopped are displayed. Statistically significant differences between the conditions ‘without system’, variable message signs’ and ‘in-car display’ were determined by using the unpaired Student’s t-Test.

In section 5.2 and 5.3 the results of the data analysis for driving behaviour and workload are described, respectively.

4.2 User acceptance

Before computing the scores of the variables (‘usefulness’ and ‘satisfying’) for user acceptance and before performing analysis of variance, reliability analysis had to be performed by using Cronbach’s alpha (Van der Laan et al, 1997). Table 4 shows the results (α values) of the reliability analysis for usefulness (U) and satisfying (S). These terms originated from the original paper.

Table 4 Results (α values) of the reliability analysis (U = usefulness, S = satisfying)

	Before measurement		**After measurement Variable message signs**		**After measurement In-car display**	
Study part	U	S	U	S	U	S
Baseline first	0.91	0.89	0.97	0.98	0.97	0.98
System first			0.98	0.97	0.95	0.94

The determined reliability is sufficiently high ($\alpha > 0.65$) and therefore, the end-scores for each subject could be computed and analysis of variance could be performed. Section 5.4 describes the results of the data analysis.

4.3 Outliers

Visual analysis of box plots and histograms of the data showed a couple of outliers. Comments notated by the experimenter during the experiment learned that in several runs a traffic jam occurred because of an error of the software. This traffic jam happened when the other traffic a couple of metres in front of the subject stopped for a red light but kept standing still at green. In six runs, this traffic jam occurred and therefore, subjects stood still for some time. In these cases, the experimenter told the subject to pass the traffic jam by the grass or the other lane. This time standing still has influence on the results of:

- Driving behaviour. Standing still for some time caused a large travel time. It also had an effect on average speed and the standard deviation of average speed. The RMS of the driven speed was influenced because of the big difference between the speed of the subject and the advisory speed shown on the variable message signs and the in-car display. Therefore, the RMS of the driven speed did not give accurate information about the run;
- Workload. During standing still the subject will have enough time for the Peripheral Detection Task or he/she does not have attention for it because he/she is concerned about the situation. In these runs the traffic jam will have influence on the workload, therefore these have to be excluded from the data;
- User acceptance. The traffic jam will have no influence on the user acceptance of both systems. It is assumed that the traffic jam may had influence on the attitude of the subject about the run or the simulator but that it had no influence on the attitude on the variable message signs and the in-car display.

Subjects 6, 8, 10 and 21 experienced a traffic jam in one run. Subject 42 experienced a traffic jam in two runs. The six runs containing a traffic jam were kept out of the data set for data analysis of driving behaviour and workload, which meant these five cases had to be excluded. For user acceptance no cases were excluded. For the frequency tables also no cases were excluded. The traffic jam happened when the traffic light was red and when there was traffic in front of the subject. It is assumed that in this case the subject was going to stop anyhow. Therefore, the traffic jam did not have influence on the data in the frequency tables.

5 Results

5.1 General

This chapter contains the results of the experiment. The results for driving behaviour consists of the variables travel time, speed, standard deviation of average speed and root mean square of the speed compared to the reference speed (section 5.2). The frequency tables can also be found in section 5.2. Section 5.3 contains the results for workload which are the variables average PDT reaction time and percentage missed PDT signals. Section 5.4 gives the results for user acceptance which was measured by questionnaires. Remarks of the subjects are given in section 5.5. A summary of the results can be found in section 5.6. Appendix D shows the values of the variables.

In each graph, results with a p-level lower than .05 are indicated by * and an *Italic font style*. When the p-level is higher than .05 no statistically significant result was found. In each figure the vertical bars denote 95% confidence intervals.

5.2 Driving behaviour

Travel time

For travel time, a significant main effect of 'reference speed' and an interaction effect between 'reference speed' and 'system' were found. No main effect of 'system' was found. Table 5 shows the statistical results of the repeated measures analysis of variance on travel time.

Table 5 Statistical results on travel time

Effect	**F**	**p**	**Figure**
Reference speed	F(1,44) = 21.946	*.000027**	Figure 11
System	F(2,88) = 0.576	.564307	
Reference speed x system	F(2,88) = 6.720	*.001924**	Figure 12

Post hoc tests on 'reference speed' showed that travel time in the low reference speed condition 65 km/h was higher than in the high reference speed condition 75 km/h (p<.000027), see Figure 11.

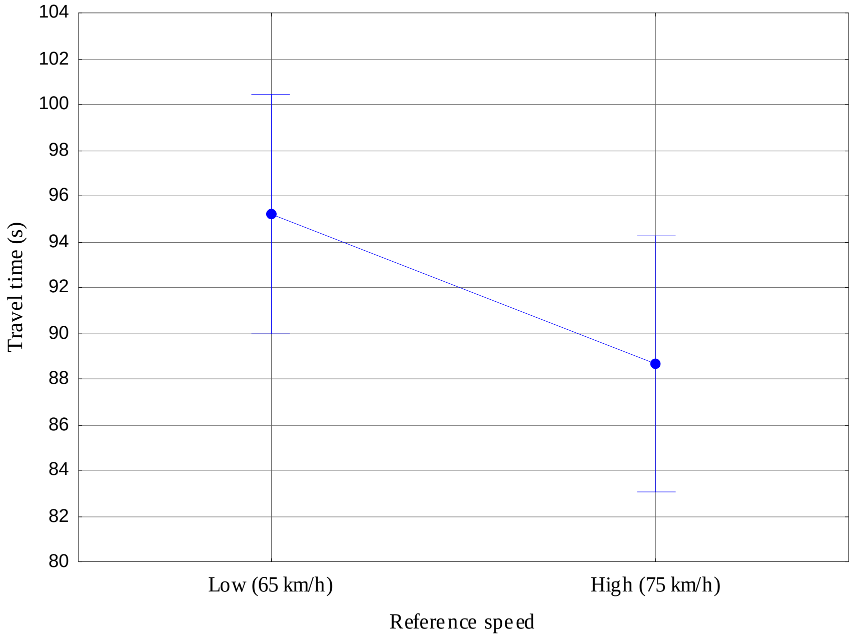


Figure 11 Travel time as a function of 'reference speed'

No statistically significant difference was found between the variable message signs and the in-car display. The interaction effects are displayed in Figure 12. Post hoc tests on the interaction effect between ‘reference speed’ and ‘system’ showed three effects. Travel time was higher:

1. In the low reference speed condition than in the high reference speed condition when using variable message signs ($p<.006871$);
2. In the low reference speed condition than in the high reference speed condition when using the in-car display ($p<.000349$);
3. In the low reference speed condition when using the in-car display than without a system ($p<.030496$).

Driving with a system for green wave speed support in the high reference speed condition resulted in a smaller travel time compared to the low reference speed condition. Apparently, the use of speed support systems in the high reference speed condition is more worth it than in the low reference speed condition. A possible explanation might be that the average speed one had to drive for the green wave was closer to the speed limit.

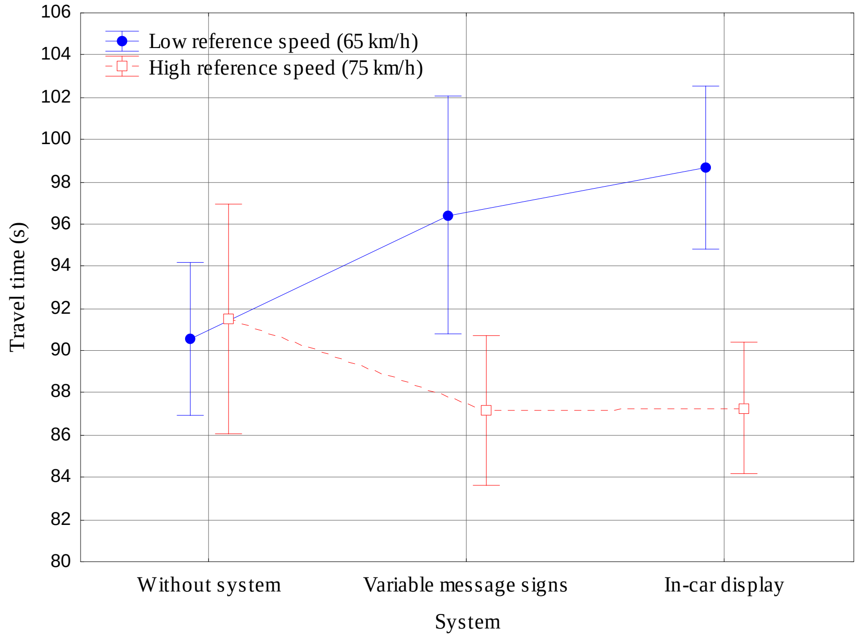


Figure 12 Travel time as a function of 'reference speed' and 'system'

Average speed

There was found a significant main effect of 'reference speed' and 'system' and an interaction effect between 'reference speed' and 'system'. The statistical results of the repeated measures analysis on average speed are shown in Table 6.

Table 6 Statistical results on average speed

Effect	**F**	**p**	**Figure**
Reference speed	F(1,44) = 35.533	*.000000**	Figure 13
System	F(2,88) = 3.277	*.042378**	Figure 14
Reference speed x system	F(2,88) = 9.264	*.000223**	Figure 15

Post hoc tests showed that average speed in the high reference speed condition (75 km/h) was higher than in the low reference speed condition (65 km/h) which can be seen in Figure 13 ($p<.000000$). Driving with an average speed of 65 km/h (18.1 m/s) in the low reference speed condition guaranteed a green wave. The lower green line shows this average speed for the low reference speed condition. From Figure 13 it can be seen that the average speed in the low reference speed condition was close to the average speed of 65 km/h one had to drive for a green wave. For the high reference speed condition, one had to drive an average speed of 75 km/h (20.8 m/s) in order to benefit from a green wave, which is displayed in the figure by the upper thickened green line. The driven speed was lower than the reference speed.

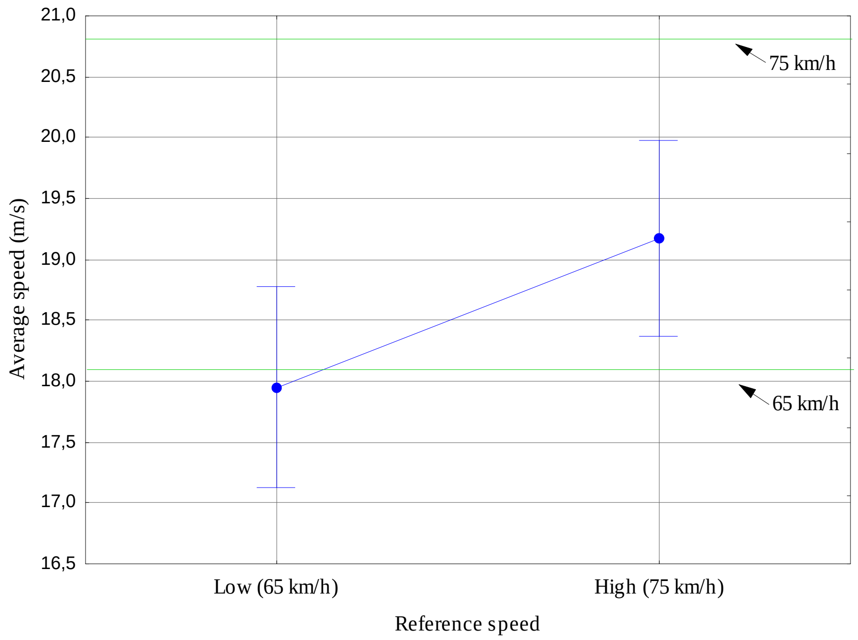


Figure 13 Average speed as a function of 'reference speed'

Post hoc tests showed that the average speed in the baseline condition was higher than when the in-car display was used (p<.036834), see Figure 14. No statistically significant difference was found between the variable message signs and the in-car display. The two green lines indicate the average speed one had to drive in the low and high reference condition to benefit from a green wave.

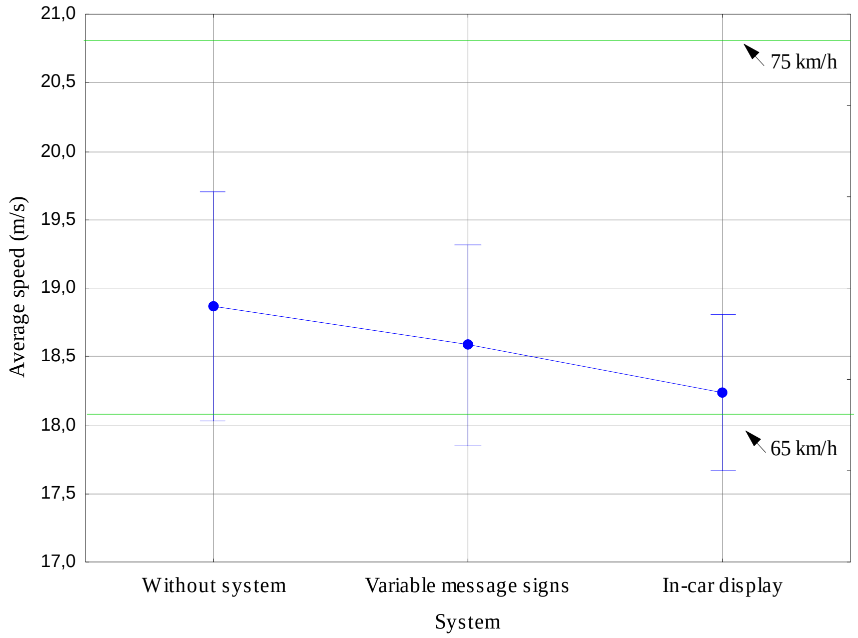


Figure 14 Average speed as a function of 'system'

The interaction effects are shown in Figure 15. Post hoc tests on the interaction effect between ‘reference speed’ and ‘system’ showed four effects. The average speed was higher:

1. In the low reference speed condition without a system than when using variable message signs (p<.029469);
2. In the low reference speed condition without a system than when using the in-car display (p<.000072);
3. In the high reference speed condition than in the low reference speed condition when using variable message signs (p<.000046);
4. In the high reference speed condition than in the low reference speed condition when using the in-car display (p<.000000).

Here again, the green lines show the average speed of the low (65 km/h) and high (75 km/h) reference speed conditions. Driving with both systems in the high reference speed condition, the driven average speed was lower than in the baseline condition. A possible explanation might be that in the baseline condition the subjects did not know the speed they had to drive in order to benefit from a green wave. From Figure 15 it can be seen that the driven average speed in the high reference speed condition for both systems was higher than in the low reference speed condition. A possible explanation might be that the average speed one had to drive for a green wave was closer to the speed limit. In the high reference speed condition, the driven average speed in all conditions was lower than the average speed of 75 km/h one had to drive for a green wave displayed by the upper the green line.

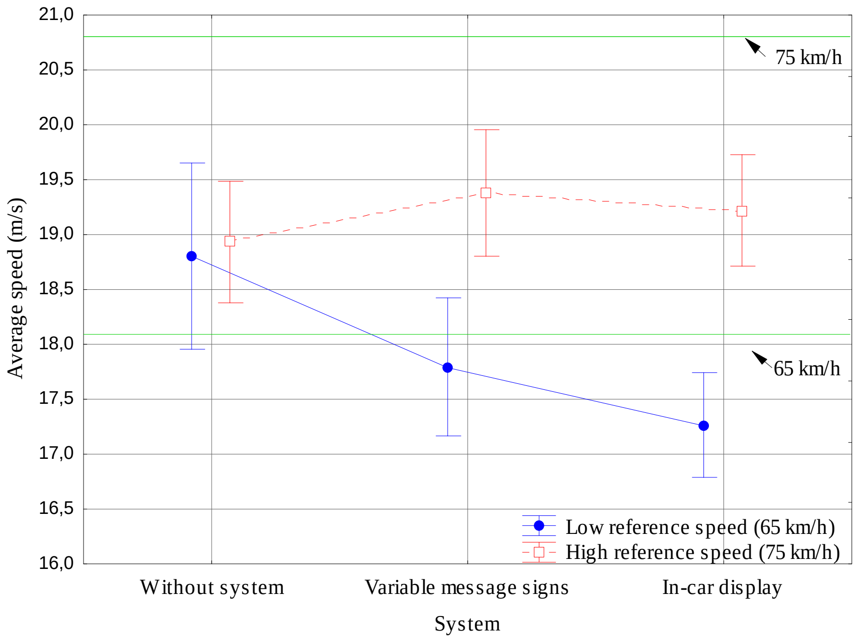


Figure 15 Average speed as a function of ‘reference speed’ and ‘system’

Standard deviation of average speed

The standard deviation of average speed is used for measuring the spread in values of average speed. If standard deviation of average speed is high, the values of the average speed are widely spread. A small standard deviation means that the values are close to the mean. There was a significant main effect of ‘reference speed’ and ‘system’ found and an interaction effect between ‘reference speed’ and ‘system’. The statistical results of the repeated measures analysis on the standard deviation of average speed are shown in Table 7.

Table 7 Statistical results on standard deviation of average speed

Effect	**F**	**p**	**Figure**
Reference speed	F(1,44) = 31.293	*.000001**	Figure 16
System	F(2,88) = 28.055	*.000000**	Figure 17
Reference speed x system	F(2,88) = 3.406	*.037608**	Figure 18

Post hoc tests showed that the standard deviation of average speed in the low reference speed condition (65 km/h) was higher than in the high reference speed condition (75 km/h), which can be seen in Figure 16 (p<.000001). In the high reference speed condition, the values of the average speed are more close to the mean.

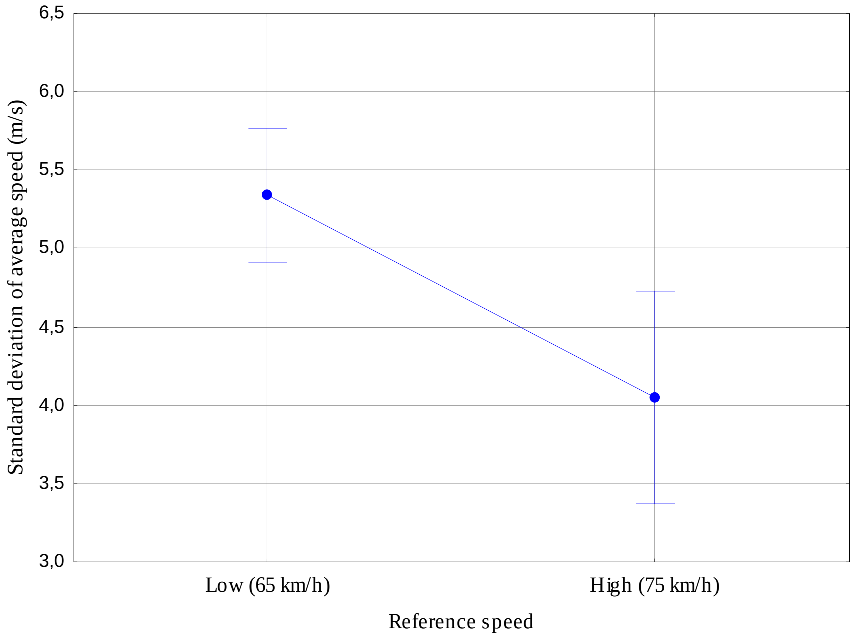


Figure 16 Standard deviation of average speed as a function of ‘reference speed’

Post hoc tests showed that the standard deviation of average speed was higher:

1. In the baseline condition than when the in-car display was used (p<.000000);
2. In the variable message signs condition than when the in-car display was used (p<.000001).

These results are shown in Figure 17.

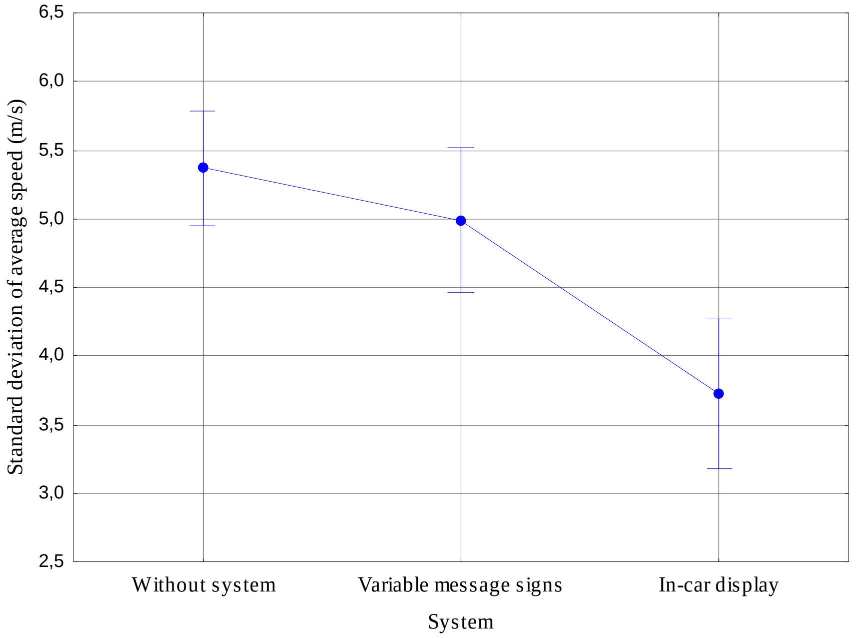


Figure 17 Standard deviation of average speed as a function of 'system'

The interaction effects are shown in Figure 18. Post hoc tests on the interaction effect between 'reference speed' and 'system' showed five effects. The standard deviation in average speed was higher:

1. In the low reference speed condition than in the high reference speed condition without a system (p<.000672);
2. In the low reference speed condition than in the high reference speed condition using variable message signs (p<.000000);
3. In the low reference speed condition without a system than when using the in-car display (p<.000000);
4. In the low reference speed condition when using variable message signs than when using the in-car display (p<.000000);
5. In the high reference speed condition without a system than when using the in-car display (p<.000066).

In the variable message signs condition, the spread in variance of speed was smaller in the high reference speed condition compared to the low reference speed condition. A possible explanation might be that the green wave speed advice in the high reference speed condition was closer to the speed limit. Compared to the baseline condition, the spread in variance of speed was smaller in the in-car display condition. Apparently, the use of the in-car display resulted in a more homogenous traffic pattern. Driving with the in-car display for green wave speed support resulted in a smaller spread in variance of speed compared to the variable message signs in the low reference speed condition. A possible explanation might be the continuously displayed green wave speed advice.

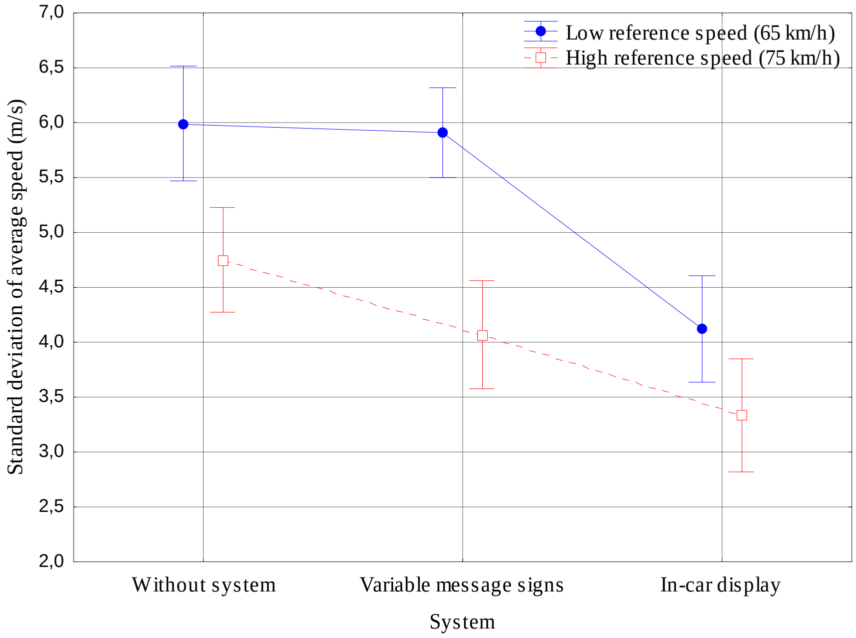


Figure 18 Standard deviation of average speed as a function of ‘reference speed’ and ‘system’

Root Mean Square of the driven speed

The Root Mean Square of the driven speed was applied to measure if subjects acted on the advice. A higher RMS meant that there was a bigger difference between the advice given for a green wave and the driven speed of the subjects. A low RMS meant the speed of the subject was more equal to the advisory speed so it can be said he/she adhered more to the green wave advice. For the RMS, a statistical main effect of ‘reference speed’ and ‘system’ was found. No interaction effect was found between ‘reference speed’ and ‘system’. The statistical results of the repeated measures analysis on the root mean square are shown in Table 8.

Table 8 Statistical results on RMS of the driven speed

Effect	**F**	**p**	**Figure**
Reference speed	F(1,44) = 36.1456	*0.000000**	Figure 19
System	F(2,88) = 15.1554	*0.000002**	Figure 20
Reference speed x system	F(2,88) = 0.9052	0.408201	Figure 21

Post hoc tests showed that the RMS in the low reference speed condition (65 km/h) was higher than in the high reference speed condition of 75 km/h (p<.000000), which can be seen in see Figure 19.

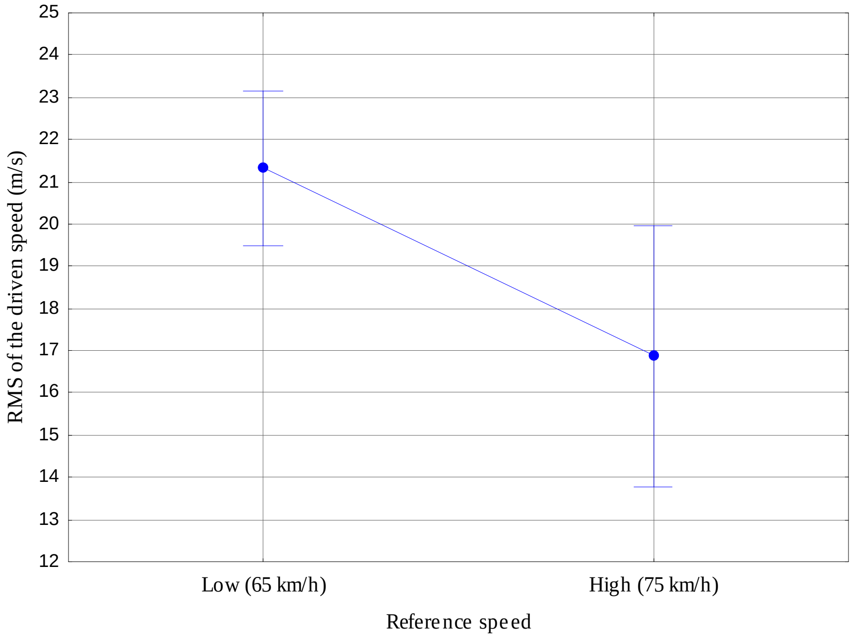


Figure 19 RMS of the driven speed as a function of 'reference speed'

Post hoc tests showed that the RMS of the driven speed in the baseline condition was higher compared to the conditions with variables message signs (p<.000005) and the in-car display (p<.000158). No statistically significant difference was found between the variable message signs and the in-car display. This is shown by Figure 20. The subjects did not get a green wave advice when driving without a system for a green wave. Therefore, they did not know which speed they had to drive in order to benefit from a green wave which resulted in a high value of the RMS of the driven speed.

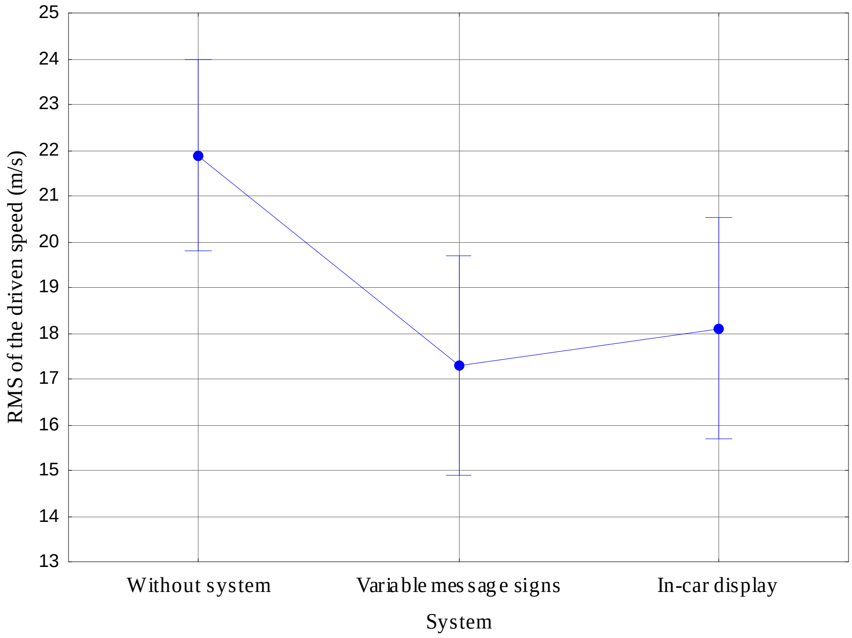


Figure 20 RMS of the driven speed as a function of 'system'

Figure 21 shows the RMS of the driven speed as a function of ‘system’ and ‘reference speed’. No interaction effects were found between ‘system’ and ‘reference speed’.

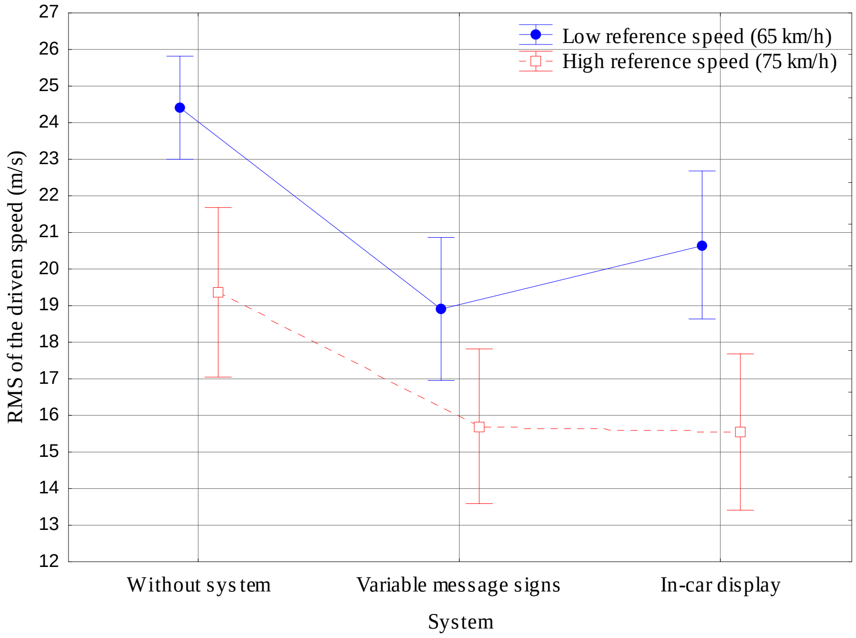


Figure 21 RMS of the driven speed as a function of ‘system’ and ‘reference speed’

Frequency tables

Besides the analysis of variables for driving behaviour, frequency tables were made. These frequency tables contain information about the subjects driving six signalised intersections in each run. Driving from west to east, intersection number 1 was the first signalised intersection the subjects encountered. Driving the opposite direction, intersection number 4 was the first one. The four frequency tables are about if the subject:

1. Stopped at the traffic light, which can be found in the frequency table with the number of stops. An interval of hundred metres in front of the traffic lights was analysed;
2. Passed the traffic light during the yellow phase which can be found in the frequency table with the number of yellow light running;
3. Passed the traffic light during the red phase which can be found in the frequency table with the number of red light running;
4. Had or should have stopped at the traffic light. Here, the number of stops (where subjects actually had stopped) and the number of red light runners (where subjects did not obey the red light) were added which resulted in the number of times the subjects had to stop for a red light.

Instead of performing an ANOVA, the Student’s t-Test was performed. Table 9 shows the results of the analysis. The number observations was fifty subjects.

Table 9 Results of the analysis of the Student´s t-Test

	Baseline versus variable message signs	**Baseline versus the in-car display**	**Variable message signs versus the in-car display**
# stops	p<.651026	p<.282771	p<*.015656**
# yellow light runners	p<.463497	p<.918762	p<.329079
# red light runners	p<.181610	p<.549014	p<.305674
# had or should have stopped	p<.163261	p<.885466	p<.127015

In each frequency table the fifty subjects passed each six traffic lights which means that the number of passages in each condition was 300 times. For example, in the without system condition the number of stops was 10 out of 300 which means in 3% of the passages a subject stopped (see Table 10). In total, eight out of fifty subjects were involved in the 10 stops. In the variable message signs condition four subjects caused 12 stops.

Table 10 shows the total number of stops at the Kruithuisweg for each system. There was found one statistically significant difference between the conditions ‘variable message signs’ and ‘in-car display’ (p<.015656). More stops were made driving with the variable message signs compared to driving with the in-car display. In the baseline condition, eight subjects stopped ten times in total which is an average of 1.3 per subject. In the variable message signs and in-car display conditions the average number of stops per subject was 3 and 2.5, respectively. On an average, one subject stopped for more than one traffic light in the variable message signs or in-car display condition than one subject in the baseline condition.

Table 10 Frequency table of the number of stops

	Intersection number								
# stops	1	2	3	4	5	6	**total**	**%**	**# subj.**
Without system	0	1	4	2	3	0	10	3%	8
Variable message signs	2	2	2	3	2	1	12	4%	4
In-car display	1	2	0	0	1	1	5	2%	2

Table 11 shows the total number of yellow light runners at the Kruithuisweg for each system. There was not found any statistically significant difference between the conditions ‘without system’, ‘variable message signs’ and ‘in-car display’. In the baseline condition, 25 subjects violated the yellow light 35 times in total which is an average of 1.4 per subject. In the other two conditions the average number was also 1.4 yellow lights violations per subject.

Table 11 Frequency table of the number of yellow light runners

	Intersection number								
# yellow light running	1	2	3	4	5	6	**total**	**%**	**# subj.**
Without system	9	2	11	4	7	2	35	12%	25
Variable message signs	4	1	8	8	2	3	26	9%	19
In-car display	4	6	6	7	6	5	34	11%	24

Table 12 shows the total number of red light runners at the Kruithuisweg for each system. No statistically significant difference was found between the variable message signs and the in-car display. In the baseline condition, nine subjects violated the red light ten times in total which is an average of 1.1 per subject. In the other two conditions the average number was 1.2 red lights violations per subject.

Table 12 Frequency table of the number of red light runners

# red light running	Intersection number						total	%	# subj.
	1	2	3	4	5	6			
Without system	1	5	2	1	0	1	10	3%	9
Variable message signs	13	6	2	3	2	1	27	9%	23
In-car display	4	1	5	3	0	1	14	5%	12

Table 13 shows the number of times there had to stop for a traffic light during the experiment by taking the number of red light runners and the number of stops together. No statistically significant difference was found between the variable message signs and the in-car display. In the in-car display condition, 13 subjects had or should have stopped 19 times in total which is an average of 1.5 per subject. In the other two conditions the average was 1.4 per subject.

Table 13 Frequency table of the number of had or should have stopped

# had or should have stopped	Intersection number						total	%	# subj.
	1	2	3	4	5	6			
Without system	1	6	6	3	3	1	20	7%	14
Variable message signs	15	8	4	6	4	2	39	13%	28
In-car display	5	3	5	3	1	2	19	6%	13

Summary

Travel time was smaller in case of the high reference speed, which was closer to the speed limit on the Kruithuisweg, than when the reference speed was low. When using variable message signs or the in-car display, travel time was higher in the low reference speed condition compared to the high reference speed condition. In the low reference speed condition travel time was higher using the in-car display compared to the baseline condition.

The average speed in the high reference speed condition was higher compared to the low reference speed condition. Driving with the in-car display resulted in a lower average speed compared to the baseline condition. When using variable message signs or the in-car display, the average speed was higher in the high reference speed condition than in the low reference speed condition. Driving without a system in the low reference speed condition, the average speed was higher compared to driving with a system (variable message signs or the in-car display). In the low reference speed condition, driving with an average speed of 65 km/h guaranteed a green wave. For the high reference speed condition, this was 75 km/h. Driving with both systems resulted in a lower driven average speed than the average speed of 65 km/h and 75 km/h one had to drive in the low and high reference speed condition, respectively.

The standard deviation of average speed was smaller in the high reference speed condition than in the low reference speed condition. The values of average speed were closer to the mean when the reference speed was high. The standard deviation of average speed was smaller when the in-car display was used than when using variable message signs or no system for the green wave speed. In the low and high reference speed condition, the standard deviation of average speed was higher when no system for the green wave advice was used compared to using the in-car display. Standard deviation of average speed was smaller using the in-car display compared to the variable message signs when the reference speed was low. The standard deviation of average speed was smaller in the low reference speed condition compared to the high reference speed condition when no system was used or when the variable message signs were used.

The Root Mean Square of the driven speed in the high reference speed condition was smaller than in the low reference speed condition. This means that subjects acted more on the advice when the reference speed was 75 km/h. In the baseline condition the subjects did not act much on the advice. This can be explained because they did not know the green wave advice. With both systems for a green wave, the difference between the advisory speed and the driven speed decreased. That means that compared to the baseline condition, the subjects act more on the advisory speed.

When driving with the in-car display there was a smaller number of stops compared to driving with variable message signs. This means that subjects using the in-car display for a green wave could continue driving better than subjects using variable message signs.

5.3 Workload

Average PDT reaction time

There was a significant main effect found of 'system'. No main effect of 'reference speed' and no interaction effect between 'reference speed' and 'system' were found. The statistical results of the repeated measures analysis on the average PDT reaction time are shown in Table 14.

Table 14 Statistical results on average PDT reaction time

Effect	**F**	**p**	**Figure**
Reference speed	F(1,41) = 0.065	.800403	
System	F(2,82) = 8.213	*.000561**	Figure 22
Reference speed x system	F(2,82) = 2.007	.140910	Figure 23

Post hoc tests showed that the use of variable message signs resulted in a higher reaction time than without a system for green wave information (p<.000344) which can be seen in Figure 22. This indicates that the workload was higher when subjects were driving with the variable message signs. No statistically significant difference was found between the variable message signs and the in-car display.

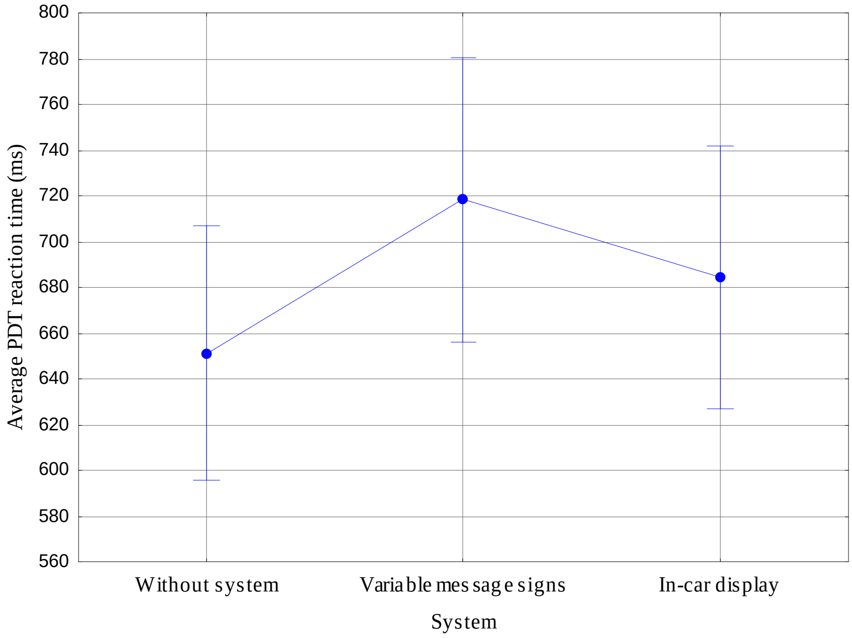


Figure 22 Average PDT reaction time as a function of ‘system’

Figure 23 shows the average PDT reaction time as a function of ‘system’ and ‘reference speed’. It can be seen that both reference speed conditions had similar effects on the PDT reaction time.

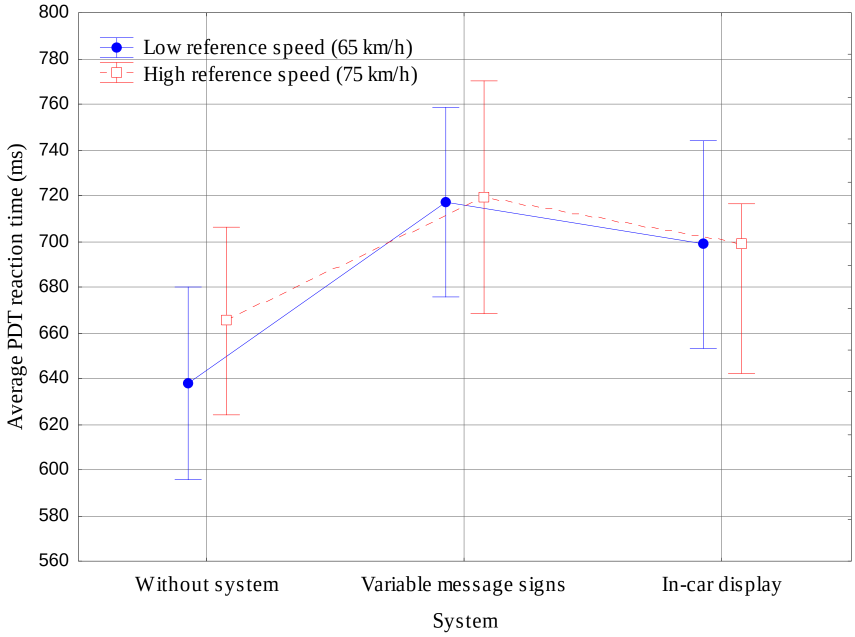


Figure 23 Average PDT reaction time as a function of ‘system’ and ‘reference speed’

Percentage missed PDT signals

There was a significant main effect found of ‘reference speed’ and ‘system’. The statistical results of the repeated measures analysis on the percentage missed PDT signals shown in Table 15.

Table 15 Statistical results on percentage missed signals

Effect	**F**	**p**	**Figure**
Reference speed	F(1,41) = 4.57051	*.038536**	Figure 24
System	F(2,82) = 4.90536	*.009722**	Figure 25
Reference speed x system	F(2,82) = 0.27246	.762194	Figure 26

Post hoc tests showed that the average PDT reaction time in the low reference speed condition had a greater percentage of missed signals than in the high reference speed condition (p<.038536). Figure 24 shows this result.

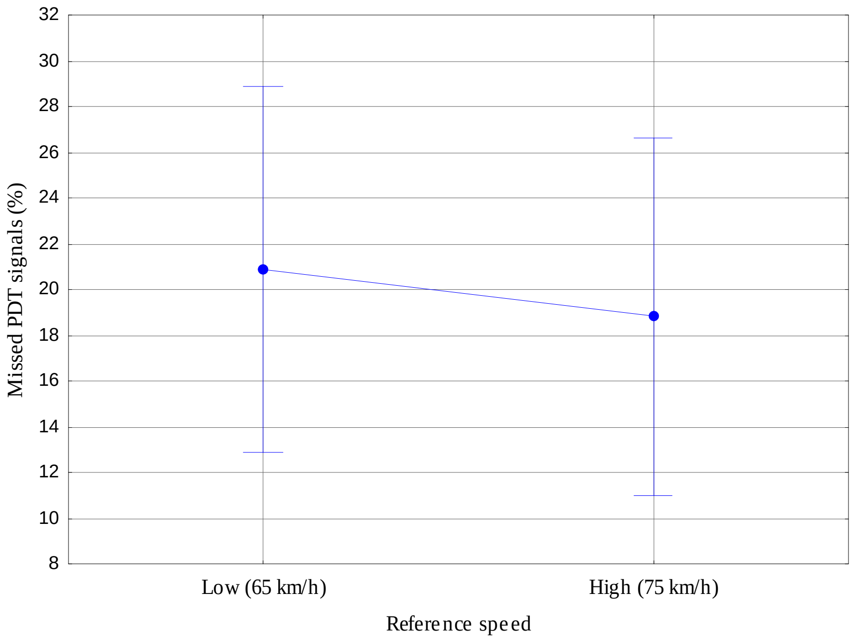


Figure 24 Percentage missed PDT signals as a function of ‘reference speed’

Post hoc tests showed that when using variable message signs the percentage missed signals was higher than without a system (p<.013572), see Figure 25. This indicates that the workload was higher when subjects were driving with variable message signs. No statistically significant difference was found between the variable message signs and the in-car display.

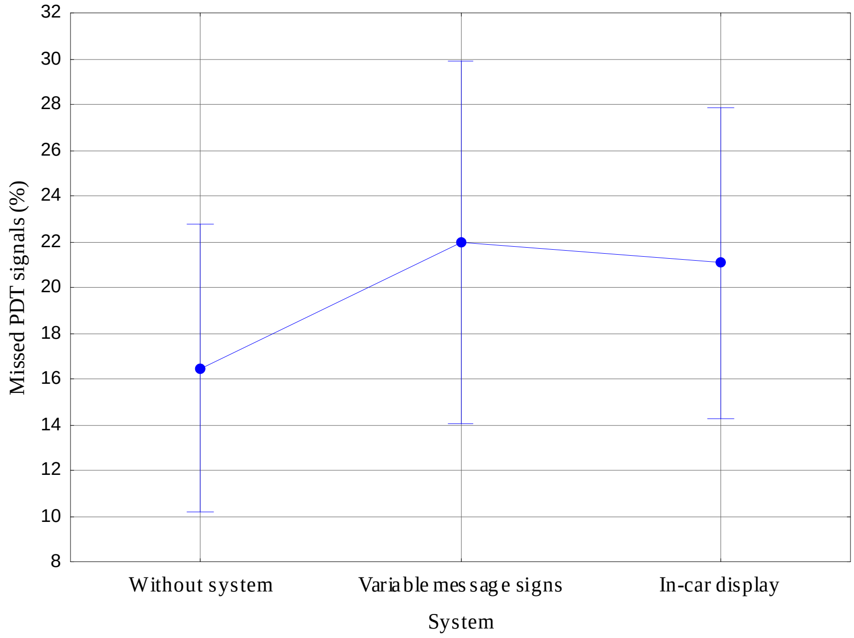


Figure 25 Percentage missed PDT signals as a function of ‘system’

Figure 26 shows the percentage missed PDT signals as a function of ‘system’ and ‘reference speed’. It can be seen that both reference speed conditions had similar effects on the percentage missed PDT signals.

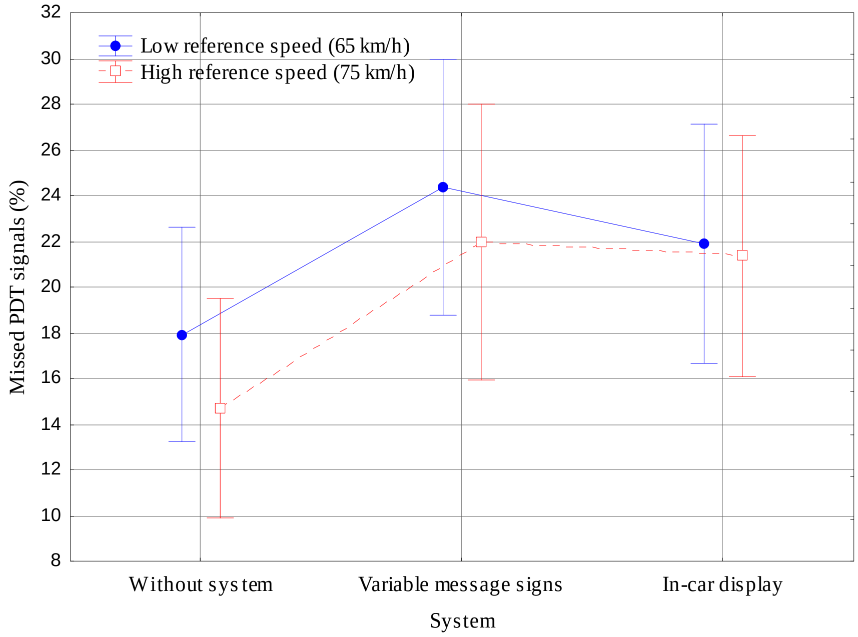


Figure 26 Percentage missed PDT signals as a function of ‘system’ and ‘reference speed’

Summary

Using variable message signs resulted in a higher reaction time than without a system for green wave information. Driving with variable message signs also resulted in a higher percentage missed PDT signals. This indicates that when subjects were driving with variable message signs the workload was higher. In the low reference speed condition the percentage missed PDT signals was higher than in the high reference speed condition.

5.4 User acceptance

User acceptance was measured by the questionnaires the subject had to fill out during the experiment. User acceptance concerned two dimensions, namely ‘usefulness’ and ‘satisfying’ (Van der Laan et al, 1997). The dimension ‘usefulness’ was about practical aspects of the variable message signs and the in-car display used for a green wave. ‘Satisfying’ reflected the pleasantness of both systems. These terms originates from the original paper. The 5-point rating scale of the dimensions ‘usefulness’ and ‘satisfying’ run from -2 to +2.

The experiment was split up in two parts for measuring user acceptance. One third of the subjects had to fill out questions about a hypothetical system for a green wave before they could actually experience the system. These subjects started the experiment with the baseline run followed by the runs with systems. This part of the study was called ‘baseline first’. In ‘system first’ subjects had to judge the systems after they were exposed to the systems. For both parts the usefulness (U) and satisfying (S) scores are shown in Table 16. The relations between the measurements of both study parts are in the same order of magnitude, horizontally and vertically. Therefore, it can be said that there is no sequence effect of the experiment runs.

Table 16 Usefulness scores (U) and satisfying scores (S) for both study parts

	Before measurement		**After measurement Variable message signs**		**After measurement In-car display**	
Study part	U	S	U	S	U	S
Baseline first (N = 17)	1.48	1.59	0.76	0.68	0.53	0.10
System first (N = 33)	-	-	0.72	0.51	0.56	0.08

Statistical analysis was performed on both study parts. For the study ‘baseline first’ a significant main effect of ‘measurement’ in ‘usefulness’ and in ‘satisfying’ was found. The statistical results of the main effects are shown in Table 17.

Table 17 Statistical results on usefulness and satisfying for baseline first

Baseline first	**F**	**p**	**Figure**
Usefulness	F(2,32) = 7.48236	*.002158**	Figure 27
Satisfying	F(2,32) = 12.39085	*.000104**	Figure 28

Figure 27 shows the main results for ‘usefulness’. Post hoc test of Bonferroni showed that usefulness scored higher:

- In the before measurement than in the variable message signs condition (p<.026015);
- In the before measurement than in the in-car display condition (p<.002335).

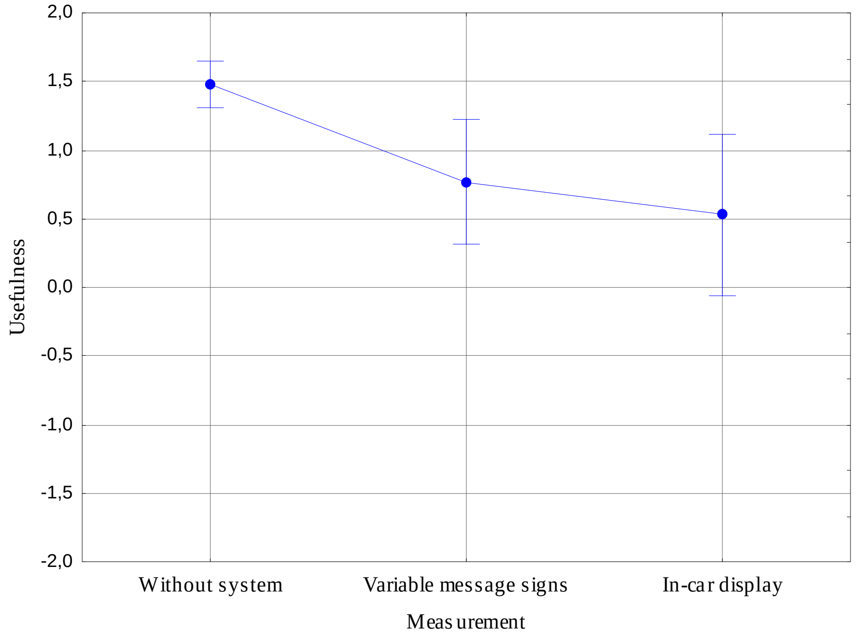


Figure 27 Usefulness as a function of ‘measurement’

Post hoc test of Bonferroni showed that satisfying scored higher (see Figure 28):

- In the before measurement than in the variable message signs condition ($p<.014440$);
- In the before measurement than in the in-car display condition ($p<.000072$).

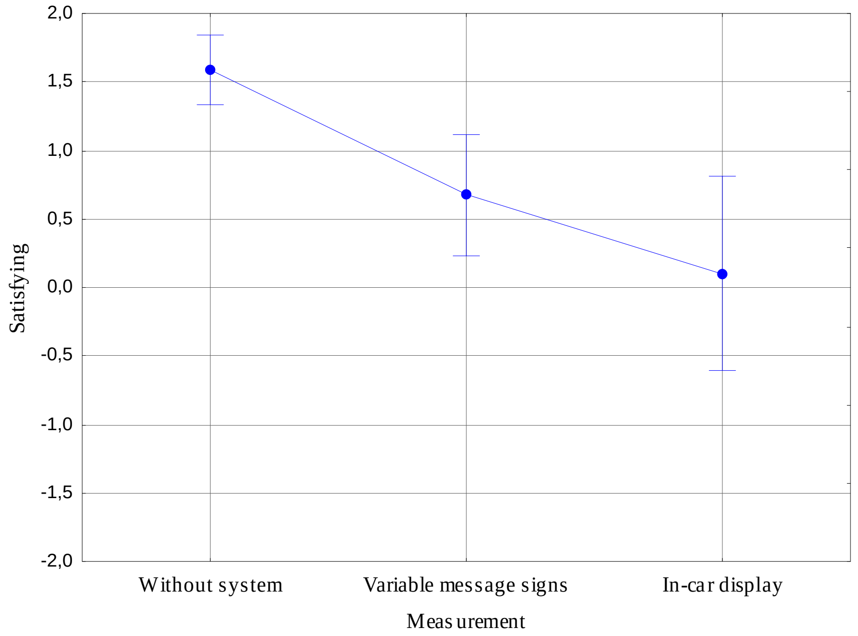


Figure 28 Satisfying as a function of ‘measurement’

No statistically significant difference was found for usefulness and satisfying between the variable message signs and the in-car display.

For the study ‘system first’, a significant main effect was found of ‘measurement’ in ‘satisfying’. No main effect in ‘usefulness’ was found. The statistical results of the repeated measures analysis are shown in Table 18.

Table 18 Statistical results on usefulness and satisfying for system first

System first	F	p	Figure
Usefulness	F(1,32) = 0.70522	.407265	
Satisfying	F(1,32) = 6.724098	*.014224**	Figure 29

Figure 29 shows the main results for ‘satisfying’. Post hoc tests showed that satisfying scored higher in the variable message signs condition than in the in-car display condition (p<.014224).

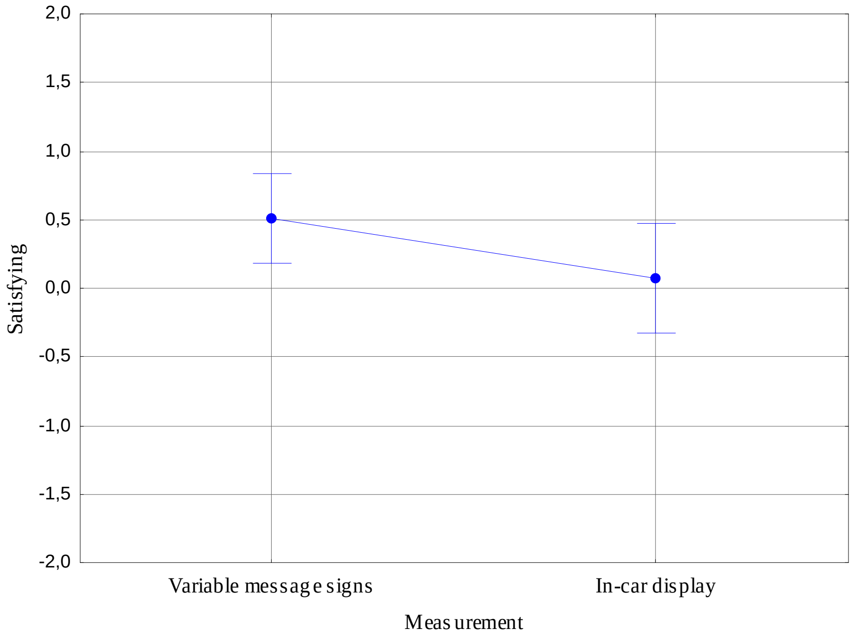


Figure 29 Satisfying as a function of ‘measurement’

Both study parts together

Table 19 shows the scores for the study parts ‘baseline first’ and ‘system first’ together. It is allowed to take both study parts together because the ratios between ‘usefulness’ in both after measurements and the ratio between ‘usefulness’ in both study parts are in the same order of magnitude. In case of ‘satisfying’, the ratios are also in the same order of magnitude.

Table 19 Usefulness scores and satisfying scores for both study parts together

Before measurement (N = 17)		**After measurement Variable message signs (N = 50)**		**After measurement In-car display (N = 50)**	
Usefulness	Satisfying	Usefulness	Satisfying	Usefulness	Satisfying
1.48	1.59	0.73	0.57	0.55	0.09

For both study parts together (a total of fifty subjects), analysis of variance was performed. A significant main effect was found of ‘measurement’ in ‘satisfying’. No main effect in ‘usefulness’ was found. The statistical results of the repeated measures analysis are shown in Table 20.

Table 20 Statistical results on usefulness and satisfying for both study parts together

	F	**p**	**Figure**
Usefulness	F(1,49) = 1.38091	.245626	
Satisfying	F(1,49) = 10.19745	*.002458**	Figure 30

Figure 30 shows the main results for ‘satisfying’. Post hoc tests showed that satisfying scored higher in the variable message signs condition than in the in-car display condition (p<.002458).

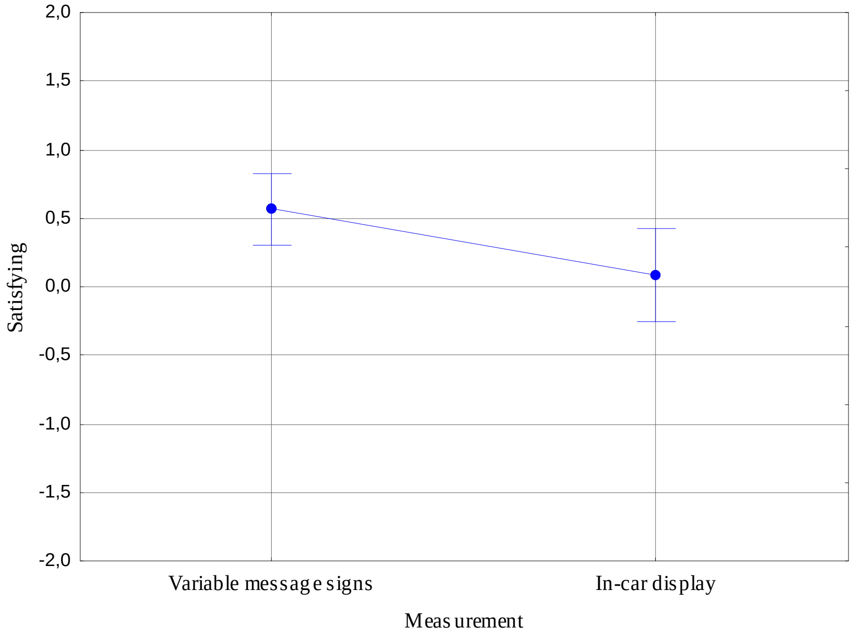


Figure 30 Satisfying as a function of ‘measurement’

Figure 31 shows the results of all the subjects for the three conditions ‘without system’, ‘variable message signs’ and ‘in-car display’. It can be seen that without experiencing a system for the green wave speed advice (without system condition), the system is found ore useful and satisfying than after experiencing such a system.

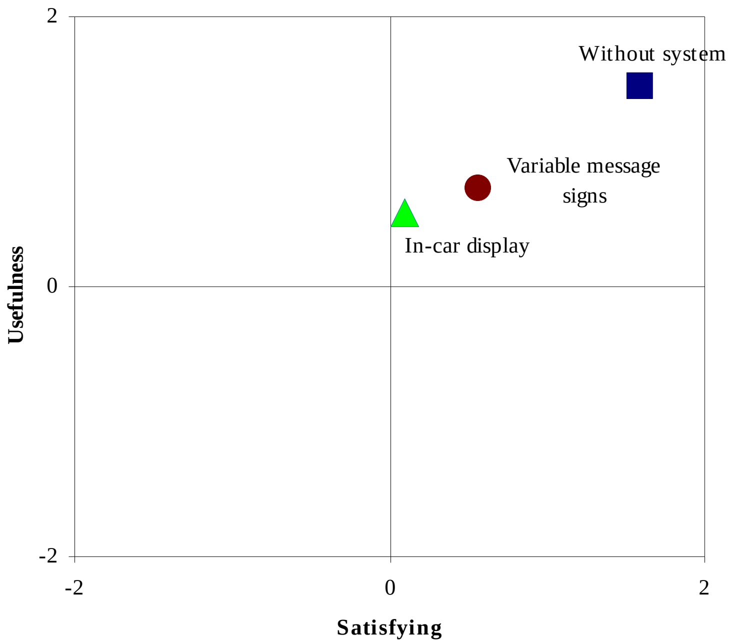


Figure 31 Overview of the scores for the three conditions

Personal messages
After using the variable message signs and the in-car display, the subjects were asked to judge the given advisory speed shown on both systems about being personal (special meant for you) or common (meant for everyone, not specially for you).

The scale for judging was from -2 for not personal to +2 for personal. The variable message signs scored 0 and the in-car display +0.52. The unpaired Student's t-Test was performed in order to examine statistically significant difference between the variable message signs and the in-car display. There was found statistically significant difference between the conditions 'variable message signs' and 'in-car display' ($p<.034728$). The green wave speed showed on the in-car display was experienced as more personal than the green wave speed showed on the variable message signs.

Summary
Before experiencing the variables message signs or the in-car display the subjects scored higher on 'usefulness' and 'satisfying' than when they actually experienced both systems. No statistically significant difference was found between the variable message signs and the in-car display. In case of only an after measurement, 'satisfying' scored higher for variable message signs than for the in-car display. The green wave speed showed on the in-car display was experienced as more personal than the advisory speed showed on the variable message signs.

5.5 Remarks of the subjects

Beside the questionnaires subjects always had the possibility to write down comments or remarks on the questionnaires. In this section the most frequently comments are shown.

General
Most subjects said they liked driving at the Kruithuisweg and experiencing the variable message signs and the in-car display for a green wave. Some subjects found it really nice driving the simulator. Most subjects wrote down they drove like they normally did.

Variable message signs or in-car display
In the before measurement of ‘baseline first’ most of the subjects (12 out of 17 subjects) preferred the variable message signs. Five out of 17 subjects preferred the in-car display. After completing the experiment, the preference shifted to fifty-fifty. Nine subjects chose the variable message signs and eight the in-car display.

For ‘system first’, 15 out of 33 subjects chose after completing the experiment for the variable message signs. Eight subject chose the in-car display and nine preferred the driving without a system for a green wave. One subject did not answer.

Several reasons were given by multiple subjects when choosing for variable message signs:

- Variable message signs are easier to realise at the roadside, because there is no need to make adjustments to cars;
- Variable message signs are like normal traffic signs, so drivers know what to do;
- Variable message signs are less distractive than the in-car display;
- It is a common way of giving information;
- Variable message signs are accessible for everyone, even for foreign drivers;
- Not everyone has an in-car display;
- There are already too many things on the control panel.

Subjects chose for the in-car display because of the following reasons. Multiple subjects gave these reasons:

- There are already too many traffic signs at the side of the road;
- It is a personal way of giving information;
- The in-car display is easier to monitor because it is always present.

When subjects did not prefer a system for a green wave the following reasons were given. They rather drive without a system, because they are more capable themselves to adjust their speed to the situation or they never act on advisory speeds.

Adhere to the green wave speed
One of the reasons for choosing to adhere to the green wave speed was that they could continue driving at the intersections, which was pleasant and saved fuel. Sometimes the other traffic made it impossible to adhere to a green wave by causing a traffic jam. One subject rather preferred a fixed green wave speed and another one preferred variable message signs above the road. Two subjects would rather get speech message next to the visual messages. Traffic lights changed to green a little too late following a few subjects.

Driving simulator
About the simulator, a frequently given comment was that it was difficult to keep the right speed because of the missing feedback forces on the acceleration pedal and sound of the engine. Due to the missing feedback on motion of the mock-up, a few subjects found it difficult to brake. Several subjects missed a cruise control and radio in the

driving simulator. Some subjects found it difficult to see the status of the traffic lights and the variable message signs from a distance. Only close to the traffic lights and signs it was possible to see which light or signal was shown. This can be explained because of the low resolution of the projectors.

Peripheral Detection Task (PDT)
A few subjects found it more difficult to use the micro switch of the PDT when driving faster, passing or in driving a curve. Because of some happenings, a subject pushed the micro switch as a reflex. For example, when the traffic light changed the light or when the subject passed other cars.

Scenarios
Driving the baseline condition, two subjects missed the variable message signs or the in-car display. Apparently they expected the systems to be there. One subject drove through another car because that car suddenly braked which he/she apparently did not notice in time. Another subject mentioned a car drove through him after passing an intersection. This can be explained because at that moment the software was not able to detect the position of the other car and the subject. Another subject liked the virtual environment of the Kruithuisweg because of the nice cars. Finishing the second run, one subject was surprised he/she had to drive the same route for a second time.

Remarkable
One subject did not drive faster than the speed limit because he did not know if there was any camera enforcement. Also he/she noticed the traffic signs ‘speed limit 120 km/h’ which in fact does not exist in the Netherlands. And the subject thought there was a conspiracy of the experimenter because in a driving simulator you will never know what to expect. Another subject mentioned there was a lot of wind on the highway so he/she had troubles with keeping the car in the right position on the road. In fact, it is impossible to simulate a storm in the driving simulator. Stepping out of the car, one subject took the key of the simulator with him. When the experimenter noticed this, he apologised for doing so by saying it felt like driving his own car. This subject also took his bag with him in the simulator. Afterwards, the subject told that he was fully prepared by bringing food and water with him in case the run would take a long time just like the previous experiment he participated in. One subject sang softly in the simulator and another one whistled during driving.

5.6 Summary of the results

Systems for the green wave speed
The following statistically significant differences between the variable message signs and the in-car display were found for driving behaviour:

- The standard deviation of average speed was smaller when using the in-car display compared to the variable message signs;
- The number of stops was smaller using the in-car display than for the variable message signs.

For user acceptance the following statistically difference between both system was found:

- The green wave advice was judged more personal with the in-car display than with the variable message signs.

Several statistically significant differences were found between the baseline condition and the conditions with a system for the green wave speed. For driving behaviour the following results were found:

- Driving with the in-car display resulted in a lower average speed compared to the baseline condition;
- The standard deviation of average speed was higher without a system than when using the in-car display;
- The RMS of the driven speed in the baseline condition was higher than in the variable message signs condition and the in-car display condition. When driving with a system for a green wave, subjects acted more on the advice compared to the baseline condition.

The following statistically significant differences were found for workload:

- The average PDT reaction time in the variable message signs condition was higher compared to the baseline condition. Using variable message signs resulted in a higher workload for the subjects;
- The percentage missed PDT signals in the variable message signs condition was higher compared to the baseline condition. Using variable message signs resulted in a higher workload for the subjects.

For user acceptance, the following statistically significant differences were found:

- Usefulness in the before measurement (baseline condition) was higher than in the after measurement of both systems. After experiencing both systems, subjects found the systems less useful as they expected the systems to be;
- Satisfying in the before measurement (baseline condition) was higher than in the after measurement of both systems. After experiencing both systems, subjects found the systems less satisfying as they expected the systems to be.

Most subjects preferred the variable message signs for several reasons. Mentioned was for example, the easy realisation, the likeness to normal traffic signs and the easy accessibility for every driver.

Green wave advice

Several statistically significant differences were found between the low and high reference speed condition. For driving behaviour, the following statistically significant differences were found:

- In the low reference speed condition the travel time was higher than in the high reference speed condition. It took more time for subjects to drive the Kruithuisweg when a low reference speed was given;
- In the low reference speed condition the average speed was lower than in the high reference speed condition. Subjects drove more slowly when the low reference speed for a green wave was given;
- The standard deviation of average speed was smaller in the high reference speed condition than in the low reference condition;
- The RMS of the driven speed in the low reference speed condition was higher than in the high reference speed condition. Subjects adhered more to a green wave speed in the high reference speed condition when the reference speed was more close to the speed limit.

For workload, the following statistically significant difference was found between the low reference speed condition and high reference speed condition:

- In the low reference speed condition the percentage of missed PDT signals was higher than in the high reference speed condition.

For user acceptance no comparison between low and high reference speed condition could be made. The subjects were asked to judge both systems which provide an advice for a green wave. No judgements were made for the low and high reference speed.

6 Discussion

6.1 The experiment

For the experiment, the fixed-base driving simulator was used which made it possible to control the traffic situation and road environment. Driving the fixed-base simulator differed in some ways from driving in a real car. One difference is the missing feedback on motion of the mock-up. However, the remarks of the subjects gave an indication that driving the simulator was reliable and did not differ that much from driving a real car.

Subjects were instructed to drive like they normally did and they said they did so. However, several happenings during the experiment or features of the experiment could cause the subjects not behaving like they normally did. A frequently mentioned remark of the subjects was the visibility of road elements on the screens. They discovered having problems with the visibility of the traffic lights and the variable message signs from a distance. Close to them, they were able to see the status of the variable message signs and the traffic lights. This can be explained by the low resolution of the projectors. A few subjects mentioned that the traffic light changed to green a little too late. A possible explanation is that the setup of the traffic light might have been a little too narrow.

The software for the virtual environment was not compatible yet for all needed features in the experiment. Therefore, extra programming had to be done to make the needed features possible. For example, it was not able for the other traffic in the environment to obey the traffic lights. The extra programming made this possible, but it did not go smooth in every situation. Some cars did not stop at the stop line but a couple of metres earlier or later. Not all subjects could respond to this in time, one subject drove through the lead car. In six runs non-programmed traffic jams occurred. Subjects waited vainly for the traffic jam to be over. Here, the experimenter had to instruct the subject to pass the traffic jam via the grass or the exit lane. The consequences of these traffic jams were that these runs had to be excluded from the data set.

The variable message signs did not always work properly. Sometimes the green wave advice shown on the variable message signs was timed a little too late when the subject approached. When computing the new advice, sometimes the projected scene stagnated.

Immediately after an intersection, it sometimes happened that the subject driving in the right lane almost got hit by another car merging from the left lane. Because of two linking paths just beyond an intersection, the software was not able to detect the position of the subject and the other car.

The existence of a lead car may have influence on the driving behaviour of the subject. The subject can drive free or his behaviour in some way depended on the lead car. However, the influence of the lead car on a subject could not be measured. It was not possible to make a distinction between car-following and free driving. The road in the database consisted of several paths. If the subject and the lead car were not at the same path which happened when crossing two path numbers, the software did not recognise the subject having a lead car anymore. Therefore, the code ‘missed signal’ was registered for data like time headway and distance to the lead car (headway). And therefore no distinction could be made between having no lead car at all or a lead car was not registered. This was discovered halfway the experiment, so extra variables were added to compute data about the lead car. Despite this additional information, it was still not possible to examine car-following and free driving.

Data sampling rate was set up to be 10 Hz, but somehow this setup resulted in a rate of around 100 Hz. However, this gave no problems for performing the data analysis and therefore, it had no influence on the results.

6.2 Driving behaviour

Each subject drove the Kruithuisweg three times. However, the runs in the experiment lasted for around 7 to 10 minutes. This maybe too short for subjects to get used to the system. However, no remarks of the subjects indicated this.

Speed support for a green wave using the in-car display resulted in a smaller amount of stops and a smaller spread in variance of speed compared to variable message signs. For driving behaviour no other significant differences between both systems were found. Compared to the baseline condition, speed support using the in-car display resulted in a lower average speed and a smaller spread in speed variance.

Hogema & Göbel (2000) performed a driving simulator study and discovered that driving behaviour was improved by dynamic queue warning information. However, they found that information displayed on variable message signs was much more effective than information on an in-car display. In the present study, the in-car display resulted in a smaller amount of stops and a smaller spread in variance of speed than with variable message signs and seemed more effective.

The ODYSA project (DTV Consultants, 2004) on a provincial road near Rijen examined the effects of a green wave. The green wave advice displayed on variable message signs resulted in a decreased travel time of 53-109 seconds and a decreased amount of stops (around 25%) during rush hour for through-traffic. During other periods, travel time increased a little bit. Due to a green wave, drivers drove more slowly compared to when the green wave system was not active. The average speed decreased per hour with a maximum of 4.7 km/h. In the current experiment, the use of the in-car display resulted in a lower average speed compared to when no system was used. However, speed support via the in-car display resulted in a smaller amount of stops compared to the variable message signs.

6.3 Workload

Workload was measured by means of the Peripheral Detection Task (PDT). It was expected that using the in-car display for speed support for a green wave would result in a higher workload than the variable message signs. However, using the variable message signs resulted in a higher workload compared to the baseline condition. No statistical significant results were found between the in-car display and the variable message signs. It was expected that using the in-car display resulted in a higher workload because of the continuously shown green wave speed and that therefore subjects had to take their attention from the road. A possible explanation can be the bad visibility of the variable message signs from a distance due to the low resolution of the projectors. The overall results for this study were an average PDT reaction time of 690 ms and 20.8 % missed PDT signals.

In a driving simulator study of Hogema (2006), subjects drove on a highway and received car-following instructions on a visual in-car display. The overall average PDT reaction time was 471 ms and the overall percentage missed PDT signals was 5.1%. Speed support for a green wave at the Kruithuisweg scored higher on workload than car-following instructions on a highway. Van Winsum & Hoedemaeker (2000) conducted a road test on a provincial road. While driving, subjects had to perform a menu control task like turning on the radio. This resulted in a average PDT reaction time of 400-500 ms for the control condition and of 900-1000 ms for the task condition. For the percentage missed PDT signals, the results were 10-20% for the control condition and 50-60% for the task condition. Performing the menu control task in a road test has a higher workload than speed support using the driving simulator in the present study. In another driving simulator study Hoedemaeker et al. (2006) examined performing two secondary tasks, the PDT and a numerical task. The average reaction time for the PDT was 450-550 ms compared to 950-1050 ms for the numerical task. Results of the percentage missed signals were for the PDT 6-8% and for the numerical task 16-18%. Comparing this to the present study, driving with speed support resulted in a lower average reaction time than performing an numerical task.

6.4 User acceptance

The variable message signs and the in-car display were judged less useful and satisfying as they were expected to be. The green wave advice on the in-car display was found more personal than the advcie on the variable message signs.

In a field experiment of Luoma & Rämä (2002) an in-vehicle terminal was used to give subjects traffic sign information. The preferred message was the visual sign. However, subjects using the in-vehicle terminal reported having driving problems. Mentioned was unintentional speed decreases and late detection of other vehicles. In the present study, the subjects found the in-car display easier to monitor and a more personal way of giving information. However, most subjects preferred the variable message signs.

7 Conclusions and recommendations

7.1 Conclusions

In this experiment, speed support for a green wave via variable message signs and an in-car display was examined. Drivers received a green wave speed advice and when following this advice, one was able to benefit from a green wave at signalised intersections. In a fixed-base driving simulator, fifty subjects completed three runs each. One run without a system (the baseline condition), one with variable message signs at the roadside and one with an in-car display. During the experiment, effects on driving behaviour, workload and user acceptance were measured.

Driving behaviour
For driving behaviour, speed support for a green wave resulted in a change in driving behaviour compared to the baseline condition. The subjects responded to the green wave advice by driving a speed more close to the advice. Driving with the in-car display resulted in a lower average speed, however the variance in speed is smaller. So subjects drove slower but more the same speed. Subjects were also more able to continue driving with the in-car display than with the variable message signs because of the smaller amount of stops.

Workload
For workload, speed support using the variable message signs resulted in a higher workload for the drivers compared to when no system was used. Following the advice on the variable message signs can be defined as a small secondary visual task. Compared to the baseline condition, using the in-car display did not result in a higher workload.

User acceptance
After experiencing both systems for the green wave speed support, both systems were found less useful and satisfying as the systems were expected to be. However, both systems were still scored positive. The variable message signs were found more satisfying than the in-car display. The green wave speed advice on in-car display was experienced as more personal than the ones shown on the variable message signs. However, most of subjects preferred the variable message signs. Reasons for this were the easy realisation and the accessibility for all drivers. Subjects said to follow the green wave advice because fuel could be saved and it was pleasant to be benefit from the green wave.

The green wave advice
A green wave was guaranteed when following the green wave advice. Driving with an average speed of 65 km/h in the low reference speed condition and 75 km/h in the high reference speed condition, resulted in a green wave. Subjects responded more on the high reference speed (which was closer to the speed limit) compared to the low reference speed. This resulted in a smaller travel time, a higher speed and a smaller spread in speed. Therefore, driving in the high reference speed condition was more comfortable. This can be an explanation for the fact that subjects missed less PDT signals in the high reference speed condition.

The best system
In conclusion, drivers responded to speed support for a green wave. Using an in-car display and variable message signs, the subjects adhered to the advisory speed. Comparing the variable message signs and the in-car display as used in this experiment, a few statistical significant differences were found between both systems. The results of this study showed that subjects drove more comfortably with the in-car display because they drove more the same speed and they made less stops during the trip. The in-car display caused less distraction to the subjects. But the subjects accepted the variable message signs more. In this study, it was possible to influence driving behaviour by using speed support for a green wave. It can be seen that the objective measurements of driving behaviour and workload differ from the subjective measurement of user acceptance.

Based on the findings of this driving simulator experiment, the best system for green wave support in terms of *comfort*, *distraction* and *acceptance* was the in-car display. An in-car display is a promising system for green wave speed support because it has advantages for the through-put and safety on the road network. However, determining the best system should be done with care because the in-car display and the variable message signs do not differ very much from each other.

7.2 Recommendations

In this research, the potential influence of lead cars on the driving behaviour of the subject could not be measured. However, this is an important aspect of driving behaviour: is a driver able to drive free or does his behaviour in some way depend on that of the lead car? In future studies, this part of driving behaviour should be studied.

Speed support for a green wave using an in-car display is relatively new. This driving simulator experiment examined the first results on driving behaviour, workload and user acceptance. The in-car display was judged by subjects less satisfying than the variable message signs. In the case of driving behaviour and workload, the in-car display had some advantages above the variable message signs. Therefore, further investigation should be performed on the aspect user acceptance. Overall, in further research the potential impact of using the in-car display for green wave speed support on driving behaviour, workload and user acceptance should be investigated. This with respect to a possible integration with navigation systems which more and more people are using.

8 References

Akamatsu, M., Okuwa, M., Funakawa, M., Kitajima, M. & Onuki, M. (2001). *Whole-view driving simulator for measuring driving behaviour in town environment*, Driving Simulation Conference (DSC), September 2001, Sophia Antipolis, France.

Akamatsu, M. (2002). *Measuring driving behaviour*, The Society of Instrument and Control Engineers (SICE), August 5-7, 2002, Osaka, Japan.

Algemeen Dagblad (a newspaper) [in Dutch]
http://www.ad.nl/denhaag/delft/article1037599.ece, consulted May 2007.

Andrade, M., Zoutendijk, A., Van Koningsbruggen, P., Hoedemaeker, M., & Frost, F. (2007). *DEPN White Paper for CVIS Workpackage 2*, 19-21.

Baart, M., Vink, W., Van der Horst, R., Van Arem, B. & Wilmink, I. (2004). *ITS for sustainable mobility: tools for designing and evaluating co-operative road-vehicle systems*, 11th World congress on Intelligent Transport Systems, 18-22 October 2004, Nagoya, Japan.

Boyle, L. Ng. & Mannering, F. (2004). *Impact of traveller advisory systems on driving speed: some new evidence*, Transportation Research Part C, 12, 57-72.

Carsten, O. & Brookhuis, K (2005a). *The relationship between distraction and driving performance: towards a test regime for in-vehicle information systems*, Editorial in Transportation Research Part F, 8, 75-77.

Carsten, O. & Brookhuis, K (2005b). *Issues arising from the HASTE experiments*. Discussion in Transportation Research Part F, 8, 191-196.

DTV Consultants B.V. (2004). *Doorrijden door Rijen, Evaluatie van het pilot project met ODYSA*. [in Dutch] Downloaded in July 2006 from:
http://www.brabant.nl/upload/documentatie/d/doorrijden%20door%20rijen.pdf.

Hoedemaeker, M., Hogema, J.H. & Pauwelussen, J. (2006). *Rijsimulatorstudie naar het effect van omgevingscomplexiteit op de werkbelasting* (Report TNO-DV 2006 C244). TNO Defence, Security and Safety, Business Unit Human Factors, Soesterberg, The Netherlands. [in Dutch]

Hogema, J.H. (2006). *Influencing driving behaviour with in-car instructions: a driving simulator experiment* (Report TNO-DV 2006 D392). TNO Defence, Security and Safety, Business Unit Human Factors, Soesterberg, The Netherlands.

Hogema, J.H. & Göbel, M.P. (2000). *In-car versus roadside queue warning information: a driving simulator experiment* (Report TM-00-D004). Soesterberg, The Netherlands: TNO Human Factors Research Institute.

Hogema, J.H. & Verschuren, R.M.A.F. (2001). *On-centre handling: a driving simulator experiment* (Report TM-01-D009). Soesterberg, The Netherlands: TNO Human Factors Research Institute.

Kemeny, A. & Panerai, F. (2002). *Evaluating perception in driving simulation experiments*, TRENDS in Cognitive Sciences, Vol.7 No.1, January 2003.

Luoma, J. & Rämä, P. (2002). *Acceptance of traffic sign information provided by an in-vehicle terminal*. 9th World congress on Intelligent Transport Systems, October 14-17 2002, Chicago, Illinois.

Ministry of Transport, Public Works and Water Management (2006). *Verkeersborden en Verkeersregels in Nederland*, The Hague, The Netherlands. [in Dutch]

Petrella, M., Bricka, S., Hunter, M. & Lappin, J. (2005). *Driver satisfaction with an urban arterial after installation of an adaptive signal system*. 12th World congress on Intelligent Transport Systems, November 6-10 2005, San Fransisco, USA.

Schaap, T.W. (2006). *Modelling of driving behaviour and behavioral adaptation to advanced driver assistance systems when driving on urban intersections*, Research project description. Enschede, The Netherlands: University of Twente, Centre for Transport Studies.

Schaap, T.W., Van der Horst, A.R.A. & Van Arem, B. (2007). *Studying behavioral adaptation in urban traffic*, Report University of Twente. Enschede, The Netherlands. [to appear]

TNO (2007). Fact sheet Network Manager, new concepts for sustainable traffic management. TNO Traffic and Transport, Delft, The Netherlands.

Van Arem, B. (2007). *Cooperative vehicle-infrastructure systems: an intelligent way forward?* (Report 2007-D-R0158/B). Delft, The Netherlands: TNO Traffic and Transport.

Van der Horst, A.R.A. & Godthelp, J. (1982). *De roodlichtdiscipline van bestuurders van motorvoertuigen in relatie tot het beëindigen van de groenfase: een literatuurstudie* (Report IZF 1982 C-11). Soesterberg, The Netherlands: Instituut voor Zintuigfysiologie TNO. [in Dutch]

Van der Horst, A.R.A, Ten Broeke, W. & Bakker, P.J. (1985). *De roodlichtdiscipline van bestuurders van motorvoertuigen onder invloed van een aanpassing van de geeltijd* (Report IZF 1985 C-11). Soesterberg, The Netherlands: Instituut voor Zintuigfysiologie TNO. [in Dutch]

Van der Laan, J.D, Heino, A. & De Waard, D. (1997). *A simple procedure for the assessment of acceptance of advanced transport telematics*, Transportation Research Part C, Vol. 5, no. 1, 1-10.

Van Winsum, W. & Hoedemaeker, M. (2000). *A road test of a prototype satellite system for in-vehicle menu control* (Report TM-00-C003). Soesterberg, The Netherlands: TNO Human Factors Research Institute.

Van Winsum, W., Martens, M. & Herland, L. (1999). *The effects of speech versus tactile driver support messages on workload, driver behaviour and user acceptance* (Report TM-01-D009). Soesterberg, The Netherlands: TNO Human Factors Research Institute.

Vialis Verkeer en Mobiliteit (2003). *ODYSA beloont weggebruikers met een dynamische groene golf*. Speurwerk, Matrix 14, 2003, 15-16. [in Dutch]

Vrancken, J.L.M, Hage, F.J. & Nifterick, W. van (2003). *Road traffic management using in-vehicle signaling*. 10th World congress and exhibition on intelligent transport systems and services, November 16-20 2003, Madrid, Spain.

Appendices

Appendix A Experiment runs

This appendix shows the design of the experiment runs.

Subject	Experiment runs		Subject	Experiment runs
1	2a 4b 6a		26	2a 4b 6a
2	2a 4b 6a		27	4b 2a 6b
3	4b 2a 6b		28	4b 2a 6b
4	4b 2a 6b		29	6a 4b 2a
5	6a 4b 2a		30	6a 4b 2a
6	6a 4b 2a		31	2b 6a 4b
7	2b 6a 4b		32	2b 6a 4b
8	2b 6a 4b		33	4a 6b 2a
9	4a 6b 2a		34	4a 6b 2a
10	4a 6b 2a		35	6b 2a 4b
11	6b 2a 4b		36	6b 2a 4b
12	6b 2a 4b		37	2b 4a 6b
13	2b 4a 6b		38	2b 4a 6b
14	2b 4a 6b		39	4a 2b 6a
15	4a 2b 6a		40	4a 2b 6a
16	4a 2b 6a		41	6b 4a 2b
17	6b 4a 2b		42	6b 4a 2b
18	6b 4a 2b		43	2a 6b 4a
19	2a 6b 4a		44	2a 6b 4a
20	2a 6b 4a		45	4b 6a 2b
21	4b 6a 2b		46	4b 6a 2b
22	4b 6a 2b		47	6a 2b 4a
23	6a 2b 4a		48	6a 2b 4a
24	6a 2b 4a		49	2a 6b 4a
25	2a 4b 6a		50	4a 6b 2a

Explanation of the runs.

Run	System	Advice
2a	Without system	Low advice 65 km/h
2b	Without system	High advice 75 km/h
4a	Variable message signs	Low advice 65 km/h
4b	Variable message signs	High advice 75 km/h
6a	In-car display	Low advice 65 km/h
6b	In-car display	High advice 75 km/h

Appendix B User acceptance questionnaire

After each run, the subjects had to fill out questionnaires (in Dutch). This appendix shows two questions from these questionnaires. The first question, subjects had to judge the speed advice as being personal or common. The second question is about the acceptance.

U heeft zojuist gereden op de Kruithuisweg buiten de bebouwde kom. Hierbij stonden langs de kant van de weg dynamische borden waarop een adviessnelheid werd getoond. Hieronder staat een aantal vragen.

Hoe persoonlijk vindt u de adviessnelheid die getoond werd?

Persoonlijk						Onpersoonlijk

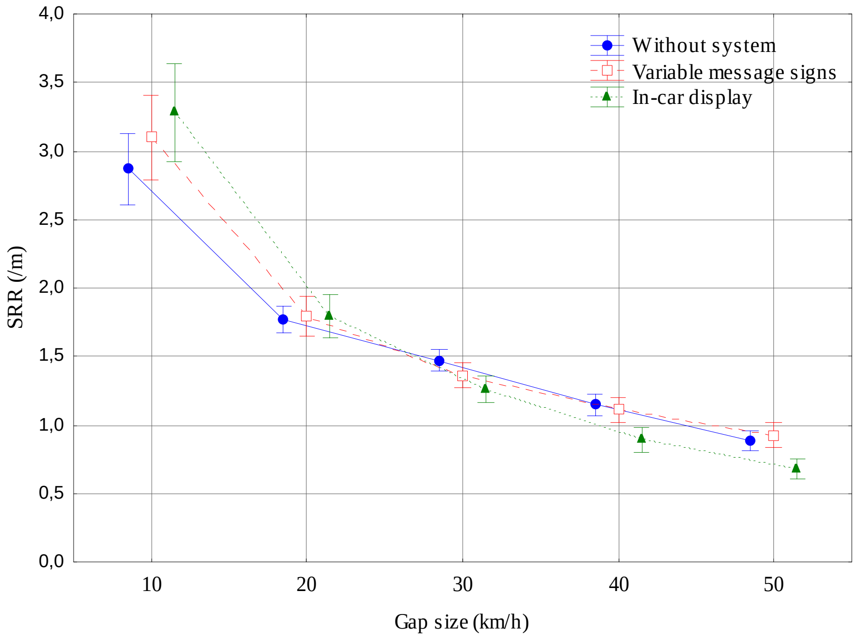
Wat is uw mening over het systeem waarmee u zojuist gereden heeft?

1	Nuttig						Zinloos
2	Plezierig						Onplezierig
3	Slecht						Goed
4	Leuk						Vervelend
5	Effectief						Onnodig
6	Irritant						Aangenaam
7	Behulpzaam						Waardeloos
8	Ongewenst						Gewenst
9	Waakzaamheidverhogend						Slaapverwekkend

Appendix C Speed Reversal Rate (SRR)

In the frequency table ‘number of stops’ in section 5.2 for each intersection is determined if the subjects could continue driving or if they had to stop. Stopping was defined as a certain decrease in speed so subjects could not continue driving in a flowing move. Therefore, the Speed Reversal Rate (SRR) was used. The SRR is a variant of the Steering Reversal Rate. Instead of counting the number of steering reversals (Hogema & Verschuren, 2001), the number of speed reversals was counted in an interval of 100 metres in front of the traffic lights. The gap size of the SRR is the magnitude of the decrease in speed which had to be determined.

No references were available about which gap size should be chosen, therefore five values of the gap were compared. The figure shows the SRR as a function of the gap size for each system condition.



From the figure it can be seen that in each system condition a gap size of 10 km/h resulted in more speed reversals per minute than with a gap size of 50 km/h. This means that there were more small speed decreases than bigger ones. With a gap size of 30 km/h, there was a turn of the different systems between 10-20 km/h and 40-50 km/h. Therefore, the gap size was set at 30 km/h (8,3 m/s) which meant that a decrease in speed of 8,3 m/s was defined as a stop.

The data sampling rate was set up to be 10 Hz, but somehow this setup resulted in a rate of around 100 Hz. This gave problems for determining the number of speed reversals because the time steps have to be similar. Therefore, the frequency was revalued to 10 Hz.

Appendix D Values of the variables

This appendix gives an summary of the results.

Baseline: baseline condition
VMS: variable message signs condition
Display: in-car display condition
Low (65): low reference speed condition 65 km/h
High (75): high reference speed condition 75 km/h

For driving behaviour

	Travel time (s)	Average speed (m/s)	SD average speed (m/s)	RMS of the driven speed (m/s)
Baseline	91.06	18.84	5.40	21.90
VMS	91.70	18.60	4.95	17.68
Display	93.88	18.05	3.81	18.64
Low (65)	95.28	17.93	5.32	21.57
High (75)	89.18	19.06	4.11	17.25
Overall	92.22	18.50	4.71	19.40

For workload

	Average PDT reaction time (ms)	Missed PDT signals (%)
Baseline	656	16.8
VMS	713	23.1
Display	701	22.3
Low (65)	686	21.7
High (75)	694	19.9
Overall	690	20.8

For user acceptance

	Usefulness	Satisfying
Baseline	1.48	1.59
VMS	0.73	0.57
Display	0.55	0.09