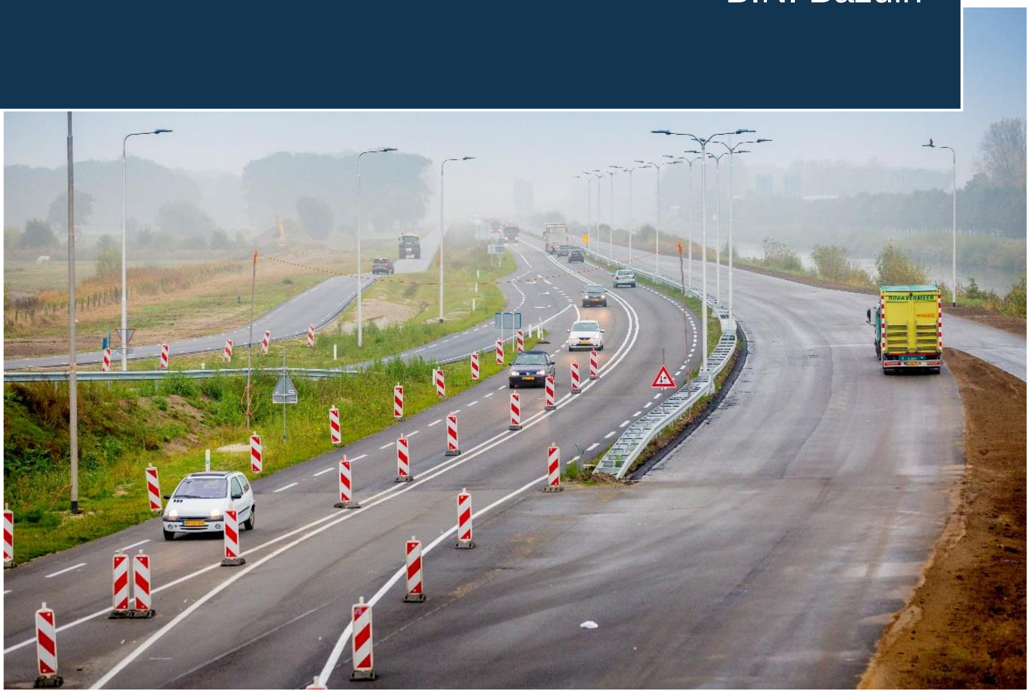
Master Thesis

Influencing Speed Behaviour at Highway Work Zones Using In-car Speed Limits and Warnings

08/05/2017

B.N. Bazuin



Colophon

MASTER THESIS

Influencing Speed Behaviour at Highway Work Zones Using In-car Speed Limits and Warnings

COMMITTEE

prof.dr. Bart van Arem (chair)	b.vanarem@tudelft.nl
dr.ir. Haneen Farah	h.farah@tudelft.nl
dr. Eric Molin	e.j.e.molin@tudelft.nl
ing. Bertjan de Boer	bertjan.deboer@advin.nl

EDITION

Date
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Author
B.N. Bazuin bram.bazuin@gmail.com

ADVIN

Advin
Postbus 437
2130 AK Hoofddorp
T (088) 023 84 60

"Speed, it seems to me, provides the one genuinely modern pleasure. But of course, speed is like all other pleasures; indulged in to excess, they become their opposites."

- Aldous Huxley (1931, p. 227)

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Preface

Dear reader,

Before you lies the final product of my student career. With this master thesis, I hope to provide insights into influencing driver speed behaviour at work zones and human response to early forms of intelligent transport systems. Ultimately, this contributes to making highways a safer place for travellers and those who work on maintaining and improving these roads. I know there is a considerable probability you are now thinking: "But Bram, didn't Elon say all cars will drive themselves next year?" While indeed these technologies are developing rapidly and early versions can be found on the road today, it is unknown whether or when the last vehicle operated by a human driver will be removed from the roads.

There are several people who I would like to thank for their contributions to this project. Haneen, Bart, and Bertjan, thank you for sharing your expertise and insights at critical moments. Eric, thank you for this new collaboration. Paul, thank you for all your help with the simulator. To Herbert, Mattieu and all other Advin colleagues: Thank you for the good time, your experience and contacts in the field. Of course, interviewees and those who participated in the experiment: Thank you very much.

On a more personal note, I am proud of this final piece. Around one year ago, I was anxious about working alone on this big career milestone. Hopefully, along with finishing this thesis, my ongoing health issues too are gone for good.

All the best,

Bram

Summary

Highway work zones in the Netherlands have a relatively high crash rate compared to regular conditions and compared to work zones on other types of roads. Even though work zones only cover a very small part of the Dutch highways, and the well-defined safety regulations available, a significant number of accidents happen at these zones: Around 4% of all serious accidents on Dutch highways.

Also, young male drivers (age 18 to 24) are relatively unsafe: This group has a ten times higher fatality rate per distance driven compared to 30 to 59-year-old drivers, this is often due to unsafe driving behaviour. Unsafe behaviour is the result of deliberate actions (e.g. speeding) or a lack of skills required by a road situation (e.g. obstacle avoidance or braking quickly). For these young drivers, important additional causes for high crash involvement are distraction by media devices and the relatively old vehicles (with fewer safety measures) operated by these drivers. The results of deliberate unsafe behaviour cannot be fixed by adding visible safety improvements to the physical work zone design as drivers may compensate for this increased safety by driving faster, however exact figures on this compensation behaviour are not known.

Given the current physical safety precautions at work zones and the perverse effects additional measures may have on driving behaviour, road operators and road construction companies are considering technological solutions to resolve work zone unsafety. Automated vehicles may contribute to these developments, but it may take a long time until this technology has a significant market penetration rate and can deal with special road situations such as work zones. Furthermore, in the next five years a 15% increase in road traffic is expected in The Netherlands. This, combined with government ambitions to halve the number of seriously injured in Dutch traffic by 2020 stresses the importance of improving safety at highway work zones in the short term. Thus, it is proposed to apply early forms of intelligent transport systems (ITS) to improve driving behaviour at highway work zones.

Success of technological systems is however limited by acceptance rates; it is desired that systems which reduce unsafe driving behaviour are accepted and used by road users, but drivers generally do not make efforts to use safety improving assistance systems.

Objectives

The practical aim of this study is to increase speed compliance at Dutch highway work zones by displaying speed limits and road work warnings inside cars. The main scientific objective is to advise on the extent to which speed and road work information displayed on a head-up display (HUD) can change speed behaviour at Dutch highway work zones. The main research question is defined as follows:

To what extent can head-up display (HUD) speed limits and warnings change speed behaviour?

In order to answer this question, several aspects are considered: speed compliance, indicators for vehicle control, stress and workload, and attitude towards the system.

Experiment

A driving simulator experiment was conducted to gather data on driver behaviour at work zones. Driving simulator experiments allow safe testing in a controlled environment. Each participant drove two sections of roughly 10 minutes each on the A67 between Eindhoven and Someren in a fixed-base driving simulator. In this experiment, questions about stress, mental effort and attitude regarding the system were asked prior, during and after the two driving sessions. The A67 has two lanes per direction and was adjusted to fit eight short work zones designed in line with Dutch guidelines for short duration road shoulder works (Figure 1). Each participant

encountered all eight zones in the repeated-measures experiment. Three conditions of two levels each were used in the scenarios (Table 1), in a counterbalanced design to avoid bias by the order at which the work zones were passed. Traffic intensity at all work zones was moderate so speeding was possible in case participants wanted to do so.

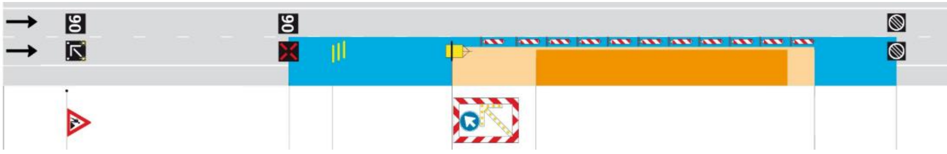


Figure 1. Work zone design (CROW, 2013)

Table 1. Experiment conditions

Condition	Level 1	Level 2
HUD ITS support	On	Off
Worker presence	On	Off
Traffic speed (km/h)	90	110

In scenarios with ITS assistance enabled, warning icons were displayed on a HUD starting at the point where regular road-side pre-announcement warnings were visible. The warnings were accompanied by a gentle warning sound. At the work zone, participants who drove 95 km/h or faster were presented a brighter speed limit icon and heard the gentle warning sound every 5 seconds. Participants who did not speed saw the original warning until the end of the work zone. Figure 2 shows the warning system in the slow-down area (top) and when speeding at the work zone (bottom).

Figure 2. HUD warnings at work zone. Top: regular. Bottom: speeding.

During the experiment, heart rate measurements were made using an optical fingertip monitoring device. Simulator software took care of logging user input and simulated vehicle information. In total, 34 drivers participated in the experiment. All participants were Dutch speaking males of age 18 to 24 who are in possession of a valid driver's license. Only three participants had driven more than 10,000 km in the year before the experiment.

Results

Simulator data was analysed using plots and linear mixed model (LMM) analysis. LMM provides a way of estimating effects of multiple conditions on a dependent variable, while compensating for effects associated with specific participants and the order of work zones in the experiment. The first zone with ITS and the first zone without ITS support for each participant were excluded as participants had to get used to driving the simulator or using the warning system. This resulted in different speed behaviour compared to other scenarios. Stated data was analysed using Wilcoxon’s signed-rank test.

Speed Compliance

The median speed of participants in the slow-down area (after the initial work zone announcement, but before the work zone) decreased by 4.5 km/h on average when speed and merge warnings were displayed inside the vehicle, the peak speed in this area decreased by 3.6 km/h on average. Deceleration started sooner and continued longer when ITS was active. There was no significant effect inside work zones and displaying an additional work activity warning did not have an effect on speed compliance. Figure 3 shows average speed of those who drove above the speed limit in the last 100 m before the HUD work zone pre-announcement. In this figure, v_t distinguishes between scenarios with high and low speed traffic.

Figure 3. Speed vs distance by ITS support and traffic speed, 30% fastest drivers

The speed reduction initiated by ITS is in line with results of previous simulator and field studies focusing on warnings presented to drivers in advance of dangerous situations. In this study, in-vehicle warnings were presented at the same point where participants could first see the VMS warnings, while in other studies in-car warnings were displayed in advance of road-side warnings.

Control Level Indicators

The warning system did not significantly change throttle variability or braking behaviour. Throttle pedal pressure was significantly lower directly after presenting the first HUD warning compared to scenarios with no warnings. Half way in the slow-down area, average throttle pressure was similar for zones with and zones without ITS support.

This is likely due to the differences in headway distance to other vehicles at this point. However, this difference could not be verified due to technical limitations. Lane changing behaviour was neither statistically confirmed, however plots suggest participants changed lanes 50 m earlier on average when ITS was enabled.

Stress and Workload

The system had no significant effect on heart rate, heart rate variability and stated stress. Though, with ITS enabled drivers stated the required mental effort was lower compared to driving past work zones without the HUD ITS warning system. The difference between these scores was 5.6% of the range of scores observed in the experiment, lowering stated mental effort from slightly above 'some effort' to ‘some effort’.

Attitude

Satisfaction of the system was ranked 62% of the maximum score before the experiment and 65% after the experiment. Those who were speeding in a measurement zone at the start of the second experiment had an satisfaction attitude of 57% of the maximum score. Satisfaction of this group increased significantly to 65% of the maximum score after using the system. Driving speed in this measurement zone and pre-experimental satisfaction are negatively correlated. Usefulness of the system was found to be an unreliable score, analysis of its components did not reveal a significant change over the course of the experiment. These results are in line with literature on acceptance of voluntary ITS systems and speed warning systems.

Conclusion

Based on experimental results, it is concluded that HUD warnings improve speed behaviour in the slow-down area of work zones by improving speed compliance, smoothness of deceleration and the point of deceleration. Young male drivers show good acceptance of this system and stated the effort required to drive past work zones was lower when using the system compared to driving past work zones with the system disabled, however those who drove faster were less satisfied with the system before using it. After using the system, satisfaction ratings were similar for both groups.

Recommendations

Speed behaviour of young male passenger car drivers at work zones can be improved with accurate in-vehicle warnings. Details of information presentation, effects at different work zone designs and effects for other groups of road users were not tested and require further investigation. For high acceptance of these systems, it is advised to cooperate with parties that currently provide location-based route, traffic or speed camera information to drivers. The directly noticeable benefits of these systems can trigger even those who drive fast and have low attitude of satisfaction of the system, and it was shown that acceptance of the system in this group of drivers increases after using the system. Simple mobile phone holders with a mirror can be used to create a HUD using a mobile phone in any car, and is furthermore expected to reduce distraction of young drivers by their mobile phone (Figure 4). Furthermore, HUD warning systems are considered safer compared to regular warning systems as drivers do not have to look away from the road. Reducing driver distraction is, like reducing vehicle speed, associated with increased traffic safety. Therefore, it is recommended to investigate the possibilities of promoting the use of mobile phones for driver assistance, preferably through a HUD system.

Figure 4. HUD mobile phone holder (HUDWAY, 2016)

The in-car warning system was not successful at increasing speed compliance at the work zone, though it is expected that the number of accidents at the work zone decreases as the result of a smoother and sooner slow-down and better driver awareness of the work zone.

Furthermore, the results of this study show that drivers in scenarios without ITS support decreased speed mostly around the road-side VMS warnings. An initial step road construction companies can take to improve safety at work zones is to place multiple signs in the sow-down area of a work zone so that drivers are presented with these warnings throughout the entire slow-down area. A literature review furthermore revealed that perceived safety improvements at work zones may lead to decreased speed compliance; Drivers value short traveling times higher than safe driving, and therefore compensate for improved safety by driving faster. Thus it is recommended to design work zones in such a way that drivers perceive the risks associated with driving past these zones.

Additional to these recommendations, it is advised that current CROW road work safety measures are experimentally tested in contrast to how this is currently done. Driving simulator experiments have shown potential for relative validity tests of driver behaviour in a cheap, flexible and safe way.

Samenvatting

Bij werkzaamheden op Nederlandse snelwegen gebeuren relatief veel verkeersongevallen in vergelijking met werkzaamheden op andere wegtypen. Werkzaamheden beslaan een zeer klein deel van de het Nederlands snelwegennet en er zijn duidelijke veiligheidsvoorschriften beschikbar. Toch gebeurt een groot deel van de ongevallen op snelwegen: 4% van het totale aantal zware ongevallen op Nederlandse snelwegen.

Jonge mannen (leeftijd 18 t/m 24) zijn bovendien een relatief gevaarlijke bestuurders: Het aantal verkeersoden per gereden kilometer ligt in deze groep tien keer hoger in vergelijking met de groep 30 t/m 50-jarigen, vaak komt dit door onveilig rijgedrag. Onveilig rijgedrag is het resultaat van bewuste acties (zoals te snel rijden) of een gebrek aan behendigheid vereist door een wegsituatie (zoals het vermijden van obstakels, of snel remmen). Overige belangrijke ongevalsoorzaken voor deze groep jonge bestuurders zijn afleiding door (sociale) media en het feit dat deze groep in relatief oude voertuigen rijdt waardoor ook veiligheidsmaatregelen oud zijn. De gevolgen van bewust onveilig rijgedrag kunnen niet worden tegengegaan met zichtbare veiligheidsmaatregelen bij de werkvakken, gezien bestuurders de neiging hebben sneller te rijden als compensatie voor deze verhoogde veiligheid. Precieze getallen zijn niet beschikbaar voor dit compensatiegedrag.

Gezien de huidige fysieke veiligheidsmaatregelen bij werkvakken en de perverse effecten die extra maatregelen kunnen hebben op rijgedrag, overwegen wegbeheerders en wegenbouwers technologische maatregelen om deze onveiligheid te bestrijden. Automatische voertuigen kunnen bijdragen aan deze ontwikkelingen, maar het kan nog lang duren voordat deze technologie veel gebruikt wordt en totdat het om kan gaan met speciale situaties zoals wegwerkzaamheden. Verder is het zo dat in de komende vijf jaar een 15% toename in wegverkeer in Nederland wordt verwacht. Dit, gecombineerd met overheidsambities om het aantal serieuze verkeersgewonden te halveren in 2020, benadrukt het belang om veiligheid bij wegwerkzaamheden op korte termijn aan te pakken. Daarom is het voorstel om intelligente transportsystemen (ITS) in te zetten om rijgedrag bij werkvakken op snelwegen te verbeteren.

Het succes van dit soort technologische system wordt echter gelimiteerd door acceptatie; het is gewenst dat systemen die onveilig rijgedrag aanpakken geaccepteerd worden door weggebruikers, maar over het algemeen doen bestuurders geen moeite om dit soort systemen te gebruiken.

Doelen

Het praktische doel van dit onderzoek is het verbeteren van navolging van het snelheidslimiet bij werkvakken langs snelwegen door snelheidslimieten en waarschuwingen in de auto te laten zien. Het wetenschappelijk doel is om advies te geven over de mate waarin snelheidslimieten en waarschuwingen op een *head-up display* (HUD, doorzichtige projectie op de voorruit) snelheidsgedrag bij werkvakken op Nederlandse snelwegen kan verbeteren. De hoofdvraag van dit onderzoek luidt:

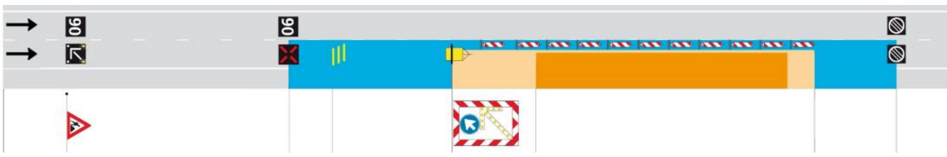
In hoeverre beïnvloeden snelheidslimieten en waarschuwingen op een head-up display (HUD) snelheidsgedrag?

Om deze vraag te beantwoorden worden verschillende aspecten behandeld: navolging van het snelheidslimiet, indicatoren voor besturing van het voertuig, stress en werkdruk, en houding ten opzichte van het systeem.

Experiment

Om data van rijgedrag bij werkvakken te verzamelen is een rijsimulator-experiment uitgevoerd. Rijsimulators geven de mogelijkheid om veilig te testen in een gecontroleerde omgeving. Iedere deelnemer reed twee

stukken van ongeveer 10 minuten per stuk over de A67 tussen Eindhoven en Someren in een niet-bewegende rijsimulator. Voor, tussen en na deze twee ritten werden vragen gesteld over stress, mentale inspanning en houding ten opzichte van het systeem. De A67 heeft twee rijstroken per richting en was aangepast om plaats te maken voor acht werkvakken voor korte duur, volgens de richtlijnen voor werkzaamheden van korte duur op vluchtstroken (Figuur 1). Iedere deelnemer de acht werkvakken tegen in het experiment met herhaalde metingen. In deze scenario's werden drie eigenschappen gevarieerd over twee niveaus (Tabel 1) in een gebalanceerd experimenteel ontwerp om effecten van volgorde uit te sluiten. Verkeersdruk in alle werkvakken was matig, zodat deelnemers de mogelijkheid hadden het snelheidslimiet te overschrijden.



Figuur 1. Ontwerp werkvak (CROW, 2013)

Tabel 1. Experimentele eigenschappen

Eigenschap	Niveau 1	Niveau 2
HUD ITS hulp	Aan	Uit
Werkers aanwezig	Aan	Uit
Snelheid verkeer (km/u)	90	110

In scenario's met ITS hulp werden waarschuwingsiconen weergegeven op een HUD vanaf het punt waar de eerste waarschuwingen langs de weg zichtbaar waren. Bij deze waarschuwingen was een zachte waarschuwingstoon te horen. Aan het begin van een werkvak kregen bestuurders die 95 km/u of sneller reden een feller snelheidslimiet te zien en vanaf dit punt was iedere 5 seconden een waarschuwingstoon te horen. Deelnemers die niet te snel reden zagen de initiële waarschuwing tot het einde van het werkvak. Figuur 2 laat de waarschuwingen zien in het vertragingsvak (boven) en in het werkvak terwijl het snelheidslimiet wordt overschreden (onder).

Figuur 2. HUD waarschuwingen bij een werkvak. Boven: normal. Onder: snelheidsoverschrijding.

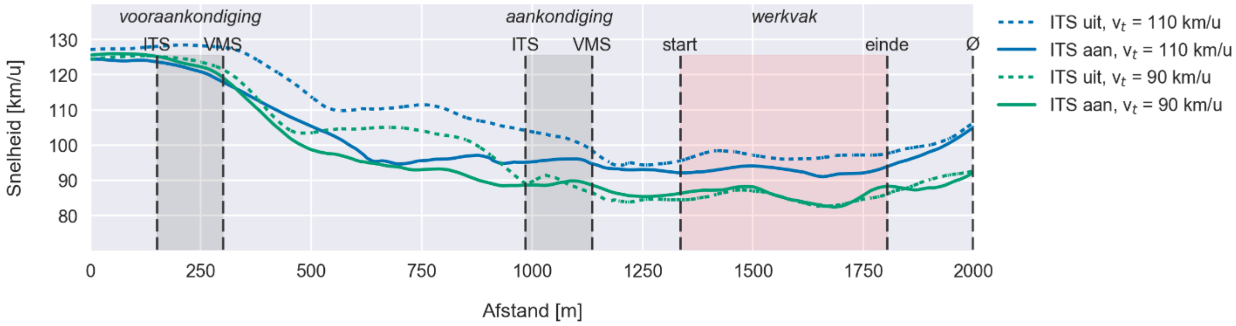
Tijdens het experiment zijn hartslagmetingen gedaan met een optisch meetapparaat op de vinger van deelnemers. De rijsimulator informatie over besturing van het voertuig en de voertuiginformatie naar een logboek. In totaal hebben 34 personen deelgenomen aan het experiment, allen Nederlands sprekende mannen in de leeftijdscategorie 18 t/m 24, en in het bezit van een geldig rijbewijs. Drie deelnemers reden meer dan 10.000 km in het jaar voor het experiment.

Resultaten

Simulatordata werd geanalyseerd door middel van grafieken en *linear mixed model* (LMM). LMM kan effecten van verschillende eigenschappen op een afhankelijke variabele schatten, en compenseert voor eigenschappen van specifieke deelnemers en de volgorde van het experiment. De eerste zone met ITS en de eerste zone zonder ITS van iedere deelnemer werden uitgesloten in deze analyses, omdat deelnemers nog moesten wennen aan het rijden in de simulator en het rijden met ITS, dit zorgde voor onbetrouwbaar en afwijkend rijgedrag. Data afkomstig van de vragenlijsten werd geanalyseerd met de rangtekentoets van Wilcoxon.

Navolging snelheidslimiet

De mediaan van snelheid van deelnemers in het vertragingsvak (na de eerste aankondiging van het werkvak, maar nog voor het werkvak) nam gemiddeld met 4.5 km/u af wanneer het waarschuwingssysteem werd gebruikt. In ditzelfde deel nam de pieksnelheid af met 3.6 km/u gemiddeld. Afremmen gebeurde eerder en hield langer aan wanneer het systeem actief was. Er is geen significant effect op snelheid binnen het werkvak, tevens hadden extra waarschuwingen bij de aanwezigheid van werkers geen effect. Figuur 3 toont de gemiddelde snelheid van deelnemers die boven het snelheidslimiet reden in de laatste 100 m voor de eerste ITS waarschuwingen. In deze grafiek is v_t de snelheid van verkeer in verschillende scenario's.



Figuur 3. Snelheid tegen afstand op basis van ITS ondersteuning en vekeerssnelheid, 30% snelste bestuurders

De afname van snelheid door ITS is in overeenstemming met de resultaten van voorgaande simulatoronderzoeken en veldstudies naar waarschuwingen binnen het voertuig voor gevaarlijke situaties. In dit onderzoek werden de waarschuwingen in het voertuig op hetzelfde punt getoond waar ook waarschuwingen langs de weg voor het eerst zichtbaar waren, terwijl in andere onderzoeken de waarschuwingen op een eerder punt werden getoond.

Indicatoren voertuigebesturing

Het waarschuwingssysteem had geen effect op remgedrag en variantie van het gaspedaal. Gemiddelde druk op het gaspedaal was direct na de eerste waarschuwing in het voertuig lager in vergelijking met scenario's zonder deze waarschuwingen. Halverwege het vertragingsvak was gemiddelde druk op het gaspedaal hetzelfde voor zones met en zonder ITS hulp.

Vermoedelijk valt dit toe te schrijven aan het verschil in afstand tot de voorganger op dit punt. Echter, dit verschil kon niet worden geverifieerd door technische beperkingen. Veranderingen in het wisselen van rijstrook kon ook niet statistisch worden bevestigd, echter de grafieken suggereren dat deelnemers zo'n 50 m eerder van rijstrook wisselden wanneer ITS hulp beschikbaar was.

Stress en werkdruk

Het systeem had geen significant effect op hartslag, hartslagvariabiliteit en door deelnemers gemelde stress. Echter, gebruikers gaven aan dat mentale inspanning bij het passeren van werkvakken lager was wanneer ITS beschikbaar was. Het verschil tussen deze scores was 5.6% van het totale bereik aan scores in het experiment, wat neer komt op een daling van mentale inspanning van iets boven 'enigszins inspannend' naar 'enigszins inspannend'.

Houding

Tevredenheid met het system kreeg voor het experiment 62% van de maximumscore en 65% na het experiment. Deelnemers die te snel reden in een ongemarkeerde meting aan het begin van het tweede deel van het experiment waren op voorhand slechts 57% tevreden met het systeem. In deze groep nam tevredenheid tijdens het experiment toe tot 65%. Er is een negatief verband tussen snelheid in deze meting en tevredenheid met het systeem voor het experiment. Bruikbaarheid van het systeem kon niet nauwkeurig worden bepaald aan de hand van de vragenlijst, en er was geen duidelijk verschil tussen de waarderingen voor bruikbaarheid of de componenten waar bruikbaarheid uit bestaat in metingen voor en na het experiment. Deze resultaten zijn in overeenstemming met de literatuur over acceptatie van vrijwillige ITS systemen en snelheidswaarschuwingen.

Conclusie

Op basis van de experimentele resultaten kan worden geconcludeerd dat HUD waarschuwingen snelheidsgedrag in het vertragingsvak positief beïnvloeden door betere navolging van het snelheidslimiet en een eerdere en gladdere vertraging. Jonge mannelijke bestuurders accepteren het systeem en de gemelde inspanning bij het passeren van werkvakken was lager wanneer het systeem werd gebruikt. Echter, zij die sneller reden waren minder tevreden met het systeem voordat ze het systeem gebruikten. Na gebruik was tevredenheid met het systeem gelijk voor beide groepen.

Aanbevelingen

Snelheidsgedrag van jonge mannelijke bestuurders van personenauto's bij werkvakken kan verbeterd worden door middel van nauwkeurige waarschuwingen in het voertuig. Details over presentatie van informatie, effecten bij verschillende ontwerpen werkvakken en de effect op andere groepen bestuurders zijn niet getest en behoeven verder onderzoek. Het advies is om acceptatie van deze systemen te verhogen door samen te werken met partijen die momenteel locatie-gebaseerd route-, verkeers- en flitsinformatie aanbieden aan bestuurders. De directe voordelen van deze systemen kunnen er voor zorgen dat zelfs degenen die snel rijden en ontevreden zijn met waarschuwingen in het voertuig het gaan gebruiken. Na gebruik van het systeem neemt onder deze groep gebruikers de acceptatie toe. Simpele telefoonhouders met een spiegel kunnen worden gebruikt om in oudere voertuigen een HUD te maken, bovendien is de verwachting dat door zo'n systeem de afleiding van jonge bestuurders door de mobiele telefoon kan afnemen (Figuur 4). Tevens is een HUD veiliger dan reguliere waarschuwingssystemen doordat bestuurders hun ogen op de weg kunnen houden. Afleiding beperken wordt, net als het terugdringen van snelheid, geassocieerd met verhoogde verkeersveiligheid. De aanbeveling is daarom om de mogelijkheden om mobiele telefoons voor rijtaak-assistentie te gebruiken te onderzoeken, het liefst door middel van een HUD systeem.

Figuur 4. HUD mobiele telefoon houder (HUDWAY, 2016)

Het systeem slaagde er niet in snelheid in het werkvak te verlagen, wel is de verwachting dat het aantal ongelukkgen bij werkvakken daalt bij gebruik van het systeem, door een betere vertraging in het vertraginsvak en beter bewustzijn van het werkvak onder bestuurders.

Tevens tonen de resultaten van dit onderzoek dat bestuurders in scenarios zonder ITS hulp voornamelijk afremden in de buurt van VMS waarschuwingen. Een eerste stap die wegenbouwers kunnen nemen om veileigheid bij werkvakken te verhogen is het plaatsen van extra signalering langs de kant van de weg zodat bestuurders over de lenge van het gehele vertraginsvak waarschuwingen kunnen zien. Een literatuurstudie heeft bovendien laten zien dat zichtbare veiligheid in bij werkvakken kan leiden tot verlaagde navolging van het snelheidslimiet; Bestuurders vinden een korte reistijd belangrijker dan veiligheid, en compenseren veiligheidsmaatregelen door middel van een verhoogde snelheid. Daarom is het aanbevolen om werkzones op zo een manier te onwerpen dat de risico's van dit wegdeel duidelijk zijn voor bestuurders.

Verdere aanbevelingen zijn om de CROW richtlijnen voor veiligheidsmaatregelen bij werkzaamheden experimenteel te testen, in tegenstelling tot de huidige gang van zaken. Rijsimulator-experimenten hebben aangetoond geschikt te zijn voor relatief valide tests van rijgedrag op een goedkope, flexibele en veilige manier.

Table of Abbreviations

Abbr.	Full	English
ABS	Anti-lock Braking System	
ADAS	Advanced Driver Assistance Systems	
aFAS	Automatisch fahrerlos fahrendes Absicherungs-fahrzeug für Arbeitsstellen auf Autobahnen	Automated Unmanned Protective Vehicle for Highway Hard Shoulder Road Works
ANOVA	Analysis of Variance	
BPM	Beats Per Minute	
CBS	Centraal Bureau voor de Statistiek	Central Bureau of Statistics
C-ITS	Cooperative Intelligent Transport Systems	
COOPERS	Cooperative Systems for Road Safety	
CSV	Comma-Seperated Values	
CVIS	Cooperative Vehicle Infrastructure Systems	
DRIP	Dynamic Route Information Panel	
DSSQ	Dundee Stress State Questionnaire	
EC	European Commission	
ESP	Electronic Stability Program/Control	
HUD	Head-up display	
I&M	Ministerie van Infrastructuur en Milieu	Ministry of Infrastructure and Environment
ITS	Intelligent Transport Systems	
JSON	JavaScript Object Notation	
KiM	Kennisinstituut voor Mobiliteitsbeleid	Netherlands Institute for Transport Policy Analysis
LMM	Linear Mixed Model	
REML	Restricted Maximum Likelihood	
RSME	Rating Scale Mental Effort	
RWS	Rijkswaterstaat	Governmental Water Estate (Operator of Dutch highways)
SAE	Society of Automotive Engineers	
SD	Standard Deviation	
SDNN	Standard Deviation of N-N intervals	
SDSD	Standard Deviation of Successive Differences	
SSSQ	Short Stress State Questionnaire	
SW	Shapiro-Wilk	
SWOV	Stichting Wetenschappelijk Onderzoek Verkeersveiligheid	Foundation Scientific Research Traffic Safety
TLI	Task Load Index	
TNO	Nederlandse Organisatie voor toegepast natuur-wetenschappelijk onderzoek	Dutch Organisation for Applied Scientific Research
TTC	Time-To-Collision	
V2I	Vehicle-to-Infrastructure	
VMS	Variable Message Sign	

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ADVIN

1 Introduction

Highway work zones are relatively unsafe compared to work zones at other road types, and this relative unsafety has gradually increase over the course of the past years (Janssen & Weijermans, 2008). This is issue affects drivers as well as road workers, and is expected to become more relevant in the following years as road traffic is expected to show a 15% increase in the following five years (Ministry of I&M, 2016, pp. 118-120). In the meantime, vehicle automation and intelligent transport systems (ITS) are gaining popularity and could help improve traffic safety. However, there is a group of relatively unsafe drivers that usually lags behind in adopting new technologies: young male drivers (SWOV, 2016a).

This research focuses on improving safe driving of this group of young male drivers at highway work zones, using ITS. This chapter introduces the problem statement, and looks ahead at the research activities.

1.1 Problem Definition

1.1.1 Safety at Highway Work Zones

In order to keep the network of highways in the Netherlands in optimal condition, Rijkswaterstaat (operator of highways in The Netherlands) is continuously performing maintenance and upgrades on the network (Rijkswaterstaat, 2016b). Work zones on or near existing parts of the road network, mean interactions between workers and traffic. Even though the working area is closed for traffic and a temporary speed limit is applied, 0.5% of all serious Dutch traffic accidents happen near work zones at highways (SWOV, 2010, p. 17). While this may seem low at first, Figure 5 shows that over 4% of all serious accidents on Dutch highways in 2005 happened at a road work zone, even though these zones do not make up for 4% of the Dutch highways (VID, 2017). Furthermore, this figure shows a high share of serious accidents at highways during road work in comparison to serious accidents at work zones on other road types and this share increased between 1987 and 2006. Serious accidents are defined as accidents with at least one hospitalised or deceased victim.

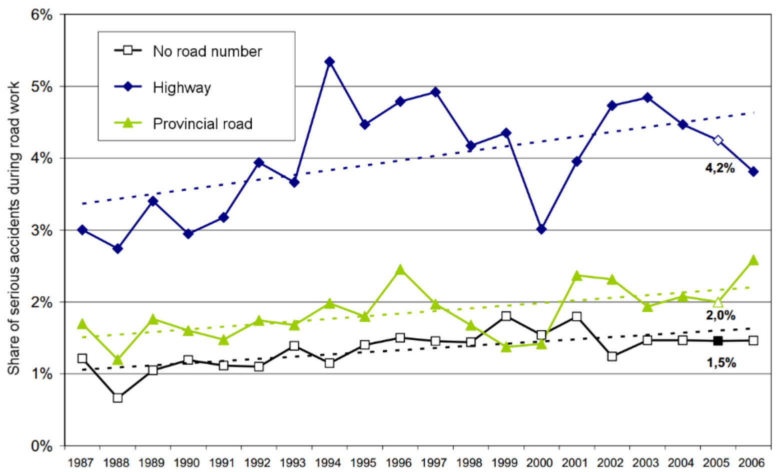


Figure 5. Share of serious accidents during road work per road type (Janssen & Weijermans, 2008)

According to a sample study by SWOV, two thirds of all Dutch serious accidents at work zones would not have happened if there was no work zone (Janssen & Weijermans, 2008, p. 6). Furthermore, Janssen and Weijermans state that 61% of these accidents could have been prevented by adjustments at the operational or tactical level (skills and rule following), 24% of the accidents required a strategic change (route choice or vehicle choice) (Janssen & Weijermans, 2008). In 2009, the Dutch labour inspection revealed that for 74 out of 223 (33%) tested locations in the Netherlands the collision danger was too high (Arbeidsinspectie, 2010).

Involvement of the labour inspection reveals another safety issue at work zones: worker safety. Due to inaccurate registration however, exact numbers about accidents involving workers are not available (Eijk, 2007).

These safety issues at work zones are not limited to the Netherlands. Considering the majority of European roads was built in the 1960s, a high number of highway work zones can be expected in the nearby future (Kreps, 2016). This is expected to lead to an increase in serious traffic accidents at work zones in Europe.

1.1.2 Relative Risk of Young Male Drivers

According to research by SWOV, the fatality rate per distance travelled is ten times higher for 18 to 24-year-old male drivers compared to 30 to 59-year-old drivers (2016a). Figure 6 shows an increasing trend in this relative unsafety. The fatal crash risk of young female drivers is roughly twice the risk of 30 to 59-year-old drivers. The elevated risks for young males is the result of a lack of experience as well as age-related factors

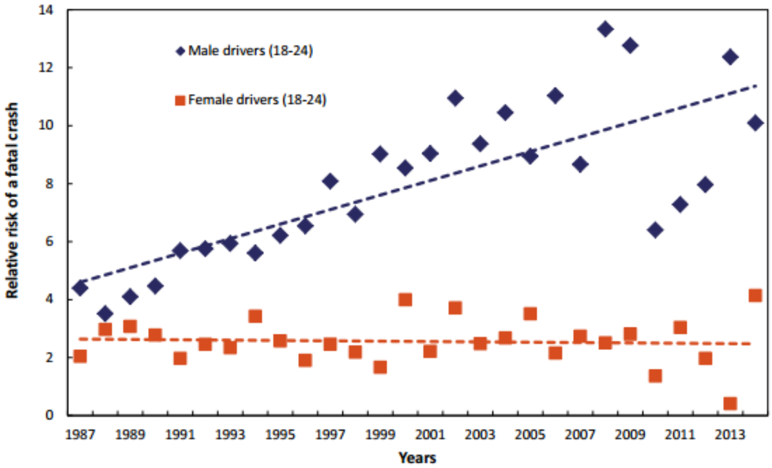


Figure 6. Development of young driver risk compared to experienced drivers, I&M in (SWOV, 2016a)

On average, 46% of the serious injuries and deaths resulting from these accidents considered young drivers themselves, while the other half considered passengers (15%) and crash opponents (38%) (SWOV, 2016a, p. 1). While only 10% of all license owners are in this age category and individuals in this group drive less kilometres per year compared to other age groups, 22% of all deaths in crashes with passenger vehicles involved one or multiple young drivers (SWOV, 2016a; CBS, 2016b). Causes for the relative unsafety of young male drivers vary from lack of skills to the age of vehicles driven by this group (SWOV, 2016a, p. 3).

1.1.3 Conclusion

Two large safety issues at Dutch highways were introduced, and both of these issues show an increase over time. These two safety issues possibly do not exclude each other. Therefore, if these trends continue it is possible that the safety of young male passenger car drivers at highway work zones grows rapidly over the course of the next few years.

1.2 Potential Solution: Intelligent Transport Systems

The issues mentioned in the previous section mainly show in driving behaviour and safety of the road at the work zone. Driving behaviour and road safety are part of the sustainable safety concept, in which it is argued that for a safe road situation it is preferred for the three pillars human, vehicle and road to be approached as an integral system (Figure 7) (SWOV, 2012b). Various methods of increasing safety have been researched, for example vision blocking barriers and trajectory speed controls (Ullman & Finley, 2011). An adverse effect of vision obstruction between traffic and the work zone was found (Ullman & Finley, 2011; Harms I. , 2016a). While trajectory speed cameras improve speed compliance, they do not increase work zone awareness and driver attention (Pauw, Daniels, Brijs, Hermans, & Wets, 2014).

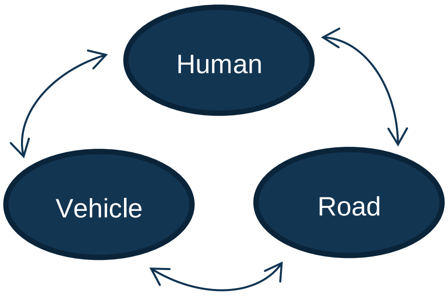


Figure 7. Three pillars of Sustainable Safety. Based on SWOV (2012b)

Possibly, alertness and can be improved by means of intelligent transport systems (ITS). ITS is defined as the application of ICT to make transport infrastructure, demand and the interaction between these two safer, cleaner and more efficient (Arem, Hogendoorn, Hangenzieker, & Schakel, 2014, p. 6). In general, this is done by supporting drivers or by taking over one or more of the driving tasks. Examples of present-day in-car ITS are Anti-lock Braking System (A), Electronic Stability Program (ESP) and early applications of lateral and longitudinal driver support systems. Other types of ITS operate on the network level, for instance traffic management systems linking road side measurements, user reports and GPS data to provide drivers with real-time traffic information through in-car systems and dynamic route information panels (DRIPs). In-vehicle ITS is also available for already existing vehicles: Aftermarket solutions or mobile phone applications can be used, however user acceptance and response is a crucial factor for the maximum effect of these measures.

Ideally, these driver support systems are tailored to the combination of the driver and the current road situation. While proven to be technically possible today, implementation of such systems requires a cooperation of many different stakeholders which is not likely to finalize in the short term (SAFESPOT, 2010). As a result, few systems are currently available to regular consumers (Rijkswaterstaat, 2016c). Furthermore, these systems often rely on signs and markings at the road side, however these are sometimes conflicting or different to regular conditions at work zones (Venema & Drupsteen, 2007a).

This showed in a recent case at the N279 provincial road where navigation system users were given wrong-way driving instructions (Nuijten, 2016). Moreover, while closed or obstructed roads are often displayed on the map of navigation systems, drivers generally do not get notified when they are about to drive through such a zone. Work zones which are of a shorter duration are sometimes not displayed at all (Google, 2016).

Furthermore, the introduction of ITS may present new safety issues, for instance: Automated vehicles do not always see small and distant objects (Hattem, 2016). Over-the-air software updates of these systems are distributed outside of regular vehicle safety tests, and work zone safety measures have yet to be adapted to these developments (Nuijten, 2016; Ticheloven, 2016). Even when implemented perfectly, driver support has potential issues: According to Schaap, low workload causes a deterioration in responding safely in dangerous situations (2012).

Currently, road construction companies are not involved in ITS and it is unclear what specific actions these companies can take. Advin and road construction companies need insights in ITS to be able to determine their role in safely guiding traffic at work zones.

1.3 Research Outline

This section provides a brief overview of the study. This is done by looking ahead to Chapter 3 and Chapter 4, in Subsections 1.3.1 and 1.3.2, and by providing an overview of the structure of the report in Subsection 1.3.3.

1.3.1 Basic Objective

Looking to apply this potential early ITS solution to solve the issue of relative low traffic safety at highway work zones, the main objective of this research is: *To improve speed compliance at Dutch highway work zones by contributing to the development of intelligent in-car systems.* In order to reach this objective, this study researches available ITS and the extent to which speed behaviour at work zones can be changed by applying these systems. Because penetration among drivers is important to significantly improve safety, attitude towards the system is also researched.

1.3.2 Methodology

In order to fulfil the research objectives, first a literature study is conducted to gather knowledge on traffic safety, driving behaviour, ITS, and methodologies in driving safety research. Based on the findings in this literature study, knowledge gaps are defined. Chapter 3 presents the comprehensive objectives of this study, consisting of delimitations, research questions and hypotheses.

In order to answer the research questions, driving behaviour data is collected. Data collection is based on a repeated measures driving simulator experiment, as this allows comparison of behaviour under different circumstances in a controlled environment, requiring a small group of participants. During this driving simulator experiment, vehicle information and user inputs are logged by the driving simulator. Driver opinions and perceptions about the system are collected by means of questionnaires.

After data processing, visualisations of average behaviour over distance are used to determine further data analysis steps. These steps are performed by applying statistical tests to experiment data, in order to estimate effect size of different input variables and to draw conclusions significance of these effects: Estimating their qualitative effect, and the probability that these effects are real and not based on chance or measurement error.

1.3.3 Report Structure

So far, this chapter introduced this research, treated the basic problem statement and introduced a potential solution. Figure 8 provides the reader with an overview of the report structure. Solid arrows represent the reading order and basic information flow in the report, dashed arrows represent feedback of information into previous chapters.

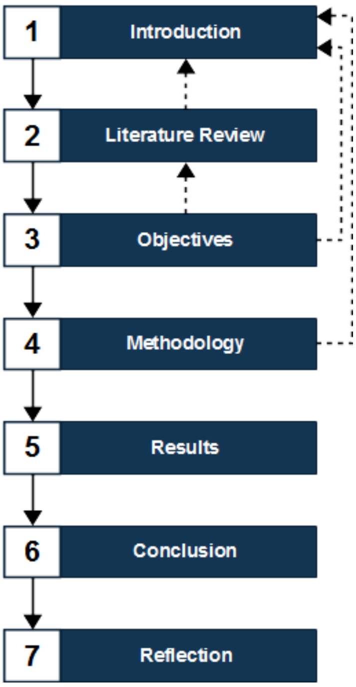


Figure 8. Report structure

2 Literature Review

For a better understanding of traffic safety at work zones, human behaviour in traffic, and ITS developments, this chapter provides a literature review on these topics. First, in Section 2.1 the methodology of this literature review is presented, Sections 2.2 to 2.4 elaborate on the topics traffic safety, driving behaviour and ITS. Section 2.5 provides an overview of methods used in previous driving behaviour studies. The final section of this chapter presents conclusions on this literature review.

2.1 Literature Review Methodology

In each of the next three sections, subquestions about the topic of that section are introduced. Then, the subsections in that section answer focus on one question each. Knowledge gaps are stated at the end of each subsection. Not all questions can be answered by information from scientific publications and public documents. To fill these gaps, experts from the network of Advin were contacted for short interviews. Section 2.1.1 elaborates on the interviewees and the methodology of these interviews.

2.1.1 Interview Methodology

The experts consulted for this project are listed in Table 2. At the start of an interview, the expert is briefly introduced to this project. This provides good basis for a semi-structured interview as explained by Leech (2002). This style is often used in elite politician interviewing and allows the researcher to gain ‘rapport’: a harmony between interviewer and expert. Gaining rapport helps to get informative answers even on sensitive questions: the common understanding and open ended questions help the interviewed person to provide as much of their knowledge as possible. The semi-structured character of this interview technique is used to provide some guidance to make sure the information provided is relevant to this project. In some cases, an Advin employee is present during this interview to explore business potential in the fields of traffic safety, road work and ITS.

After the interview, contact is maintained with these experts to lay foundations for further exchange of information. Experts are only cited as a source when no printed source is available, i.e.: an expert who is currently working on a traffic safety study which is not yet published.

Table 2. Experts to interview

Name	Institution	Area of Expertise
Alkim, Tom	Rijkswaterstaat	ITS, automotive, automation, vehicle regulations
Harms, Ilse	Connecting Mobility, RUG	Traffic and driver psychology
Hattem, Jan van	Rijkswaterstaat	C-ITS, standards and traffic safety
Koenis, Maaikel	Rijkswaterstaat, CROW	Highway work zone layout and safety (CROW, 2013)
Nägele, Reinoud	Rijkswaterstaat	Traffic safety research

2.2 Traffic Safety

Traffic safety is an important goal of the Dutch Ministry of Infrastructure and the Environment (I&M). Table 3 provides an overview of most recent numbers and goals regarding Dutch traffic safety. The aim for 2020 is to halve the number of serious accidents compared to 2014, while total road traffic is expected to increase by roughly 15% (Ministry of I&M, 2016, pp. 118-120). Currently, around 800 serious injuries per year happen on highways (SWOV, 2016b).

Table 3. Dutch traffic safety goals (Ministry of I&M, 2012; CBS, 2016a; Adminaite, Allsop, & Jost, 2015)

	Current	Goal (2020)
Fatalities [person]	570	< 500
Seriously injured [person]	20,700	< 10,600
EU ranking [-]	9	< 4
Traffic performance [10^9 km]	127	> 130

According to Rumar, traffic safety can be described as the product of three dimensions (1999, pp. 17-20):
- exposure [vehicle / time],
- accident risk [accident / traffic volume], and
- injury consequence [injury / accident].

This indicates that in order to improve traffic safety, at least one of these values must be reduced while the others stay at the same level. Exposure and accident risk can be related to driving speed: According to Finch et al., reducing driving speed by 1 km/h translates to a roughly 3% decrease in the number of people injured. Standardisation by the Abbreviated Injury Scale can be used to classify the severity of injuries (AAAM, 2016) when dealing with the safety aspect 'injury consequence'. Taking this into account, safety can be improved by reducing the severity of injuries as well.

The subsections in this section attempt to answer the following questions:
- What are causes for work zone unsafety? (2.2.1)
- What safety precautions are currently taken at work zones? (2.2.2)
- How is ITS currently applied at work zones? (2.2.3)

2.2.1 Safety Issues at Work Zones

In Section 1.1 it was mentioned that 0.5% of fatal Dutch traffic accidents happen at highway work zones (SWOV, 2010). Around two thirds of all work zone related accidents are unlikely to happen in case there is no work zone (Janssen & Weijermans, 2008). Furthermore, Janssen & Weijermans (2008) showed an increasing trend in the share of serious accidents at work zones in relation to the total number of serious accidents on the Dutch roads between 1987 and 2006 (see Appendix A for more graphs).

In terms of severity of work zone crashes, Yang et al. (2014) compared data from 179 papers published between 1962 and 2013, and did not find clear evidence for a difference in severity between work zone crashes and non-work zone crashes. Dutch statistics of relative work zone unsafety were confirmed in this state of the art review: The work zone crash rate was found to be higher than the regular crash rate in 85.7% of all analysed studies (Yang, Ozbay, Ozturk, & Xie, 2014).

Yang et al also revealed that, registration inaccuracies aside, buffer and activity areas showed higher crash percentages than other areas at work zones (2014). The distribution of crashes over the different work zone areas is displayed in Figure 10. In Dutch standards for work zones the buffer and activity areas are referred to as the safety and work areas (CROW, 2013). Most crashes occur because of inattentive driving, speeding or failing to yield, these crash causes can be grouped as unsafe driving behaviour (Yang, Ozbay, Ozturk, & Xie, 2014). Though, it is not exactly known what share of road work accidents is the result of deliberate misbehaviour (Janssen & Weijermans, 2008, pp. 42-43).

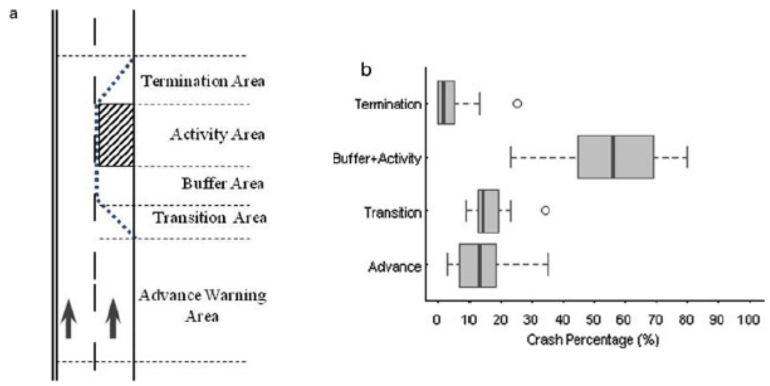


Figure 10. Work zone areas (a) and crash rate distributions (b) (Yang et al., 2014)

Speeding and short following distances are main causes of rear-end collisions (SWOV, 2010). 31% of all collisions at work zones outside built-up areas are rear-end collisions, this is twice the share of rear-end collisions in regular road condition crashes. The probability of an accident is slightly higher for night-time road works compared to daytime road work activities, corrected for the number of vehicles and number of work zones per type (National Technical University of Athens, 1998; SWOV, 2010). The lower number of vehicles on the road during night-time compensates: A Swedish study showed comparable crashes per hour rates for daytime and night-time driving (Akerstedt & Kecklund, 2001). A relatively high number of trucks is involved in serious accidents at work zones: 13% of these accidents involve trucks while in regular situations only 6% of serious accidents involve trucks (SWOV, 2010). Trucks account for less than 2% of the total traffic performance of the Netherlands, measured in kilometres (CBS, 2016a).

Another important cause for traffic accidents at work zones is the reduction of space for road traffic, a lacking or confusing barrier between traffic and the work zone, or conscious unsafe behaviour of drivers or workers (Venema & Drupsteen, 2007b; Ullman & Finley, 2011). A model study on work zone crashes at a highway section in New York City indicated work zone crashes positively correlate with work zone length, traffic volume as well as the number of closed lanes (Yang, Ozbay, Ozturk, & Yildirimoglu, 2013).

Registration of road work accidents were found to be lacking detail and consistency on a national and international level (Venema & Drupsteen, 2007a), but road workers perceive the safety level of work zones as being low, addressing driving behaviour as the main issue (Kuiper, Giesbertz, & Bloemhoff, 2007). The effects of unsafe driving at work zones are not limited to traffic: Venema and Drupsteen found that Van den Berg Infra and parts of BAM group had 25 registered cases of collisions between traffic and workers in 2004 to 2006 (2007a).

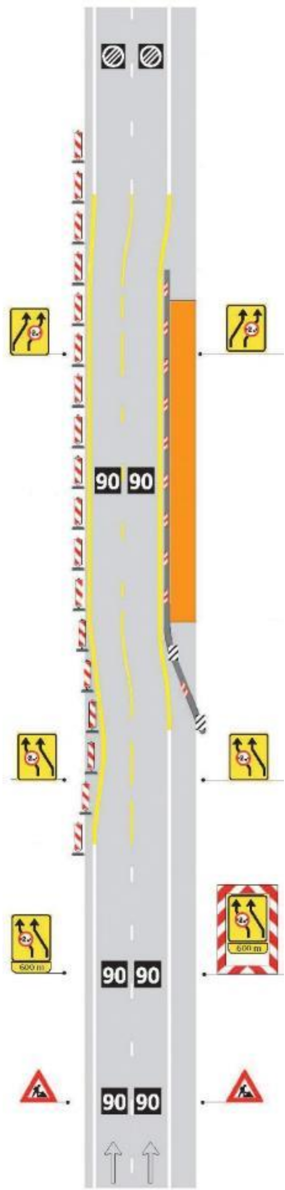


Figure 9. Example of work zone safety measures. Based on CROW (2013)

In conclusion, traffic safety literature provides some useful insights in the causes of work zone unsafety. While the road condition at work zones is sub optimal, the main causes for unsafety are unawareness and (sometimes deliberate) unsafe driving behaviour. This results in an increased accident risk at work zones, mainly in the buffer and activity areas of work zones. Exposure to work zones and the injury consequence in case of an accident play a smaller role in work zone unsafety.

2.2.2 Safety Precautions at Work Zones

The figures in the previous subsection suggest that work zones might not always be adequately indicated. Current measures include providing road operators and construction companies with trainings, recommendations and guidelines (European Union Road Federation, 2015; National Technical University of Athens, 1998). An example of Dutch guidelines is shown in Figure 9 on page 7. Such guidelines are applicable to all planned and unplanned work activities at, above or next to public roads in the Netherlands (CROW, 2013, p. 7). Specific signs, barriers and locations are provided in these guidelines, aiming to make drivers well-aware of the upcoming work zone and adjusted traffic rules.

These guidelines contain many scenarios for different road types and road work types: Number of lanes, maximum speed, availability of VMS, duration of work and length of work zone play a role in determining required safety precautions. In order to cover all unique situations, a decision tree and minimum distances between work zone parts per design speed (the regular speed limit in case there is no work zone) are provided. Work zones that take more than one day require a traffic plan and stationary road closures. The guidelines in publication 96a does not mention ITS other than the speeds and warnings displayed on VMSs near a work zone. Furthermore, these guidelines are based on expert opinions and occasional consults of literature, rather than structural scientific research (Koenis, 2016).

Speed limits are part of the measures listed in these guidelines: Typical speed limits on Dutch highways are 130 km/h, 120 km/h and 100 km/h or 80 km/h (Rijkswaterstaat, 2016d). A speed limit with an odd first digit (90 km/h or 70 km/h) is generally used at work zones to make these special situations stand out from regular road situations (CROW, 2013).

To conclude this, the current safety precautions at work zones focus on raising awareness amongst drivers and protecting road workers in case of an accident. However, as shown in Section 2.2.1, lack of awareness of work zones and the related safety risks related to this are large issues for work zone safety.

2.2.3 Current Applications of ITS at Work Zones

The lack of awareness amongst drivers is addressed with basic ITS measures. Current in-car and road side systems improve overall traffic safety at work zones mainly by redirecting traffic and thus reducing exposure (Venema & Drupsteen, 2007a). This section provides insight into these current measures.

Road side ITS used at work zones include per-lane variable message signs (VMS) and dynamic route information panels (DRIPs) used to warn drivers about oncoming and current work zones, to slow them down, as well as providing traffic information for various route sections (Connekt, 2011). These systems are shown in Figure 11. In 2003, 40% to 45% of drivers on Dutch highways were found to violate the dynamic speed limit, which can be mostly attributed to low driver awareness of traffic signs (Hoogendoorn, Harms, Hoogendoorn, & Brookhuis, 2012). Part of this blindness for adjusted speed limits is the result of driver familiarity with a road section: In a simulator study by Harms and Brookhuis, 58% of drivers failed to notice the increased speed limit on a VMS. This is in line with the suggestion that unawareness is a major contributing factor to work zone unsafety (2016b).

Figure 11. From left to right: DRIP, bank DRIP, VMS (Rijkswaterstaat, 2016a)

A deployment test of smart work zones in Arkansas used a system of traffic sensors, several bank DRIPs and a pager alert to provide drivers more personally with traffic, delay and speed advisories (Tudor, Meadors, & Plant, 2003). Besides successfully reducing rear-end collisions, a reduction in fatal accidents compared to other work zones in Arkansas was also observed. Similar results were found in the Netherlands: A dynamic speed limit at the A12 highway between Bodegraven and Woerden successfully contributed to improving traffic safety during heavy showers by immediately lowering the speed of 20% to 35% of vehicles (80 km/h limit) and 55% to 80% of vehicles (100 km/h limit) (Burgmeijer, et al., 2010). This indicates awareness of variable speed limits in special situations is higher compared to regular situations. In the case of work zones, a pre-announcement of the work zone is made well ahead of the work zone, and as drivers are often driving on a regular road section at this point, these signs may still go unnoticed.

Very short road works can use a work zone designed to move in the direction of traffic, for instance when placing signs or beacons for the real work zone. In these work zones, a DRIP on the back of a truck warns drivers behind the moving work zone. To reduce the risk involved with head-tail collisions at these types of work zones, German project aFAS developed an automated unmanned truck for these moving road closures (Stolte, Reschka, Bagschik, & Maurer, 2015). Applying this technology to a narrow vehicle allows road construction companies to perform moving road shoulder work with in a safe way without the need to close the right lane (Vioss, 2016).

Additional to dynamic panels, road work information website vanAnaarBeter.nl provides links to route planning tools, suggestions for alternative modes of transportation and suggestions for alternative working locations (Rijksoverheid, 2016). A main disadvantage of these systems is that they cannot be targeted towards a single driver, but instead broadcasts the same message to all who choose to visit the website. Besides the ITS applications operated by the government and aimed to manage traffic flows, an often-used system is developed by market parties: Navigation and traffic information systems that provide users with network information. Examples of such companies are TomTom, Google Maps, Flitsmeister, Waze and various systems by car manufacturers. In an explorative test of smart phone applications, it was observed that most systems currently display full closures and icons for work activity on the map, but do not provide dynamic warnings or other forms of driver assistance. Again, these measures do not target accident risk or injury consequence, but merely exposure by suggesting drivers take an alternative route.

These voluntary ITS applications show high acceptance amongst drivers (SWOV, 2015), most likely due to other features of the system, e.g.: route information or speed trap information. Some navigation systems provide lane assistance in regular situations, however these features usually provide faulty information when a road is under construction. The discrepancy in instructions from in-car systems on one hand and the road situation and road-side instructions on the other hand, decreases traffic safety at work zones (Kroon, et al., 2016).

In conclusion, current ITS applications at work zones mainly focus on reducing exposure rather than raising awareness of upcoming potentially unsafe situations. Most of these systems are aimed at all road users or those who choose to make use of the service and have no specific effect on those passing a work zone. As a result, drivers may not notice the information or they may choose to ignore it.

2.3 Driver Behaviour

Previous sections about traffic safety showed human behaviour plays an important role. Part of the cause for work zone unsafety lies at deliberate unsafe behaviour by motorists. The effect of safety precautions is dependent on human response to it, which might cause diminished results. This section focuses on the behaviour of drivers, by finding answers to the following questions:

- What determines safe driving behaviour? (2.3.1)
- Why do young male drivers show a high relative crash risk? (2.3.2)
- How can ITS influence driving behaviour? (2.3.3)

2.3.1 Driver Behaviour and Safety

Substantial to describing human driving behaviour is Michon's hierarchical model. This model distinguishes three driver decision levels, influencing each other in a top-down manner. Per level, an example task and influenced risk aspects are listed (Michon, 1985). Speeding and steering mistakes can be a conscious action at the manoeuvring level or an unconscious mistake at the control level (Gent A. v., 2007).

Table 4. Structure of driving task and safety influence (Michon, 1985; Rumar, 1999)

Level	Output	Example	Risk Influence
Strategic	General plans	Route, modal choice, risk and cost evaluation	Exposure, accident risk and injury consequence
Manoeuvring	Controlled actions	Obstacle avoidance, gap acceptance, overtaking, lane changing	Accident risk and injury consequence
Control	Automatic actions	Steering, throttle, brake	Accident risk and injury consequence

In work zones, task demand is increased due to uncommon and unexpected situations. Fuller stated tasks of lower demand can be responded to by anticipatory control while reactive control is used to respond to tasks demanding more of a driver's capabilities (2005). Figure 12 shows how this reactive control mechanism leads to increased deceleration. This may lead to another high demanding task for the driver in the following vehicle. Besides capabilities of drivers, sometimes a driver willingly decides to ignore advices and rules. In fact, the Dutch road operating body describes drivers as 'quite selfish' (Godthelp, 2012, p. 11), which is in line with the disutility generally associated with the act of transportation.

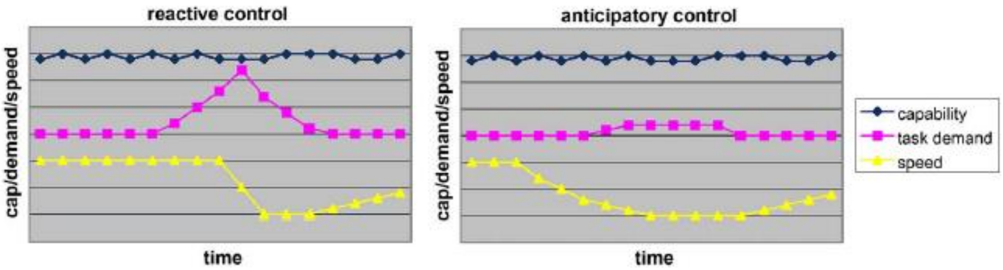


Figure 12. Reactive and anticipatory control for different task demand levels (Fuller, 2005)

On the other hand, reducing workload too much may have undesired effects on alertness (Schaap, 2012). A decreased workload may also cause drivers to underestimate the dangers of a situation and drive faster to meet their preferred target risk (Fuller, 2005). Speeding is an important cause of work zone unsafety (Gent A. v., 2007).

Similar risk-seeking patterns are observed when traffic is separated from work zones by large concrete barriers which block work zone visibility. Areas of high work zone activity have shown to lead to lower average speeds but increased speed variability (Reyes, 2008). This suggests that work zones with higher visual activity result in better compliance to rules and driver advice when compared to longer and lower activity work zones, even though driver distraction is lower when the work zone is not visible.

In conclusion, safe driving behaviour is composed of three levels: strategy, manoeuvring, and control. Of these levels, manoeuvring and control are related to accident risk and injury consequence. The driving task should not demand skills higher or close to the capability of individual drivers, as this results in an elevated accident risk. However, a workload or workload perception which is too low may result in deliberate risk seeking behaviour. Similarly, a negative effect on safety was shown in situations where drivers are unaware of the dangers of that situation.

2.3.2 Young Male Drivers and Safety

Young males drive more dangerously compared to other groups of passenger car drivers. In the Netherlands, male drivers between 18 and 24-year-old show a ten times higher fatality rate of young males when compared to 30 to 59-year-old male and female drivers (SWOV, 2016a).

According to SWOV (2016a, p. 3), there are several causes for the relative unsafety of young male drivers:

- ***Biological:*** the part of the brain that ensures we think before we act is not fully developed until the age of 25.
- ***Lack of higher order skills:*** Young drivers are less experienced and therefore less capable of anticipating possible hazards.
- ***Social-psychological:*** Driving is seen as a means of status, freedom and something to impress friends with.
- ***Cognitive-psychological:*** Distraction by media devices.
- ***Exposure to danger:*** Young drivers drive in relatively old cars with fewer safety features and they drive in the dark more often.

Looking at the relative crash risk of drivers against age, grouped by the age at which the driver acquired his or her driver's license, a downward trend in the number of crashes per million kilometres can be seen (Figure 13). While the relative crash risk of young female drivers is also higher compared to the relative crash risk of older drivers, it is much lower compared to young male drivers: The relative crash risk of young female drivers is double that of older drivers, in contrast to a tenfold risk for young male drivers (SWOV, 2016a).

SWOV has suggested that the increasing use of social media, vehicle automation and intelligent transport systems plays a role in relative crash risk of young male drivers (2016a, p. 6). The effects of these inventions can be negative or positive: Social media distracts drivers from the driving task and partial automation may lead to lack of skills, while automation and warning systems can reduce the three risk aspects (SWOV, 2016a).

No specific scientific literature on safety of young male drivers at work zones could be found. However, Akerstedt and Kecklund studied another type of non-standard road situation with increased driver demands: Early morning highway accidents in Sweden (2001). The late-night crash risk for men was found to be double that of women, while the odds of being involved in a crash for young drivers is five times higher when compared to 25 to 65-year-old drivers, this excluded alcohol-related incidents (Akerstedt & Kecklund, 2001, p. 107). Overall road safety in Sweden is slightly better compared to road safety in the Netherlands (ETSC, 2015, p. 14).

The increased crash risk at night is partly influenced by fatigue, which plays a less distinct role at work zones. Akerstedt and Kecklund suggest, in line with SWOV, that risk taking behaviour, lack of experience and peer pressure causes the increased crash rate of young male drivers, however this was found to play a bigger role in night-time driving compared to day-time driving (2001, pp. 107-108).

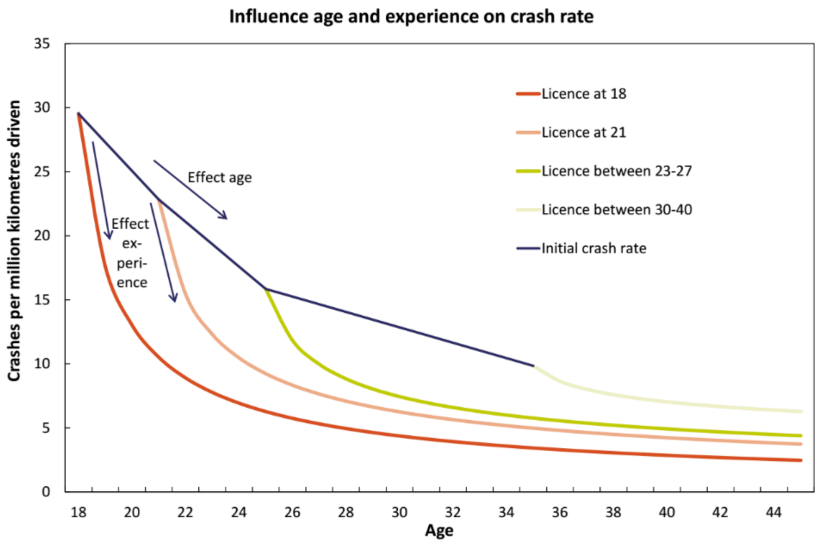


Figure 13. Influence of age and experience on crash rate (SWOV, 2016a)

2.3.3 Influencing Driver Behaviour Using ITS

The speed at which new types of ITS are introduced cannot be linked to traffic safety directly. For instance, market penetration of these systems plays a major role in the safety increase they can bring. Penetration young drivers vehicles for instance, lags behind market introduction as drivers in this group generally drive older vehicles (SWOV, 2016a). And even when a system has a high penetration, the question is whether or not driving behaviour is actually altered by this system, and in what direction?

Optional and aftermarket ITS solutions are especially sensitive to these acceptability issues: For instance, adaptive cruise control instance showed to have low acceptance at first, only to show increased acceptance after trying the system (SWOV, 2015). Adaptive cruise controls that force maximum speeds showed lower acceptance when compared to advisory systems (SWOV, 2015). On the other hand, acceptance of a congestion warning system was high in a study by Brookhuis et al. (2009). Negative self-selection is an issue in acceptance of these systems: Those who would invest in these systems and those that would use the system, are generally the safer drivers (SWOV, 2015, p. 4).

One reason for slow penetration of new safety-improving technologies is willingness to pay. Electronic Stability Programme (ESP) for instance, has been publicly available since 1995. Despite ESP's potential of avoiding 20% of all car accidents, the penetration rate in the Netherlands in 2007 was only 7% (Baum, Grawenhoff, & Geißler, 2007; Christoph, 2010, p. 19). In 2011, ESP was made mandatory on all new models in the European Union (Ranocchiari, 2009). This results in an estimated current penetration rate of around 50%, suppressed by the replacement rate of passenger car vehicles (Christoph, 2010).

While on one hand the penetration of ITS limits its potential effects, another issue is the trend of traffic information divergence: Many different systems present slightly different information to drivers (Kroon, et al., 2016, p. 4). The divergence of traffic information causes potentially unsafe situations when different drivers respond to different types of information at the same time and place. Furthermore, the messages could lead to unsafe workload levels when presented at the wrong moment or in the wrong way. Kroon et al. wrote a set of human factor guidelines for the design of safe in-car traffic information services (2016). According to these guidelines one should:

- limit additional workload;
- present information on time, ideally 36 seconds before the point of action or 200m before the first road sign;
- prioritise information by importance to the driver in relation to context and urgency;
- avoid visual and auditory attraction away from the driving task;
- show information that is non-ambiguous, valid and reliable;
- make information recognisable and consistent with legal traffic signs, signals and local road side information.

Hoedemaeker, Korse and Van Arem used a driving simulator to show that lane departure warnings can increase traffic safety (2004). Nevertheless, participants in this study indicated the system did increase subjective effort required to drive. When given a secondary task unrelated to driving, lane keeping performance was better compared to other scenarios with or without assistance of this warning system (Hoedemaeker, Korse, & Arem, 2004).

This task unrelated to driving is related to another undesirable effect which might result from active driver support systems: Compensatory behaviour, similar to compensatory behaviour at visibly safe work zones. This occurs when drivers apply systems aimed at improving safety as a means to increase their personal comfort or to decrease travel time. For instance, a study on sensation seeking and risky driving showed both high and low level sensation seekers stated they will drive faster and follow shorter on highways and wet roads when their vehicle is equipped with ABS (Jonah, Thiessen, & Au-Yeung, 2001, p. 4). This indicates the perceived utility of increased safety is lower than the utility of comfort and the disutility associated with travel time.

Overall, a foundation for ITS acceptance has been shown, however research indicates drivers' main preference is to reach their destination sooner and with a lower variance, preferably at low cost (Muizelaar & Arem, 2007).

Furthermore, while drivers do prefer safe systems over unsafe systems, they have a tendency towards neutralising and denying risks; Most consider themselves better drivers than others and think they will have a lower chance to be involved in an incident (Brookhuis, Waard, & Janssen, 2001).

As a solution to this gap as well as the issue of negative self-selection, Brookhuis, Waard & Janssen suggest including comfort enhancing features into ITS to increase willingness to use amongst drivers (2001). An example case is the integration of ambulance notifications in Flitsmeister (speed camera master), an application with as the main goal to inform drivers about speed cameras (Flitsmeister, 2016). Also, pushing systems towards drivers helps: Nearly every vehicle produced these days includes a system that displays basic traffic information. This is accepted and even used by drivers, while in general users spend little effort to obtain or use these mobile phone applications (Harms, Vonk Noordegraaf, & Dicke-Ogenia, 2015).

ITS can influence driving behaviour in a positive way, however this is not always the case. First, market penetration of these systems is slow, and acceptance has shown to be passive and biased towards safe drivers. When presented with such these services however, drivers do tend to accept and use it. Once these systems are being used, adverse effects may show: drivers compensate for the extra safety by driving more dangerously. When designing new information systems, attention should be paid to avoiding these adverse effects, as well as avoiding sudden distractions or an increase in workload.

2.4 Intelligent Transport Systems

Driving behaviour aside, this section focuses on current and future ITS. After a short introduction on ITS and vehicle automation, the subsections deal with the following questions:

- What ITS are currently available? (2.4.1)
- What ITS are currently being researched? (2.4.2)
- What can be expected from ITS and vehicle automation in the long term? (2.4.3)

A more comprehensive definition of ITS compared to the one provided in Subsection 1.1.2 was formulated by the European Parliament and Council (2010):

"Intelligent Transport Systems (ITS) are advanced applications which without embodying intelligence as such aim to provide innovative services relating to different modes of transport and traffic management and enable various users to be better informed and make safer, more coordinated and 'smarter' use of transport networks. ITS integrate telecommunications, electronics and information technologies with transport engineering in order to plan, design, operate, maintain and manage transport systems." (p. 1)

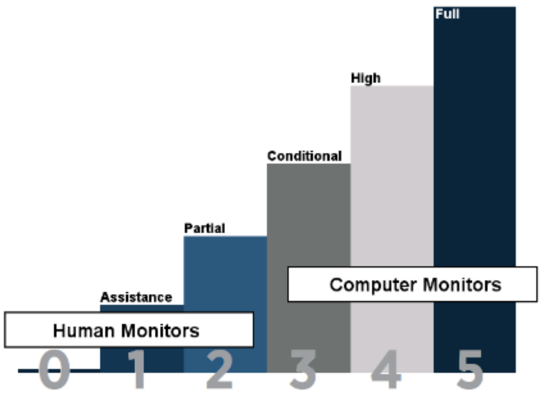


Figure 14. Levels of on-road vehicle automation. Based on SAE (2014)

More advanced ITS combined with vehicle control is called automation. The future of autonomous driving can be described by the six levels of automation in the SAE J3016 displayed in Figure 14. Higher levels of automation take over more tasks from human drivers. The first human driving tasks to be fully replaced by automated performance are the execution of lateral and longitudinal control, followed by monitoring. A possible hazard of such systems is the attention deficit caused by the simplification of the driving task (SWOV, 2012a). In the transition from level 2 to level 3 autonomous driving, monitoring of the environment is also taken over by the intelligent system. Cooperative ITS (C-ITS) can play a role in improving the monitoring of the environment, by sharing sensor information between vehicles and the infrastructure. Such systems rely on some of the technologies used today by utilising GPS data and data from counting loops.

2.4.1 Systems Currently Available

Some applications of intelligence to make passenger transport safer, more coordinated and ‘smarter’ already exist. These types of ITS can be separated based on the system they act in: the macroscopic traffic network or the mesoscopic and microscopic ITS applied inside vehicles.

Vehicle-oriented ITS mainly consists of systems that support drivers in performing small tasks on the operational level correctly. Systems of this type bring a direct benefit to the end user and usually require integration with vehicle monitoring and control. This ITS type therefore requires efforts by companies in the automotive industry more than companies in the road construction industry. Some systems, focused on improving safety or reducing environmental damage, show mainly benefits to society and not to the individual user of this system. As a result, individual vehicle owners are not likely to accept the cost of such systems. This is inhibitory for the penetration of these systems. Authorities can respond to this by making systems mandatory on new vehicles, however road construction companies have no such opportunity.

Network-oriented ITS deal with the optimisation of traffic at an aggregated level. These systems help to avoid congestion but also maximise traffic safety by providing information about closed lanes due to accidents, upcoming traffic jams and other special situations on the road. Additional to privately held mapping and navigation companies, several public organisations work together to monitor and count traffic using road side systems (Wegenwiki, 2016). The relatively high activity by governmental parties in this field of ITS can be explained by the relation to the infrastructure in these systems. Road side panels are considered public good: It is hard to exclude certain drivers from using information provided by these systems. The large target audience is positive for the potential effect, however drivers might not notice these panels or use the information provided on these panels.

The high penetration of smartphones and in-car navigation systems can be related to these systems as well: Traffic information to these systems is provided by Traffic Message Channel or over an internet connection. In-car displaying of regular speed limits and basic road work warnings is supported by newer systems, as is a split-lane display of highway off-ramps and intersections. Even systems which in first place seem unsuitable for aftermarket deployment are available at this moment: HUDWAY allows drivers to use a mobile phone to create a head-up display or HUD (HUDWAY, 2016). A study by Winkler, Kazazi & Vollrath revealed that well-designed HUD warnnigs do not distract drivers and help to decrease reaction time to dangerous situations (2015).

These aftermarket intelligent transport systems mainly operate in the vehicle pillar of sustainable safety. Network developments on the other hand, are available at the road side, current applications of ITS are limited. This is more distinct in special situations like road work zones. Road construction companies do not know how users respond to these applications of ITS or how to integrate these systems into the traffic safety plans of work zones.

2.4.2 Research in Intelligent Transport Systems

Efforts to explore and design new ITS systems are made by The European Commission (EC). The EC funded many projects which explore and develop intelligent vehicle systems (ERTRAC Task Force, 2015). To gain an insight into the future directions ITS can take, important connectivity and communication projects are described in this chapter. Literature indicates these types of systems can reduce the total amount of traffic fatalities by 25% to 50%, dependent on the rate of compulsiveness (Arem, Jansen, & Noort, 2008).

CVIS (Cooperative Vehicle Infrastructure Systems) by Kompfner et al focused on the core technologies underlying cooperative infrastructure systems (2010). The main goal of CVIS was to create a wireless vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) network with an open platform, and to increase road efficiency and safety through vehicle-infrastructure cooperation. This was done by creating a peer-to-peer (P2P) network containing nodes with similar architecture and no particular hierarchy, making the system robust and scalable. Alongside the technical developments, several deployment enablers for cooperative systems were identified; mainly focusing on accessibility, security, utility, business models and reliability.

A sister project of CVIS was SAFESPOT, a concept aimed at improving road safety by using cooperative systems (Andreone, et al., 2010). In this project, a network is formed between roadside units and vehicles using P2P connections, virtually extending a vehicle's sensors. The system, interoperable with CVIS, allows V2V and V2I communication about each vehicle's safe driving spot. Like CVIS, SAFESPOT collaborated with many different parties, helping to create technologies and platforms, applications, and studying business and legal aspects of the system.

The COOPERS (Cooperative systems for Road Safety) project used a continuous connection between vehicles and the road infrastructure. The road segment data is exchanged to increase overall road safety and enable co-operative traffic management, putting focus on road operators and drivers (Toulminet, Boussuge, & Laurgeau, 2008). Test results have shown that the system successfully increases safety by harmonising behaviour, with a larger impact for older drivers compared to younger drivers (Farah & Koutsopoulos, 2014, pp. 71-72). However, impact at different penetration levels and traffic conditions has not been tested. WILLWARN, a Wireless Logical Danger Warning system is part of PReVENT, the first EC funded ITS research project. During the design of these warning systems it was estimated that a minimum of 10-20% equipment rate is required for an effect on traffic flow, corresponding with a minimum of 6 years of market availability of the system (Schulze, Nöcker, & Böhm, 2005).

A well-known Dutch project is Praktijkproef Amsterdam (Practical Trial Amsterdam), aiming to spread traffic over multiple routes, times, modalities and parking lots by integrating smart phones, information panels and traffic lights to optimise traffic (Groenendijk, 2016). The public-private I2V partnership proved successful in effect and user satisfaction, and using existing applications was shown to be possible (Groenendijk, 2016). A similar large-scale project in the Province of North Brabant successfully countered shockwave traffic jams on the A58 by giving drivers speed advice via a mobile phone application, this project too showed a successful cooperation of private and public parties (Province of North Brabant, 2017, p. 6). Furthermore, the system showed to be scalable, transmissible and privacy-proof (Province of North Brabant, 2017, p. 6). This A58 project is part of a larger set of projects, named the ITS Corridor. This is a route between Rotterdam and Vienna which serves as a pilot for ITS and vehicle automation applications, one project of which is providing in-car road work warnings (Rijkswaterstaat, 2016c). The trajectory of the ITS corridor in the Netherlands covers the A16, A58, A2 and A67 highways.

Other practical studies in the Netherlands focused on increasing safety in unplanned temporary situations by providing Rijkswaterstaat road managers with a method to send information about accident locations and lane closures to users of the Flitsmeister smartphone app (Koenis, 2016). Road managers were positive about the use of this application, unfortunately no methodological assessment of the effect on traffic safety was performed. Scientific research regarding early methods of driver support systems showed a positive effect on traffic safety, however this was stronger for older people and usually in combination with more advanced assistance systems (Farah & Koutsopoulos, 2014; Maag, Mühlbacher, Mark, & Krüger, 2012).

Research and developments in the field of ITS focus on different methods of communication technologies: Short-range communication (e.g. WiFi-p) and longer range mobile data communication (4G or 5G). Furthermore, some research into early ITS at temporary situations like work zones show promising results in terms of safety improvements. However, it is unclear to what extent providing young drivers with simple personalized speed limits and work zone warnings helps to improve their driving behaviour and compliance with the adjusted speed limit.

2.4.3 Future of ITS

In the longer term, what can be expected from these ITS and automation developments? The level of cooperation and changes in driver opinion on driver support systems are key factors. To gain insight into the possible directions, Kennisinstituut voor Mobiliteitsbeleid (KiM, 2015) developed four future scenarios of ITS use in Dutch society. These four scenarios are displayed in Table 5 with high and full automation, and low and high levels of sharing in society. As automation plays an important role in these scenarios, Figure 15 displays the path from the current state of the art towards fully connected, cooperative and automated driving.

Table 5. Four future scenarios of personal transportation (KiM, 2015)

Auto / Share	High	Full
High	**Multimodal shared automation:** Low acceptance and developments regarding ITS. Sharing vehicles is common.	**Mobility as a service:** Public and private transport integration. Automatic vehicles available anywhere.
Low	**Letting go on highways:** In cities, humans drive like today. On highways, intelligent systems take over the driving task.	**Fully automated private luxury:** Consumers still value car ownership. ITS is applied to make travel comfortable.

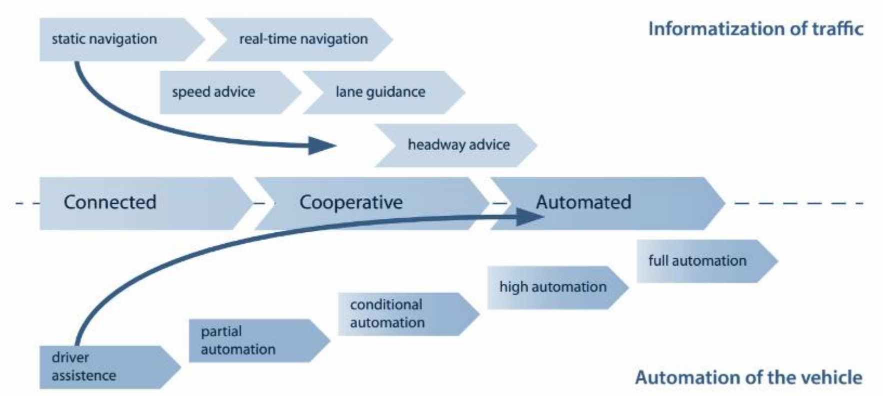


Figure 15. Integration of ITS and vehicle automation (Ministry of I&M, 2015)

2.5 Experiment Methodology

To fill the knowledge gaps as identified in the previous sections of this chapter, data is collected in an experiment. Chapter 4 presents the full methodology for this step of the research, but first this section presents literature on data collection and data analysis in order to provide insight into the advantages and disadvantages of the different methods available for gathering and working with data in a driving behaviour study. The subsections provide answers to the following questions:

- What data collection methods can be used in a driving behaviour study? (2.5.1)
- What methods for data analysis can be used in a driving behaviour study? (2.5.2)

2.5.1 Data Collection

Experiments which aim to provide data for comparison of different situations can be conducted in several ways: By collecting data of participants under multiple combinations of circumstances (repeated measures experiment) or by collecting data on separate groups of participants under different circumstances per group (between-subjects experiment). An important advantage of repeated measures experiments in this case is the lower number of participants it requires compared to a between-subjects experiment.

Furthermore, several methods of data collection can be used in a driving behaviour study. In order to test effects of a new in-car system, the interest is behaviour when the system is enabled in comparison to behaviour when this system is not enabled. For this reason, simply performing an observational study will not produce a useful dataset as this type of experiment does not allow control of the system. Instead, a designed experiment is required to analyse behaviour of drivers. Even with this limitation, several methods are available. These methods, the advantages and the disadvantages of these methods are listed below.

- ***Field test***: A real world situation is analysed. This is done either by selecting participants and driving them past work zones with and without HUD warnings, or by building a simplified version of the warnings in an existing in-car system and remote enabling it for a share of its users. This provides high validity behavioural data; however little situational control is possible. Another important disadvantage of this experiment type is safety of participants, drivers and workers might be at risk.
- ***Test track:*** At a closed track, an artificial situation is created. While still approaching reality closely if performed correctly, safety issues might still exist. Normal interference with other vehicles is hard to implement and is forced by researchers, resulting in a bias. Also, a test-track experiment is expensive, as this does not only require a real vehicle but also a closed road segment which represents real-world scenarios closely.
- ***Driving simulator:*** Tests are conducted in a fully controlled and accurately measurable environment. This allows structured testing and good comparison of performance under different conditions, even for scenarios which do not often occur or cannot occur at all in the real world. Like test-track experiments, there is some bias involved when creating the driving experiment scenarios. Other drawbacks: Behaviour might not be representative for real-world behaviour of drivers, and users might feel uncomfortable or get sick when driving the simulated vehicle.
- ***Questionnaire:*** Respondents are asked to fill out a questionnaire, possibly about videos or photos of road situations. In this type of experiments, a large sample of motorists can be reached with limited resources. A downside of a questionnaire is that it reveals stated perceptions and opinions, rather than real-world actions. This causes some bias in the results.

For this study, a test track study is simply infeasible due to the costs associated with this type of experiment. Performing a field test is more feasible when, but this requires proper cooperation with current providers of in-car systems, is limited by technology and there are safety objections. Any data collection performed in this study will thus have to rely either on a driving simulator and or on a questionnaire. More details on these two remaining methods of data collection are presented in the remainder of this subsection.

Driving Simulator

According to Blaauw, driving simulators offer relative validity: Differences between experimental conditions in the simulator have the same order and direction as the same experiment in a real vehicle (1982). Absolute validity requires equal numerical values in both types of experiment, which is not the case in driving simulator studies.

A literature review Mullen, Charlton, Devlin & Bédard showed that driving simulators offer relative validity for

- speed,
- lateral position,
- braking response,
- assessing road safety countermeasures in the real world,
- assessing complex driving behaviours in the real world, and
- physiological measures (2011).

When looking at sub categories of driving simulators, two types can be defined: Simulators in which the participant physically moves according to the movements of the simulated vehicle (moving base simulatior) and simulators which do not move (fixed-base). Relative validity of driving simulators holds for fixed-base simulators as well, as found in literature studies by Bella and by Knapper et al. (2009, pp. 121-124; 2015, pp. 205-209). Though drivers are more likely to speed in a fixed-base simulator compared to a real-world situation due to the absence of forces that provide clues of driving speed, it is this same absence of forces that results in overall more conservative driving behaviour compared to real world situations (Bella, 2009, p. 122). As a result, moving-base simulators, while less cost efficient, offer a slight advantage over fixed-base simulators when studying speed behaviour (Knapper, Christoph, Hagenzieker, & Brookhuis, 2015, pp. 205-209). According to Knapper et al., participants in fixed-base driving experiments still "were well able to distinguish between faster and slower driving" (2015, p. 207).

Questionnaire

A questionnaire can be used as the main method of data collection, or as a supportive method in a driving experiment. When relying on a questionnaire as the main source of data, adding videos to the questionnaire adds an advantage in the way information is presented in comparison to text or image-based questionnaires (Tsapi, 2015). Several supportive questionnaires were used in driving experiments found in literature. These questionnaires focused on perceived workload, stress and acceptance of the system and can be applied as part of a questionnaire research, or as a supportive method of data collection in driving experiments.

To start with, multiple methods of measuring stated perceived mental effort are available. A comparative study by Hill indicated higher factor validity and user acceptance for the NASA Task Load Index compared to three other scales: MCH, Overall Workload and SWAT (1992). However, NASA TLI contains six different scales and thus takes more time to complete when compared to the other scales, moreover there is no validated Dutch version of this test (Hart & Staveland, 1988; Hill, et al., 1992). This is a makes the NASA TLI test unsuitable: It was shown that "culture and language differences influence the measurement of subjective mental workload" (Widyanti, Johnson, & Waard, 2013, p. 70).

Zijlstra's Rating Scale for Mental Effort (RSME) deals with these issues and reduces the abstract aspects of mental workload to a unidimensional scale (Waard, 1996). The result is a continuous scale of 150 mm, ranging from 'absolutely no effort' to 'extreme effort' (Zijlstra, 1993). This scale is quick and easy to fill out, and is popular in transportation research (Waard, 1996; Brookhuis, Waard, & Janssen, 2001). The original version of this scale also available in Dutch.

Like mental effort, perceived stress can be measured in by a variation of questionnaires. Tsapi compared several questionnaires for a study on advanced driver assistance systems on driver learning and testing (2015, pp. 36-42). These questionnaires are used to form factors: Unobservable latent variables found by weighting and combining measurable indicators (Yong & Pearce, 2013, p. 80):

- ***Driver Behaviour Inventory*** (DBI, 1989): This method uses 40 statements about driving behaviour to find six scales of driver stress: driving aggression, driving alertness, dislike of driving, general driver stress, irritation when overtaken and irritation in overtaking (Glendon, et al., 1993). DBI looks at stress of the driver and not specifically driving stress.
- ***Driver Stress Inventory*** (DSI, 1996): Based on the results of various studies which used DBI, the method was revised and named DSI. DSI removes overtaking factors and constructs five factors instead of six in DBI: driving aggression, dislike of driving, fatigue proneness, thrill seeking and hazard monitoring.
- ***Dundee Stress State Questionnaire*** (DSSQ, 1998): This comprehensive stress state questionnaire contains 10 scales in three secondary dimensions: task engagement, distress and worry (Matthews, et al., 1998). The most recent version of the DSSQ contains 90 items (Helton, 2004).
- ***Short Stress State Questionnaire*** (SSSQ, 2002): Helton stated that although the DSSQ is a reliable measure of subjective stress state its length is a serious limitation, especially in applied settings (2004). DSSQ deals with this issue by constructing three factor scores from a 24-item questionnaire: engagement, distress and worry. There are two major disruptions from DSSQ: First, concentration, tense arousal and task-relevant interference sub-scale items are left out. Second, the confidence and control items loaded on the

engagement factor in DSSQ but load on the distress factor in the SSSQ. Nevertheless, SSSQ appears to be a reliable measure of stress state and has an empirical structure which is in line with old mental phenomena classifications (Helton, 2004; Helton & Näswall, 2015).

Unfortunately, none of the above questionnaires was originally designed in Dutch, nor were Dutch translations found in literature. Therefore, if one of these questionnaires is used to measure driver stress in a group of Dutch drivers, it is best to translate the questionnaire to avoid random interpretation errors by drivers due to filling out an English questionnaire.

A third topic to be covered by a questionnaire would be acceptance of the system. Van Der Laan developed a scale specifically to assess the acceptance of new in-car technologies (Driel, Hoedemaker, & Arem, 2007). This scale distinguishes between acceptance and satisfaction, and was made available in Dutch by the original author (Laan, Heino, & Waard, 1997). While this scale is called a scale for acceptance, it can be argued that when filled in before experiencing a new technology it measures attitude towards the system as participants are not yet familiar with it.

Conclusion

In conclusion, there are many possible methods for data collection in driving behaviour experiments. For this study, the methods are limited by costs and safety issues associated with real-world experiments. If data on driver perception and opinion is to be collected, it is suggested to add a questionnaire is added to the driving experiment. In case a driving experiment and questionnaire are combined, including videos in the questionnaire might not be as beneficial as it is when relying on questionnaire data only. The exact methods and designs of data collection in this experiment are defined in Chapter 4 and take into account the precise objectives of this study.

2.5.2 Data Analysis

After collecting data, various methods for analysis can be applied to find results in the data. These methods are based on statistical tests to check whether presumed effects are structural, or whether these differences may be based on chance or experimental design aspects.

Before real data analysis is performed, scores of any present latent factors need to be calculated, which itself is preceded by an analysis of internal consistency, using Cronbach's Alpha (Equation 1). In this equation, *N* is the number of items in the factor, *c* the covariance between items and *σ* the standard deviation of the values within an item (Field, 2009, p. 674).

$$\alpha = \frac{N^2 \bar{c}}{\sum \sigma_{item}^2 + \sum c_{item}} \qquad (1)$$

An alpha of .7 or higher is generally seen as an indicator for internal consistency that is at least acceptable, however the minimum alpha is dependent on the number of items in the factor and the application of the scale (Field, 2009, p. 675; Peterson, 1994).

In order to compare mean factor scores or other mean values in different conditions or for different groups of drivers, Student's t-test is normally used to determine whether or not these differences are statistically significant, however this test relies on the assumption that differences between measurements are approximately normally distributed (Field, 2009, pp. 316-320). When this is not the case, for instance in experiments with a sample size below or close to 30, it is best to use the non-parametric alternative for repeated measures experiments: Wilcoxon's Signed-Rank test. This test trades some power of the t-test for robustness (Field, 2009, pp. 552-554). A statistic is said to be robust when it performs well on a wide range of probability distributions, including non-normally distributed data (Field, 2009, p. 155). Wilcoxon's Signed-Rank test is performed by the following steps (Field, 2009, pp. 552-554):

- Calculate differences between two values per case.
- Create a total of the positive differences, create another total for the negative differences.
- Rank the differences by their size.
- Take the smallest total rank and call it the test statistic *T.*
- Apply Equations in (2) to retrieve the mean *T** and standard error SE_{T*}.
- Calculate the *z*-score as per Equation 3 and use it to find the p-values.

$$T^* = \frac{n(n+1)}{4}, \qquad SE_{T^*} = \sqrt{\frac{n(n+1)(2n+1)}{24}} \tag{2}$$

$$z = \frac{T - \bar{T}}{SE_{T^*}} \tag{3}$$

There is, by design, a 5% chance of making a Type I error (false-positive) in each test when using α = 0.05. In case multiple comparisons are made, this drastically increases the overall probability of making a type I error. A correction of the alpha resolves this issue, a Bonferroni correction is used for repeated measures experiments (Field, 2009, p. 473). This correction is performed by adjusting *α* based on the number of comparisons *n*:

$$\alpha' = \frac{\alpha}{n} \tag{4}$$

This correction leads to a rapid decrease of α when making multiple comparisons, which goes hand in hand with a loss of power. As this is unavoidable when analysing data based on multiple independent variables, it is preferred to use Analysis of Variance (ANOVA) in such cases. ANOVA was used in various driving and simulator studies (Knapper, Christoph, Hagenzieker, & Brookhuis, 2015; Brookhuis, Driel, Hof, Arem, & Hoedemaeker, 2009). ANOVA compares three or more means at once and reduces the number of tests required as well as the overall probability of false rejection of the null hypothesis (Field, 2009, p. 348). ANOVA and its derivative models require normal distributions of dependent variables in each group and it has low tolerance to missing data as it requires a fully balanced design (Field, 2009, pp. 359-360).

An alternative to ANOVA is Linear Mixed Model (LMM). LMM does not rely on independence of data: It deals with correlated within-subject errors by giving each test subject a personal random intercept, making it more likely for remaining random effects to be normally distributed and uncorrelated (Seltman, 2015, pp. 358-361; IBM, 2005). Approximately normally distributed and uncorrelated random effects are assumptions of the LMM, besides the assumption that the relationship between the mean of a dependent variable and fixed random effects is linear (McCulloch, Searle, & Neuhaus, 2008, pp. 157-179).

In other words, LMM is flexible on some points where ANOVA and its derivative models are not (Seltman, 2015, pp. 358-378):

- Correlations of errors.
- Missing data, as long as data is missing at random.
- Uneven spacing of repeated measures.

While this flexibility is a big advantage of LMM, it has an important limitation in driving simulator studies as well. LMM estimates single dependent variable models and thus cannot compare variables on a large interval in detail. This limits LMM to estimate aggregated effects in slices of the data, similar to ANOVA.

2.6 Conclusion

This chapter provided a literature review on traffic safety, driver behaviour, ITS and driving experiment methodology. The result of this literature study are several knowledge gaps, and some insights in the methods available to fill these knowledge gaps. This section offers some concluding remarks on the knowledge gaps, and presents a theoretical model which links these concepts.

Despite current traffic regulations and work zone safety precautions, highway work zones show increased unsafety for motorists and road workers compared to regular traffic or working conditions. While exact numbers are unclear, it is known that many accidents happen as a result of unawareness by drivers or by deliberate misbehaviour. Current methods to raise attention for work zones rely on road-side systems, however it was shown that drivers do not always notice these signs. ITS currently applied at work zones mainly focuses on reducing exposure by providing drivers with delay information and alternative route information, but intelligent systems that help to reduce accident risk and injury consequence are not yet fully understood.

This lack of understanding follows from the elasticity between the aimed effect and realised effect of safety precautions, which is caused by several issues:

- A gap between driver skill and task demand may show at work zones due to the reduction of safety provided by the infrastructure, lowering engagement.
- Drivers are willing to take larger risks when visible safety precautions are taken.
- Drivers are unaware of the work zone or the potential dangers involved with driving past this zone.

The gap between driver skill and task demand is larger for young male drivers, a group which in general is more risk-taking compared to older and more experienced drivers. Road construction companies are unsure about the actions required to improve optimal safety at work zones and in the future. In the meantime, large improvements can be made when focusing on young male drivers. Intelligent transportation systems can potentially contribute to these improvements. However, a combined result of the slow market penetration of new in-car technologies and the generally old vehicles driven by young drivers is that systems which come integrated into new vehicles may take many years to reach this group of relatively unsafe drivers.

The relationships between various aspects of safe driving, ITS and work zones are visualised in Figure 16. The aspects that are tested in this research are indicated by their dark blue colour, relationships that are tested in this research are indicated by the solid lines. Dashed lines and grey blocks indicate relevant parts found in literature, though these are not explicitly tested in this study. The detailed objectives of this study are presented in the following chapter.

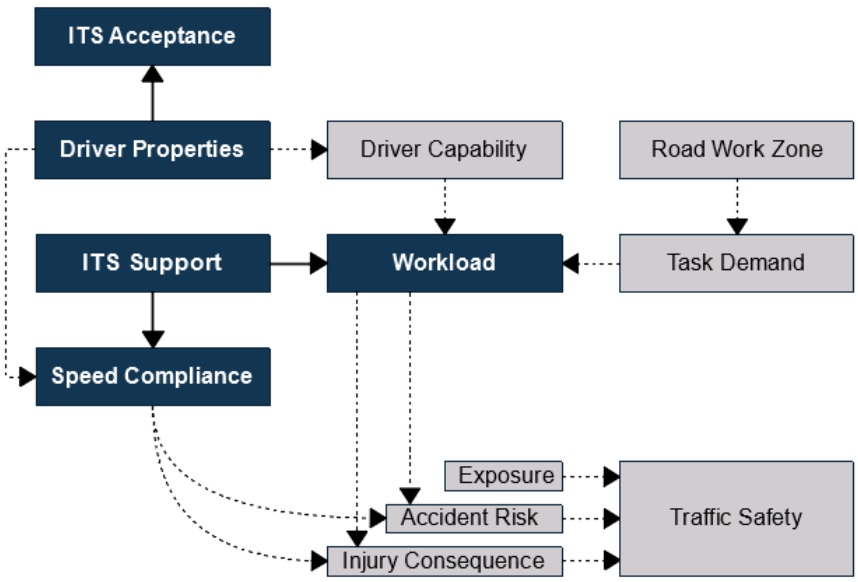


Figure 16. Theoretical model

3 Objectives

Following the literature review and the identified knowledge gaps on work zone safety, intelligent transport systems and human behaviour, objectives for this study are defined in this chapter. Section 3.1 provides the aim and main objective of this research, in Section 3.2 the research is further delimited. In Section 3.3, the research questions are presented.

3.1 Main Objective

The main objective describes the scientific relevance of this research: Gaining knowledge about traffic safety and the influence of ITS, and providing handles for future research. The aim has a more practical focus and is mostly applicable to road operators and road maintenance companies who want to use outcomes of this study in the field.

The practical ***aim*** of this study is:

Improving speed compliance at Dutch highway work zones by contributing to the development of systems that display speed and road work information inside the car.

The ***main scientific objective*** is:

To inform on the extent to which speed and road work information displayed on a head-up display (HUD) can change speed behaviour at Dutch highway work zones.

3.2 Delimitations of Research

In this section, delimitations of research are discussed.

Geographical

The geographical delimitation of this research is on a national level, to ensure the road design is uniform. Advin is mainly active in the Netherlands, so this research is limited to Dutch roads.

Road Type

For similar reasons of uniformity, only one road type is considered: highways. The issue of unsafety at work zones is highest at highway work zones. Also, current ITS deployment mainly focuses on highways and provincial roads.

The road sections within this research are furthermore considered being of proper quality with sufficient signage and clear markings.

Visibility and Traffic Conditions

This research considers road situations with clear sight and limited traffic. This is a common traffic situation on Dutch roads, however traffic might be denser at real work zones. As dense traffic reduces the ability to speed, this research focuses on light traffic situations.

Night-time traffic is outside the scope of this research: The accident risk at night is partly due to fatigue and substance abuse which cannot be accurately mimicked in experimental conditions. Thus, visibility due to night-time driving or weather conditions will not be part of this study. This delimitation inherits an important research limitation: Some road work is conducted at night-time or when visibility is limited due to weather circumstances. This study does not provide valid conclusions for these situations.

Work Zone

Work zones considered in this research are static and located at the shoulder of the road, while traffic is still allowed to use (some of) the lanes of this road. Work zones of this exact type are mostly used for short-duration road work (one day or less).

Safety within the work zone caused by work zone activities (intra-zonal safety) is not considered, as safety improvement in this field requires different kinds of measures compared to traffic safety improvements.

Time Scope

Given the interest of Advin and knowledge gaps regarding application of ITS to improve work zone safety, time delimitation of the research is for the coming 4 years: until 2021. Furthermore, it is well possible that after this point in time, vehicle automation has a noticeable effect on traffic.

ITS

Resulting from the time scope, this project focuses on the research of early ITS with potential relevance at work zones. Early ITS mainly consists of in-vehicle communication to drivers (C-ITS Platform, 2016, pp. WG1 - ANNEX 1). From these systems, road work warnings inside the vehicle and speed limits inside the vehicle are most relevant to highway work zones. In this study, it is furthermore assumed that the ITS in question is available and automatically provides the driver with perfect information about the work zone.

Drivers

A high relative accident risk was shown for young male drivers (age 18 to 24). Additionally, early forms of automation and other in-vehicle safety improvements are uncommon among this group of road users. These aspects make young male passenger car drivers an important group when looking to improve traffic safety at work zones.

Safety

Subsection 2.3.1 lists several types of safety and the related control levels. This research does not consider the exposure aspect of safety, as systems that warn users during the route planning stage are an already available. Instead, the aim is to increase the accident risk and injury consequence dimensions of safety. These risk aspects are mostly related to controlled actions and manoeuvring actions by drivers.

3.3 Research Questions and Hypotheses

In order to fulfil the aim and objective, a research question is formulated. An answer to this question is required to fulfil the aim and objective of this study. Based on the literature review in Chapter 2, a hypothesis for the research question is provided. Four subquestions are introduced to split the main research question in separate parts. Hypotheses are provided for each subquestion.

The ***main research question*** is as follows:

To what extent can HUD speed limits and warnings change speed behaviour?

The ***main research hypothesis*** is:

HUD speed limits and warnings improve slowing down in advance of work zones and reduce traffic speed at work zones.

The ***subquestions*** of this research are:

1) Do HUD speed limits and warnings improve driver compliance with the speed limit?
2) Do HUD speed limits and warnings influence vehicle controls related to speed behaviour?
3) Do HUD speed limits and warnings influence driver stress and workload?
4) What is the attitude towards usefulness and satisfaction on HUD speed limits and warnings?

The ***hypotheses of the subquestions*** are:

1) HUD speed limits and warnings improve driver compliance with the speed limit in the slow-down and activity areas of work zones by providing drivers with individual visual and audible warnings.
2) HUD speed limits and warnings influence vehicle controls related to speed behaviour by providing drivers with individual visual and audible warnings.
3) HUD speed limits and warnings decrease peak workload ahead of the work zone. Stated stress and mental effort scores do not decrease as drivers are consciously paying more attention to the work zone compared to situations without ITS support.
4) Before using the system, drivers generally have good attitude of HUD speed limits and warnings for usefulness and satisfaction, though those who would benefit the system most are expected to accept the system least. Personally experiencing these HUD warnings does not reduce acceptance of the system and may even increase acceptance for those who had low acceptance at first.

4 Methodology

User response to early forms of ITS is crucial for its success at improving traffic safety. A speed behaviour study is conducted to help answer subquestions 1 to 3 regarding the ways in which in-car speed limits and road work warnings can improve traffic safety. Section 4.1 first provides a description of the conceptual framework of this experiment, after which Section 4.2 provides a description of the design choices of the speed behaviour study and the scenarios participants encounter in the experiment. Sections 4.3 and 4.4 describe the research population, and a detailed data collection plan. Section 4.5 elaborates on the methods used for analysis of data gathered through the experiment. Finally, 4.6 concludes on the experiment methodology.

4.1 Conceptual Framework

Combining the information gathered in the literature review (Chapter 2) and the objectives of this study as described in Chapter 3, a conceptual framework is made (Figure 17). This framework describes the input and output variables for the speed behaviour experiment, and shows the presumed relationships between these variables. The presumed effects of driver characteristics on output variables is indicated with dashed lines. Workload is measured in two ways: By stated feedback of participants, and by analysis of heart rate indicators for workload. Section 4.4 presents details on the collection of output data in the driving simulator experiment.

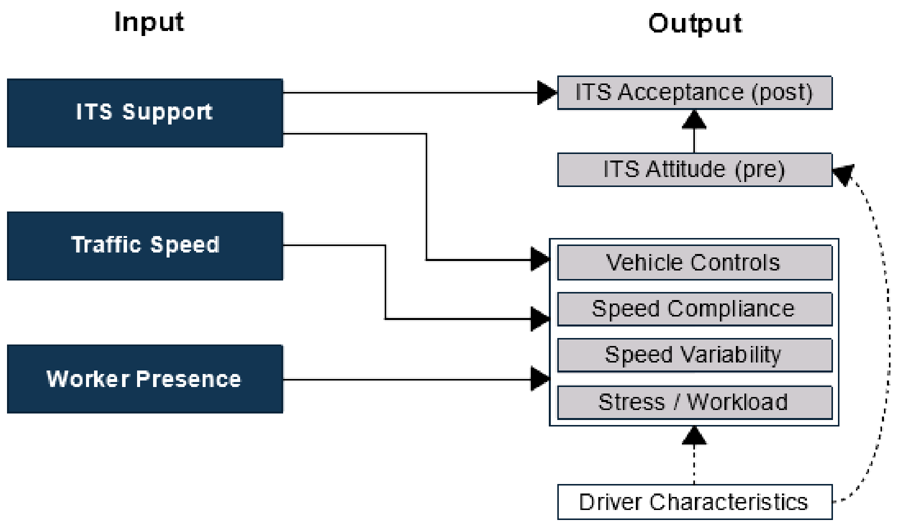


Figure 17. Conceptual framework of variables and relationships

The main interests of this research are to investigate the relationship between ITS support and speed compliance at work zones and acceptance of these systems. For validity of this study under different circumstances, different levels of traffic speed are tested. Furthermore, work zones where workers are present and work zones with no activity are included. The HUD warnings provided to drivers differ with worker presence: When workers are present at the zone, an additional worker icon is shown inside the vehicle.

Attitude towards ITS is measured before the drivers experience the system and after participants have finished driving in the simulator. This allows an estimation of the relationship between attitude and effectiveness, as well as an estimation of the change in ITS acceptance after using the system.

4.2 Driving Experiment

From the literature study on data collection methods (Section 2.5), it becomes clear a fixed-base driving simulator experiment balances cost, effort and validity. An additional advantage is the high level of control this give the researcher in controlling the details of the road and traffic situations of the experiment.


Figure 18. Green Dino simulator at TU Delft faculty of Civil Engineering

The Transport and Planning department of the faculty of Civil Engineering and Geosciences has access to a Green Dino fixed-base driving simulator. This driving simulator is used for the study, along with questionnaires to gather additional data about opinions and perceptions of participants. This way, driver feedback and changes in attitude regarding the system over the course of the experiment can be studied as well. The software in this simulator is based on the Unity 3D gaming engine, which combines visual objects and code to simulate a real-world road situation. Accurate vehicle controls are available in this simulator, set-up as a vehicle with an automatic gearbox to make driving the simulator as easy as possible. The driver experiences some physical feedback by means of chair vibrations which simulate driving vibrations and interactions between the simulated vehicle and simulated obstacles. The steering wheel of this simulator does not yet support force-feedback, a system which increases the force required to turn the steering wheel when driving at high speeds. Figure 18 shows the specific driving simulator used in this experiment.

In the pilot study, 5 participants are asked to take part in the experiment, to provide feedback and to discuss their experiences. The findings of this pilot study are then used to adjust the experiment in terms of clarity, flow and validity. In case major changes are required, a second iteration of the pilot experiment is performed. Furthermore, the pilot experiment allows the researcher to get familiar with the practice of conducting driving experiments. Data collected during the pilot experiment is used to get an idea of which data processing steps need to be taken on the full dataset. After finishing the pilot study, data accumulated in this stage of the experiment is not further considered.

4.2.1 Driving Simulator Design

For this study, a repeated measures design is most suitable, as this minimises variability introduced by researching different groups of participants, and thus reduces the number of subjects needed for the experiment. This reduces efforts required for conducting the experiment as well as efforts required to recruit participants. Important effects in a repeated measures design experiment are the influence of time and learning effects. In the data analysis phase, these effects should be accounted for.

In addition to this, the order at which participants encounter work zones is balanced to minimise these effects. In this case, the availability of ITS support at a specific work zone is counterbalanced: Half of the participants first encounter multiple work zones without ITS support, the rest of the participants first encounter work zones with ITS support. For each next participant, the set of zones in which ITS support is available is alternated. This is done to minimise the effect of different recruitment strategies and locations in different stages of the experiment. Within these two sets of work zones, traffic speed and worker presence variations are based on the same principle. Balancing the work zone specifications is done using a balanced Latin square as provided in Appendix B.

The overall design is the same for each work zone in the experiment: fixed-location, short-time planned road work zones with little adjustments to the road. Road work activity is conducted at the shoulder at a distance of less than 1.10m from the right lane. The right lane is closed for traffic, according to CROW 96a guidelines for work zones at highways. The specific design of the work zones in this experiment is illustrated in Appendix B.

Figure 19. Arrow car at a work zone in a simulator scenario

The geographical location of these simulated work zones is at the A67 between Eindhoven and Venlo. This highway has a 2x2 setup indicating that there are two lanes in each direction seperated by guardrail. The simulator representation of this highway layout and its surrounding environment were developed by PhD candidate Paul van Gent for for use in a driving simulator study in which the effect of mental effort on driving performance and physicological workload measures is measured.

The simulated road segment is split in two parts, one from Eindhoven to Someren (A to B in Figure 20), another from Someren to Venlo (B to C). Each of these two segments contains four work zones with varying ITS and road conditions as described before. Availability of HUD warnings is always the same for all four work zones within a segment. This improves the ease and accuracy at which zones with and without ITS can be targeted in the questionnaires which are part of the full experiment. Additionally, a measurement zone with no work zones or ITS is indicated with a grey line in Figure 20, this zone can be used as a base scenario for phsyiological measurements and driving behaviour in regular road conditions.

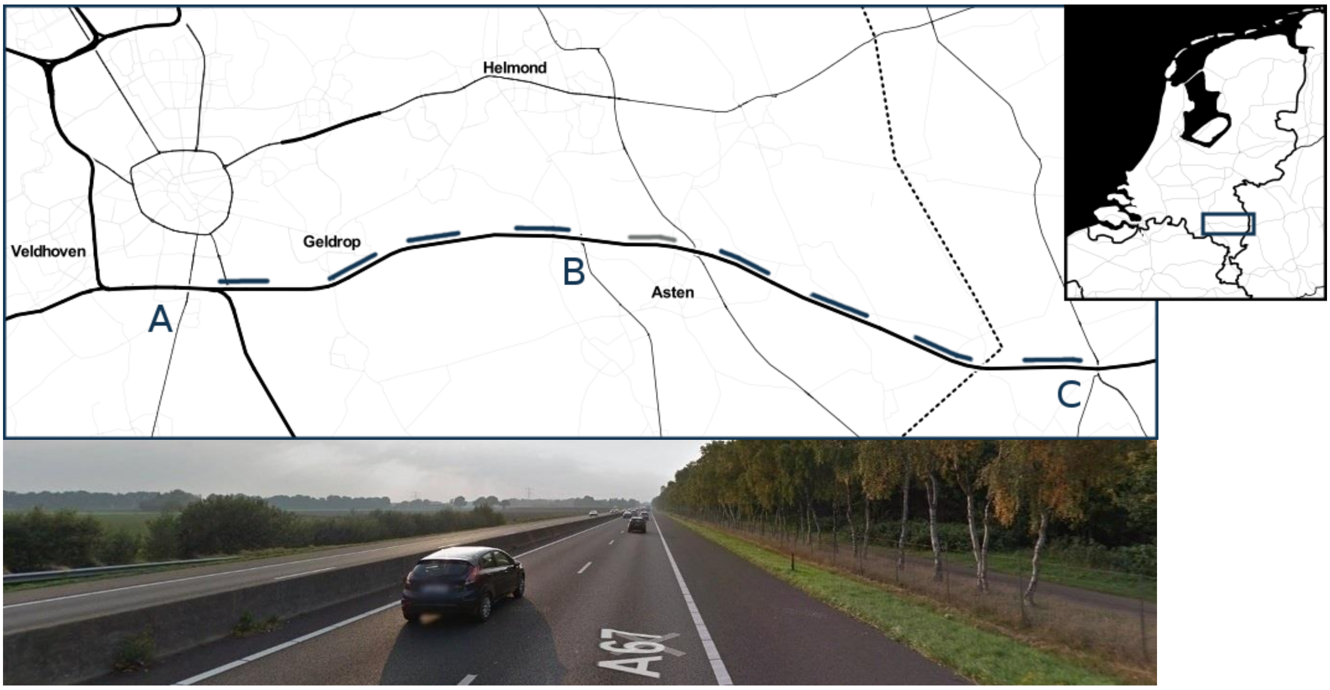


Figure 20. A67 between Eindhoven and Someren, based on Google and Stamen Design (2016; 2017)

When ITS support is included, a speed limit icon and an arrow indicating the lane closure are displayed, accompanied with a neutral warning sound. In case workers are present at the work zone, a work zone icon is displayed next to these icons.

At the pre-announcement location of each work zone, the speed warning becomes active and provides speeding drivers with feedback. The distance between different parts of the work zones is as close as possible in the different scenarios, with an accepted error margin of 5% when an item cannot be placed at a certain location due to the road design. The sign on a VMS is clearly visible at 150 m before each VMS, ITS is enabled at the same point. So, participants that pay close attention have the opportunity of seeing the VMS announcements before seeing the ITS announcement. A more detailed overview of the work zones, ITS and impressions of simulator scenarios are provided in Appendices B, C and D respectively.

Each icon displayed on the HUD is a representation of a road-side sign, to ensure easy and unambiguous interpretation (Kroon, et al., 2016, p. 21). An overview of the icons is provided in Table 6 below, distances in this table are relative to the start of the work zone.

Table 6. Overview of warning icons. Signs based on CROW (2016)

Icon	Start	Stop	Description
	-1300 m	-300 m	• Based on sign T32-2L • Simplified for HUD compatibility
	-1300 m	+450 m	• Only when workers are present • Based on sign J16
	-1300 m	+450 m	• Based on sign A2
	-300 m	+450 m	• When v_{max} > 95 for 5 seconds or more • Accompanied by neutral notification sound each fifth second (‘ding’) • Based on sign A2

The total length of each work zone is between 1710 and 1750 metres, which is a 70 seconds at the adjusted speed limit of 90 km/h. Work zones are separated by a regular road section of roughly 2.2 km with a 120 km/h speed limit, also a drive of slightly over 1 minute. Two types of traffic are simulated at the work zones: Speeding traffic (20 km/h above the adjusted speed limit) and slower traffic (driving at the adjusted speed limit). Traffic speeds vary between 117 km/h and 121 km/h in regular road conditions to simulate real world traffic and overtaking. From the point where the adjusted speed limit is visible, traffic is instructed to decelerate smoothly with a preferred deceleration of 1 m/s². Table 7 displays the possible combinations of work zone properties, more details on the work zones are available in Appendix B. Appendices C and D contain a detailed CROW design of the work zones in this experiment and screenshots of the simulator scenarios. Throughout the entire experiment, little traffic is present. This has two reasons:

1) Reduction of model effects and bias introduced by participants copying behaviour.
2) Participants are able to speed at the work zone, as opposed to situations with higher vehicle counts.

Table 7. Scenarios in the simulator experiment

	A	B	C	D	E	F	G	H
Work activity		✓	✓			✓	✓	
ITS support					✓	✓	✓	✓
Traffic speed (km/h)	90	110	90	110	90	110	90	110

The vehicle driven by participants has the appearance of a second-generation Ford Focus, the maximum speed of this vehicle is limited to 140 km/h. This speed limit was chosen because the simulated vehicle is hard to control without force-feedback steering when driving above this speed.

4.2.2 Questionnaire Design

A questionnaire is used to gain insight into driver preferences regarding in-car speed limits and road work warnings. As a computer survey is easy to fill in and allows quick error-free data processing, this is the preferred method of conducting the questionnaire. Keeping in mind the target audience of this study, the questionnaire is made in Dutch. The main parts of the questionnaire are conducted using typeform.com. Typeform allows creation of free online surveys with multiple types of input fields. The results of a questionnaire can be exported as a comma-separated-values file (CSV), which allows easy and accurate data processing. A paper copy of the questionnaire is available to use should technical issues arise.

The questionnaire is split in three parts: A questionnaire before driving the simulator, a questionnaire between the two simulator segments, and a concluding questionnaire after finishing the driving experiment. The remainder of this subsection provides the rationale behind this division as well as the contents per questionnaire part.

Pre-Driving Questionnaire

The questionnaire starts with socio-demographic questions regarding age, educational level and driving experience. These values are to be used to check the heterogeneity of participants in this sample, and to be able to distinguish between different groups of drivers.

Participants are asked about their current stress state using a stress state questionnaire as listed in Section 2.5. The stress-related question in this experiment focus on stress regarding participating in the simulator experiment at first, and about stress associated with driving in the simulator with ITS and without ITS support. Driver Behaviour Inventory and Driver Stress Inventory do not seem suitable at this point as these questionnaires focus mainly on driving behaviour. Dundee Stress State Questionnaire (DSSQ), while very accurate for measuring subjective stress, is too long and time-consuming for this simulator experiment when applied in its original form. Short Stress State Questionnaire trades a small part of DSSQ's validity for a reduction of 66 questions or 75% and is therefore chosen as the subjective stress questionnaire applied in this experiment. An overview of the validated SSSQ model and its factor structure are provided in Appendix F.

Acceptance of in-car speed limits and road work warnings are measured using the Van Der Laan scale for acceptance. Each participant is provided 9 statements: "I think a system inside my vehicle which warns me about active road works and the corresponding speed limit is…" which can be answered by picking one of five Likert-scale options. Details of this scale for attitude and acceptance are provided in Appendix G.

Between-Driving Questionnaire

After the first driving session, a second questionnaire is used to gain insights into stress and mental effort associated with this part of the experiment.

In order to measure stated mental effort, Zijlstra's Rating Scale Mental Effort (RSME) is used. This scale has a practical disadvantage: No online surveying tool which allows creation of an RSME scale was found. This scale is thus provided to the participant on a piece of paper, the design of the scale is displayed in Appendix H.

The order of the questions inside the stress state questionnaire is not changed for follow-up measurements, as there is no reason to assume that a repeated questionnaire yields validity issues. Changing the order of questions in this part of the questionnaire might however invalidate the SSSQ due to a change in perception initiated by the shuffled set of questions.

Post-Driving Questionnaire

To measure statements about stress and mental effort with and without the HUD support system, the questionnaire used after finishing the driving experiment again contains the RSME and SSSQ questionnaires.

The questionnaire is then concluded with the Van Der Laan Scale for acceptance. Being identical to the scale before experiencing the system, this is used to gather data on a change in acceptance for HUD speed and work warnings at highway work zones induced by personally experiencing this system in the driving simulator.

4.3 Research Population and Participants

As specified in the delimitations (Section 3.2), the research population of this study consists of Dutch male drivers between 18 and 24 years old. This population consists of around 450.000 people in the Netherlands which constitute 4.3% of the total population in possession of a passenger car drivers license, the share of annual kilometres driven by members of this group is lower (SWOV, 2016c; CBS, 2016c). The relative homogeneity of this research population helps to increase validity of this research with respect to the real world.

Recruitment of participants is performed in the following ways:

- TU Delft campus advertisements and in-person recruiting.
- TU Delft lecture announcements by supervisor H. Farah.
- Online advertisements (LinkedIn, Twitter, Facebook).
- In-person recruiting at other educational institutions in Delft.
- A network of personal contacts who are not inhabitants of Delft.

A sample advertisement for the simulator experiment as used on-line and at educational institutions is provided in Appendix I. As the research population consists of Dutch young males, the advertisements contain Dutch text only.

When a participant arrives at the test location, he is told that this is a driving simulator study regarding work zones. No further details are provided until the experiment has finished, to avoid bias by intentional behaviour adaption. The subject is informed via the informed consent form that several types of data are collected during this experiment. A copy of the informed consent form is included in Appendix J, it is based on guidelines from the Faculty of Behavioural studies at the University of Twente (2012). Each subject is told that he can quit the experiment at any time with no further consequences.

4.4 Data Collection

The conceptual framework in Section 4.1 presented indicators for driving behaviour and the presumed relationships with independent variables in this study. Table 8 displays these indicators and provides additional information on these indicators.

Table 8. Speed behaviour indicators in driving simulator studies

Indicator	Unit	Type	Individual
V_{85} - V_{max}	km/h	Simulator	
Acceleration (max, μ, min)	m/s²	Simulator	✓
Speed (max, μ, σ)	km/h	Simulator	✓
Vehicle controls (μ, σ)	0-1	Simulator	✓
Heart rate (μ, σ)	bpm	Physiological	✓
Short Stress State Questionnaire	-	Stated	✓
Rating Scale Mental Effort	-	Stated	✓
Van Der Laan acceptance	-	Stated	✓

The indicator V_{85} - V_{max}, is the difference of the speed exceeded by 15% of the drivers on a road segment and the speed limit on that same road segment. This percentile is an often-used measure speed limit compliance in the reviewing and planning process of traffic and infrastructure (Advin, 2016).

In order to find the indicators listed in Table 8, the simulator has a data logging component which writes vehicle data at a rate of 50 Hz. This data includes information on the position, velocity and acceleration of the vehicle in relation to the lane and in relation to the previous and next vehicle. The data is logged in the JavaScript Object Notation (JSON), which is easy to read and write for both humans and machines. In JSON, data is nested at several levels. After each participant finished driving in the simulator, the timestamp and file size of each log file are inspected to check if the log was correctly saved. An annotated log entry of the logged simulator data is provided in Appendix K.

Besides missing data, data collection is subject to another issue: floating-point imprecision. Computers use the floating-point datatype to handle decimal values without compromising speed (Borgwardt, 2017). A result of using floating-points is that it can collect rounding errors over time. In order to avoid floating-point inaccuracy issues during simulation as well as in the vehicle logs, objects may not move too far from the origin (location 0, 0, 0) of the virtual world (Thome, 2005). In the Green Dino simulator, this is worked around by resetting the origin to the location of the simulated vehicle as soon as the distance between the vehicle and the current origin exceeds a threshold value. In this case, the threshold value is 5000 m. Resulting, the total vehicle distance in the simulator always ranges from 0 m to 5000 m and then continues at 0 again.

Heart rate of participants is monitored using a Pulse Sensor fingertip heart rate monitor. This device is easy to install and can perform continuous optical heart-rate measurement (World Famous Electronics lld., 2017). The signal gathered by this sensor is a DC voltage log at roughly 100 Hz which shows the double peak created by the contractions of the right and left heart chambers. Drawing conclusions from heart rate only might be difficult, as both physical and mental workload have a clear impact on heart rate and heart rate variability. In case of mental workload, the effect on heart rate can be on either or both heart rate (positive correlation) and heart rate variability (negative corellation) (Brookhuis, Driel, Hof, Arem, & Hoedemaeker, 2009). To deal with this issue, the absolute value of the difference between heart rates is considered and stated mental effort is included as a second indicator for workload.

In this data collection phase, it is possible participants experience simulator sickness. Simulator sickness is caused by vection, which is the visual illusion of ego-movement (Kennedy, Drexler, & Kennedy, 2010). According to Kennedy, Drexler & Kennedy, simulator sickness is more common in older people compared to young people (2010). Simulator sickness is tested implicitly in this experiment as it is not expected to cause issues in the young male participants in this experiment. Furthermore, explicit investigation of simulator sickness may induce this sickness as a result of talking about sickness symptoms. In case the participant suggests he is experiencing a form of simulator sickness, the experiment can be interrupted immediately by the researcher who is sitting behind the subject at all times.

In total, the experiment takes between 30 and 45 minutes for each participant. Around 25 minutes of this total experiment time is spent driving in the simulator, divided over the two driving sessions. Between these two driving sessions, a questionnaire is conducted and the participant is offered a short break from the experiment. The total experiment duration is below the 40-minute point where effects of stress, fatigue and boredom start to play a more significant role in task performance (Szalma, et al., 2004). Furthermore, this limited driving time is preferred as effects of simulator sickness are positively related to exposure duration (Kennedy, Drexler, & Kennedy, 2010).

4.5 Data Processing and Analysis

This section describes initial processing of simulator, heart rate and questionnaire data in 4.5.1, followed by a methodology for visual inspection and statistical data analysis in 4.5.2 and 4.5.3. The methods listed in this section are based on the literature review in Section 2.5.2.

Multiple tools are used for data processing and analysis:

- ***Python***: a programming language and interpreter, the following extension packages are used:

  - ***numpy***: adds support for array objects and mathematical functions to Python,
  - ***pandas***: to handle and manipulate data structures,
  - ***matplotlib***: a 2D plotting library for quick visualisations of data,
  - ***seaborn***: a statistical visualisation library for visual inspection of data.
- ***SPSS***: to perform statistical tests.

4.5.1 Initial Data Processing

Before analysing simulator and questionnaire data, some data processing is required. In this phase, data is parsed into a format which analysed, and factor scores are constructed from separate indicators of stress and acceptance.

Questionnaire Data

Questionnaire data is available in a CSV format. The Rating Scale Mental Effort was filled out on a paper scale, these scores are measured using a ruler and added in two columns at the end of the questionnaire dataset. As the segment in which ITS support is available at work zones is changed for each next participant, mid and post-experimental answers do not correspond to ITS availability in these segments. This is changed based on the parity of the participant ID for each row in the data set, so variables can be distinguished in terms of ITS availability rather than chronological order in the experiment.

Most stated data are used to form factors for acceptance (*usefulness* and *satisfaction*) or stress (*engagement*, *distress* and *worry*). While these factors have already been constructed by Van Der Laan and Helton respectively, it is possible that they are invalid for this specific experiment. Validity of factors depends on the level of consistency between the different measured variables, for example: The diameter of car wheels is inconsistent with engine displacement, vehicle weight and torque. Therefore, the diameter of car wheels is probably not a good indicator for the factor 'maximum acceleration' and it is probably better not to include it when estimating this factor. When one does not succeed in finding consistency between several variables, this is an indication that these variables do not represent a common factor.

The Cronbach's Alpha of the pre-experimental measurements is used for determining consistency within the factor. This is expected to reduce the variation of self-reporting introduced by participants who try to compare their answers to previous answers. It has been shown that this type of variability increases Cronbach's Alpha while the actual consistency of the factor might not have improved (Field, 2009, p. 675). Factors with an alpha less than .7 are removed from the factor construct and the alpha is recalculated. Similarly, when an item has a low total item correlation it is removed from the factor. When Cronbach's Alpha is sufficiently high, factor scores are calculated using the designs of Helton and Van Der Laan, presented in Appendices E and F.

Measured Data

Simulator data is logged in the JSON (JavaScript Oriented Notation) format. While this format uses human-readable words to make a tree of nested data per log entry, it is hard to perform data analyses on data in this format due to its nested design. The data is parsed to the CSV format which is flat and table-like. Data parsing is performed using a script written by TU Delft PhD candidate Paul van Gent. During this process, three-dimensional data related to vehicle position and movement is translated to the Euclidean value: A single value which describes positional and movement data relevant to the road in the same way the gauges inside a car would display these values. The Euclidean velocity v of a three-dimensional speed in x, y and z direction is defined by Equation 5:

$$v = \sqrt{v_x^2 + v_y^2 + v_z^2} \qquad (5)$$

Due to the origin reset of the simulator, each CSV file contains a single timeline from 0 to roughly 10 minutes with a distance ranging from 0 to 5000 m which then continues at 0 again. To account for this reset and get rid of the duplicate values, the full distance in each log is processed so that a decline in distance from the origin of 4000 m or more in two consecutive log entries is corrected by adding the difference in distance resulting from the origin reset to the following values. This results in an estimation of the total distance driven for each entry in the log file. It is an estimation, because the distances to the origin do not account for lateral movements on the road or for the slight curves which are present in the A67. As this estimated total distance is merely used as an indicator for vehicle position on the route, this imprecision is not important. The locations of the pre-announcement VMSs, the start of work zones and end of the work zones are known by this same estimation with a high systematic error and a random error close to nil.

The relative vehicle position between two VMSs is calculated using the distance driven since the pre-announcement of the current work zone. Per zone, log entries starting 300m before the pre-announcement up to those 50 m after the end VMS are selected and labelled as being before or after the second VMS. Participant and zone numbers and the three indicators for independent variables are added to these logs for the purpose of identification. This leaves a single version of the clean data file per participant.

To be able to perform location-based analysis on heart rate, relevant heart-rate data is appended to each simulator data file, based on the timestamp of each log entry, with a correction factor for the structural difference in system time of the simulator and the computer used to measure heart rate of participants. Both logs contain POSIX.1-2008, which is the time in (milli)seconds since epoch (1 January 1970, 00:00:00), or in the case of the heart rate monitor: picoseconds since the Epoch (IEEE and The Open Group, 2017). Heart rate data is logged at 99 to 101 Hz and simulator data is logged at 50 Hz, so these two types of logs initially do not align. This is dealt with by combining the data using a nested index which allows multiple time points per distance, multiple distances per part of a zone and so forth. Selections and filters inside a nested index table can be made at any level or combination of levels. An example of the nested index structure is displayed in Table 9. For the sake of readability, part of the timestamp is visible in this example table.

Table 9. Example nested index simulator and heart rate data

ppid	zone	activ	its	vmax	part	dist	time	Data Type
1	**1**	**no**	**yes**	**110**	**0**	**2894.4**	**14..7996000**	Simulator
							14..8002033	Heart
							14..8017933	Heart
						2895.3	**14..8030000**	Simulator
							14..8034049	Heart
							14..8035000	Simulator

Variations in speed inside a time-based log cause a variation between consecutive distance values at different points in the log. This causes issues in further analysis as some of the tools used require an equal spread of data (see Subsection 4.5.3). This is dealt with by interpolating data on the distance level of the nested index, applying a linear spline interpolation to the data based on the distance of each log entry. The code for this processing step is included in Appendix L to demonstrate the conversion from time to distance based data, as this step is alters experiment data. Distances between the successive VMSs and between the start and end of the work zones have a coefficient of variation c_v (Equation 6) of between 1% to 2%. In the interpolation process, data is scaled so, that the distance between two successive VMS is equal to the average of this distance over all scenarios. This increases the ease at which data from the different work zone locations can be compared in following analyses. In this step, distances are converted to decimetre values, to allow high-resolution data analysis.

$$c_v = \frac{\sigma}{\mu} * 100 \quad (6)$$

4.5.2 Visual Inspection and Data Slices

Analysis of data is performed in two iterations: Visual data inspections and follow-up statistical analyses. The visual inspections are performed to explore data and to find basic patterns. Based on these patterns, detailed hypotheses for statistical tests are formulated. This subsection describes the methodology of the data analysis of both questionnaire and simulator data.

For questionnaire data, visual inspection of participant demographics is done using a histogram for educational level and box plots for values of interval and ratio measurement level. Tukey box plots visualize the distribution of data by showing indicators for the median value, quantiles and outliers. Factor scores and stated mental effort for different experimental conditions are visualised by interval plots with 95% confidence intervals. Interval plots allow visualisation of multiple scores or factors at two or more points in time with visualisation of uncertainty. In case a division in questionnaire data is made based on participant driving speed, this cannot be done on a per-scenario basis as the questionnaire dataset is too small for LMM analysis: Only two to three measurements are available per participant, this only covers the ITS variable. Therefore, an unmarked work-free measurement zone at the start of the second drive is used to estimate speed behaviour of each participant in regular conditions.

For simulator data, distance plots are made for the indicators speed, acceleration, vehicle input, and lane number. The indicator is located on the vertical axis, distance on the horizontal axis. These figures show per input variable the mean of an indicator at each point in the zone, with 68% confidence interval bands around this mean line to show the standard deviation of this value in the different measurements. Because relatively high variability of vehicle data is expected and because the number of samples is relatively low, each plot is based on a data set obtained by performing 1000 bootstrap iterations. As explained by Field, in a bootstrap sample data is treated as a population from which multiple (1000 in this case) random samples are constructed with replacement (2009, p. 163). This reduces noise in the dataset and allows calculation of the mean and standard deviation by looking at the mean and the spread of means of the bootstrap iterations (Field, 2009, p. 163). Using these graphs, a more detailed plan for statistical analysis of measured data is made. This plan contains the dependent variables tested and a specification of subsections of scenarios for which data is reduced.

Based on this plan, data is reduced in such a way that the performance of a single participant in a predefined part of a scenario represented by an individual simulator indicator as provided in Table 8 on page 32. To avoid introducing errors, these calculations are performed on the original unscaled dataset. The mean indicators as found in literature are replaced by medians to minimise the effect outliers in the small interval logs. For the same reason, minima and maxima are replaced by a 2^{nd} and 98^{th} percentile. From this point on, the 2 and 98 percentile scores are referred to as the minimum and maximum values in the log.

The raw heart rate signal requires processing as well. From the distance-based slice used to reduce simulator data, the average heart rate and two indicators for heart rate variability are calculated. To do this, the raw heart rate signal has to be filtered in such a way that peaks can be identified. Also, movement of the sensor creates spikes and noise in the log, which need to be filtered from the dataset to ensure correct detection of heart rate in a zone part of interest. The filtering and detection is performed by applying the methodology of Van Gent (2016):

1) Calculate heart rate signal rolling means for different windows (green line).
2) Find all peaks above the rolling mean (green dots).
3) Detect outliers based on detrended between-beat intervals and a threshold (300 ms, bottom chart).
4) Find best rolling mean window by minimising SDSD.

A visualisation of this heart rate detection process is shown in Figure 21. In case participants and sensors move due to high physical effort, it may be required to apply a low-pass filter to the heart rate signal before attempting to detect peaks (Gent P. v., 2016). However, this method suffices for heart rate detection in a simulator as participants did not make rapid movements as they would do in sports experiments for example.

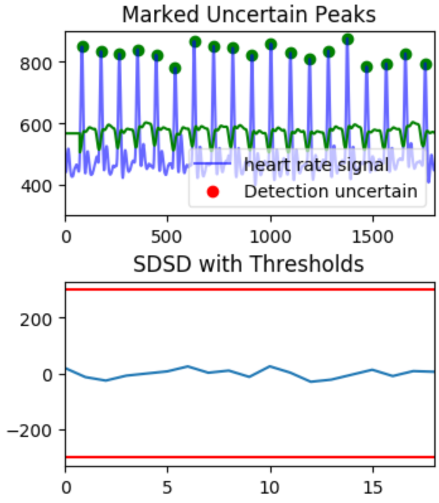


Figure 21. Heart rate detection

For variability, the standard deviation of intervals between heartbeats (SDNN) and the standard deviation of successive differences between adjacent peak intervals are used (SDSD) (Wikipedia, 2017).

4.5.3 Statistical Analysis

Several methods are used to find and statistically confirm or reject presumed effects in experimental data. Various tests are available and were discussed in Subsection 2.5.2. In this subsection, details and operations specific to statistical analysis of the data in this experiment are discussed.

As stated before, LMM assumes residuals are roughly normally distributed after fitting the model. Usually, this is confirmed by a Shapiro-Wilk (SW) test for normality. The high power of this test however, means that it might be hard to find normally distributed residuals in this experiment with 34 participants (Razali & Wah, 2011). Therefore, the histogram of residuals is inspected instead to see whether the distribution approximates a normal distribution.

For aggregated indicators of driving performance and workload in this experiment, LMM can include the three independent variables, participant ID and scenario order as well as potential interaction effects in a single model. LMMs flexibility regarding missing data allows free selection of cases on multiple criteria, even when this selection means the dataset is no longer balanced or complete. When estimating the model, the independent variables of two levels are treated as factors, and a covariate may be included to include effects of continuous variables, like speed before the work zone, when estimating the model.

The LMM parameters are estimated using the Restricted Maximum Likelihood (REML) method, a sample SPSS syntax for estimating this model is included in Appendix M. REML has some advantages over its alternative Maximum Likelihood (ML) for the data collected in this experiment: Sample size is taken into account when estimating, making it more suitable for small sample sizes. Also, REML is less sensitive to outliers in the data (McCulloch, Searle, & Neuhaus, 2008, pp. 178-179). Likelihood calculation in LMM using REML depends on the included effects, so models with different fixed effects cannot be compared by likelihood-based values (McCulloch, Searle, & Neuhaus, 2008, p. 178). Model selection therefore has to be performed in a stepwise manner: Estimating a model and changing it by adding or removing one indicator at a time. The goal of this process is to find a model consisting of only significant indicators.

In this case, the backward selection procedure is chosen, where a complicated model with all main effects and interaction effects with ITS are included at the start. This provides an overview of the possible effect sizes of each term. The insignificant term with the highest p-value for the F-test is removed in each iteration and the model is re-estimated, until all terms are significant. A downside of stepwise selection is the risk of finding a local optimum: Ending up with a sub-optimal model due to the order in which terms were removed (Seltman, 2015, p. 374). The default covariance structure settings are used: Variance components for the random effects and diagonal for repeated effects. Both these structures assume all variances are independent and thus use zeroes for the covariances (Field, 2009, p. 738). These structures help to keep the model simple, which provides advantages in this experiment: Statistical power generally decreases when more random parameters are added to the model, which can cause trouble in this small-sample experiment (Field, 2009, p. 738).

LMM is not suitable for analysis of stated data due to the low number of measurements and the design of the experiment which results in single scores for multiple scenarios with multiple levels of worker presence and traffic speed. Therefore, these analyses are based on a simpler but robust test: Wilcoxon's Signed-Rank test.

4.6 Conclusion

In order to answer the research question of this study, a better understanding on the effects of ITS on speed behaviour is required. This chapter elaborated on the methods found in literature, and applied them to design the methodology for the speed behaviour experiment in this study.

The experiment focuses on the effects of HUD warnings at work zones, traffic speed and worker presence on speed behaviour. Data is gathered by means of a fixed-base driving simulator experiment on young male passenger car drivers from The Netherlands. During the experiment, heart rate data is collected as a physiological measurement of workload. Participants drive past eight work zones in different set-ups, counterbalanced to reduce effects of experiment order.

After processing raw simulator and heart rate data, data analysis is based on visual inspections of indicators, and on LMM. LMM is suitable for this experiment and is highly flexible, as it allows including several effects in a single model, such as the order at which work zones were passed. Due to this property of LMM, missing data and the scenario imbalance caused by removing cases does not invalidate the results of the experiment.

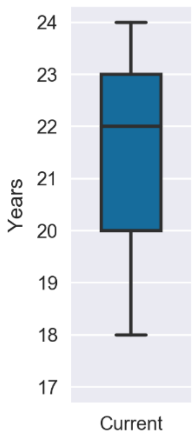
Before, between and after the two drives in the simulator made by each participant, they are presented several questions in an on-line questionnaire. These questions focus on socio-demographic properties of participants, attitude and acceptance of HUD in-car warnings, and stated indicators of workload and stress. Datasets resulting from questionnaires are smaller, and not presented for each work zone encountered. Thus, analysis of this data is based on simpler methods. These methods allow collection and estimation of driving data which helps to answer the research questions of this study.

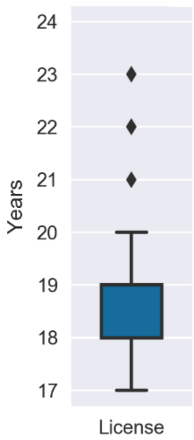
5 Results

This chapter contains visual representations of experimental data and provides results of statistical tests, based on the methods as presented in Chapter 4. Section 5.1 focuses on the demographics of participants in this study, results regarding the perception of these participants before and during the experiment are provided in Section 5.2. Heart rate measurements are presented in Section 5.3, Section 5.4 shows results of driving performance in the experiment.

5.1 Demographics

With restrictions for gender, age, language and license possession as described in Section 4.3, the participants in this experiment were expected to have fairly homogenous demographic properties. Box plots in Figure 23 and Figure 22 visualise this homogeneity by boxes and whiskers covering nearly the entire ranges of possible values: Participants of age 18 to 24 who are in possession of a drivers' license. 15 participants (44%) received their drivers' license at the age of 18, which means they have close to the maximum number of years driving experience for Dutch drivers of their age. 27 participants (80%) had less than five years of driving experience, categorised as a novice license (ANWB, 2017).





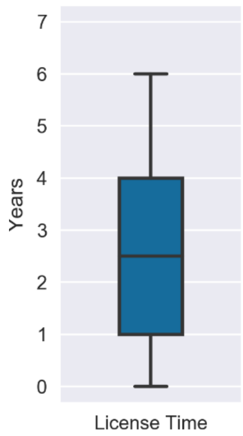
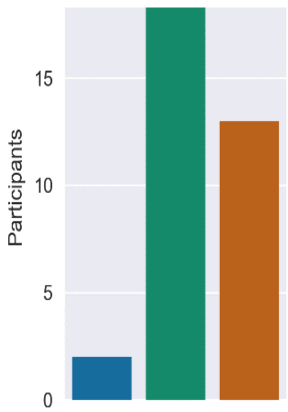


Figure 22. Left: Current age of participants

Figure 23. Middle: Age when obtaining license

Figure 24. Right: License possession time

A plot of the highest completed education of participants (Figure 25) shows a bias of highly educated participants. This is the result of intensive recruitment at TU Delft. Only three participants stated they drove more than 10,000 km in the past year (Figure 26).



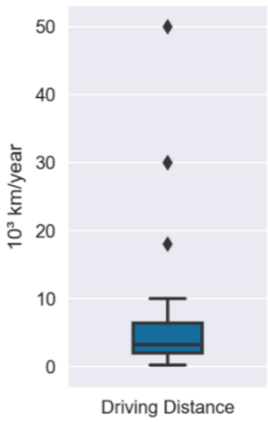


Figure 25. Left: Education of participants

Figure 26. Right: Distance driven last year

5.2 Perception

Perception of stress (*distress*, *engagement* and *worry*) and acceptance (*usefulness* and *satisfaction*) was analysed by constructing factor scores. Table 10 shows the consistency of each factor at the start of the experiment, the low alpha for *usefulness* indicates a lack of internal consistency. When the indicator for *effectiveness* is removed from this factor, Cronbach's Alpha increases to .542, which is still low. The *distress* factor has a sufficiently high alpha, however the correlation of the item *dissatisfied* is only .098 and the alpha increases by .08 when this item is removed. Therefore, the item *dissatisfaction* is removed from the *distress* factor.

Table 10. Cronbach's Alphas of pre-experiment factors, big improvements in bold

Type	Factor	Alpha	Lowest Correlation	Alpha if Removed
Stress	Distress	.786	Dissatisfaction	***.873***
	Engagement	.732	Confidence	.745
	Worry	.725	Thought about performance of others	.730
Acceptance	Usefulness	.366	Effectiveness	***.542***
	Satisfaction	.824	Pleasantness	.811

Individual stress scores vary for measurements at different points in time as well as measurements with different levels of ITS support. The score for distress is lower compared to the other two stress scores as the item *dissatisfaction* has been removed from the original factor construct. The interval plots in Figure 27 below show effect indications. As the 95% confidence intervals of different measurement points overlap these effects may very well be insignificant. Overall, these plots suggest stress increases during the first 10 minutes of driving. In the second part of the experiment, *worry* and *distress* decrease again. This is conform the expected learning effects associated with driving the simulator for the first time and being the subject in an experiment. The *engagement* score does not significantly change between the mid- and end measurements. The effect of ITS on stated stress is absent or very small, with lower stress when ITS is available. To test these results statistically, a Wilcoxon Signed-Rank was used (Table 11). Pairwise comparisons were made for *engagement*, *worry* and *distress* for three points in time and both with and without ITS support. This test has null-hypothesis H_0 and alternative hypothesis H_1:

H_0: The mean difference between the pairs of observations is zero.

H_1: The mean difference between the pairs of observations is unequal to zero.

As explained in Subsection 4.5.3, performing multiple comparisons requires an adjustment of α to bound the overall probability of making a Type I error. In this case, 9 comparisons are made, so α is adjusted to 0.006. *W-orry* decreases significantly after the second part of the experiment, but no other significant effects were found in stated stress scores.

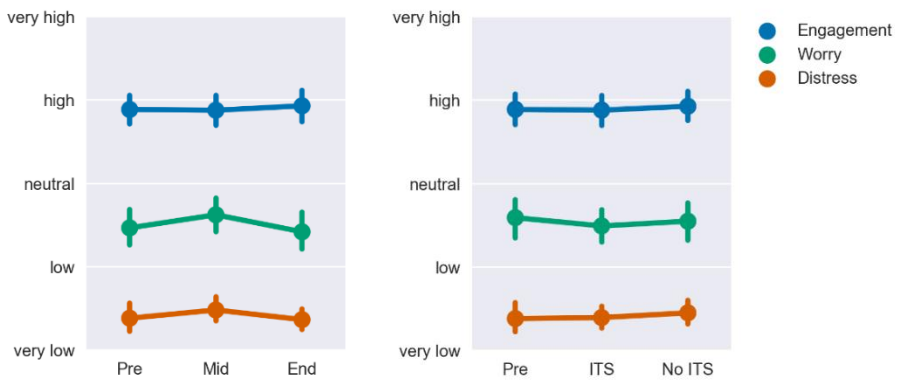


Figure 27. Stated stress scores by time (left) and ITS support (right)

Table 11. 2-tailed test statistics of Wilcoxon signed-rank results for stress (α = 0.006)

	Mid - Pre			End - Mid			ITS – No ITS		
	Eng.	**Worry**	**Distress**	**Eng.**	**Worry**	**Distress**	**Eng.**	**Worry**	**Distress**
Z	-0.829	-0.009	-1.349	-1.150	-3.100	-1.730	-0.926	-0.777	-0.703
Sign.	.407	.993	.177	.250	***.002***	.084	.355	.437	.482

An increase in acceptance of the HUD was expected from the literature findings in 2.3.3. The left plot in Figure 28 shows little effect of using the system on acceptance indicators (*usefulness* and *satisfaction*). Patterns may be clearer for those who drove above the speed limit. To test this, participants were grouped by their median speed in the first 2 kilometres of the second part of the experiment. Median speeds were used as this is a more robust statistic (insensitive to data distribution, see Subsection 4.5.2). Those who drove faster than simulated traffic in this section have a significantly lower pre-score for *satisfaction* (Z = -2.342, p = .019) compared to their score after using the system. For this group, average *satisfaction* increased from 56.6% of the maximum score to 65.4% of the maximum score, visualised by Figure 28 (Table 27 and Table 28 in App. N, p. 85).

The *usefulness* score showed to be unreliable. When nevertheless comparing *usefulness* scores before and after the experiment, no significant difference in this score was found. An analysis of the separate items of the *usefulness* scale did not return significant results after adjusting alpha for multiple comparisons (Table 29. In App. N, p. 85). Interestingly enough, participants on average rated the system as being good (86% of maximum score), but not useful or assisting (15.5% and 18.5% of the maximum score).

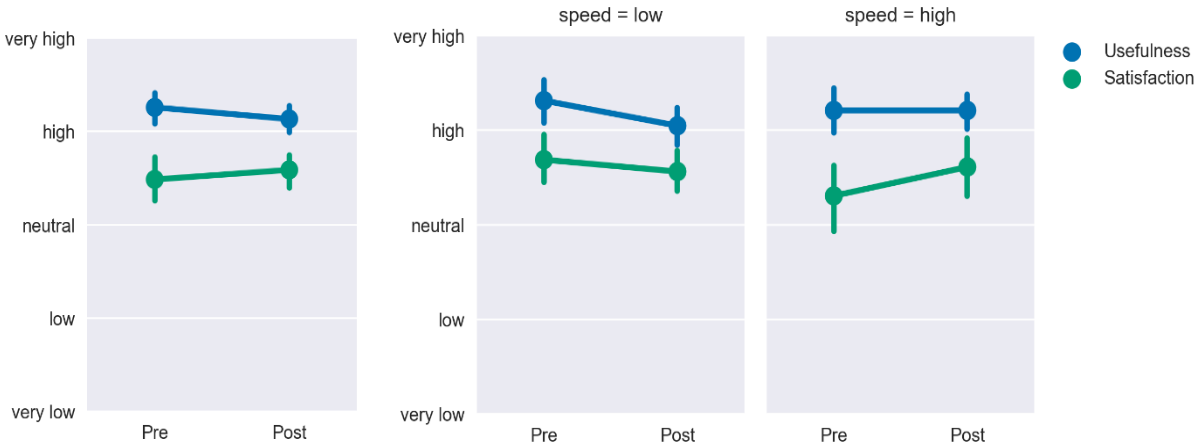


Figure 28. Stated acceptance scores overall (left) and participant average speed (mid/right)

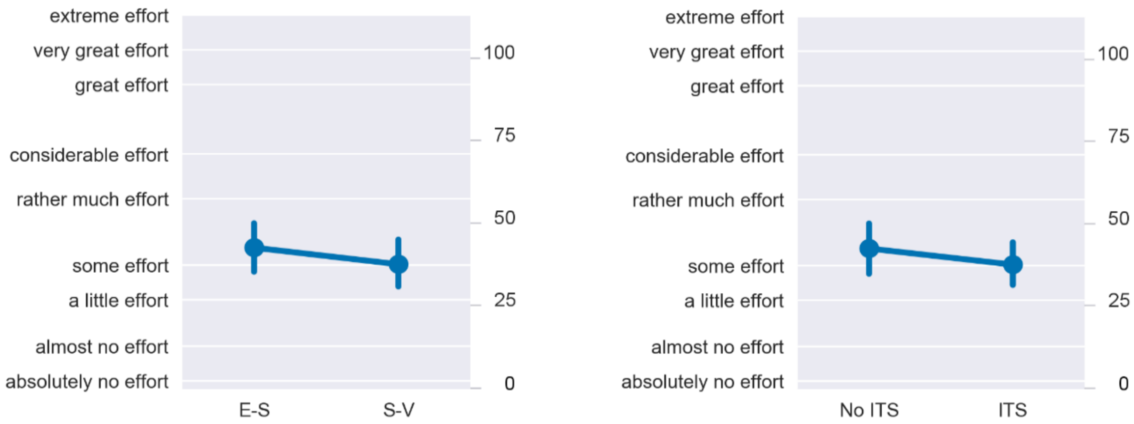


Figure 29. RSME by road segment (left) and ITS support (right)

Stated mental effort (Figure 29) decreased when ITS was used, similar in effect size to the difference in RSME between driving past work zones in the first segment (Eindhoven-Someren) compared to the second segment (Someren-Venlo). A test for difference in mean ranks (Table 30 and Table 31 in App. N, p. 85) shows significance of the difference in RSME for scenarios with and without ITS support ($Z = -2.039$, $p = .041$). On average, ITS availability lowers RSME from slightly above 'some effort' to 'some effort'.

Up to this point, median speed in at the start of the second part of the experiment was treated as a categorical variable: Participants who had a median speed which was above the speed of simulated traffic was considered fast drivers, other participants were considered slow drivers. This is a simplification of the actual speed of participants. When treating median speed in this unmarked measurement zone as a continuous variable instead, more accurate analyses can be performed. When doing so, patterns of negative self-selection became clearer: *Satisfaction*, the post-experimental score for *satisfaction* and the score for *worry* without ITS support show hints of correlations. Before plotting this graph (Figure 30 on the next page), a single outlier (participant 28) with a median speed of 138 km/h in the measurement zone was removed from the data set. The histograms on the main diagonal show distributions of each variable. A Pearson correlation test was conducted with the following hypotheses per pair of variables:

H_0: There is no correlation between the two variables.

H_1: There is a correlation between the two variables.

This test is significant for the correlation between *median speed* and the pre-driving score for *satisfaction* ($r = -.344$, $p = .050$) and the correlation between *median speed* and *worry (no its)* (again: $r = -.344$, $p = .050$). Full results are provided in Table 32 (App. N, p. 85).

In conclusion, stated stress levels of participants are not significantly different after driving past highway work zones with ITS support compared to driving past similar work zones without ITS support. Stated mental effort does decrease significantly when ITS is made available, with an average score labelled as 'some effort'. Significant correlations exist between median speed at the start of the second part of the driving experiment (to identify fast drivers) and the pre-experiment score for *satisfaction*, as well as between median speed and the score for *worry* when ITS is not available.

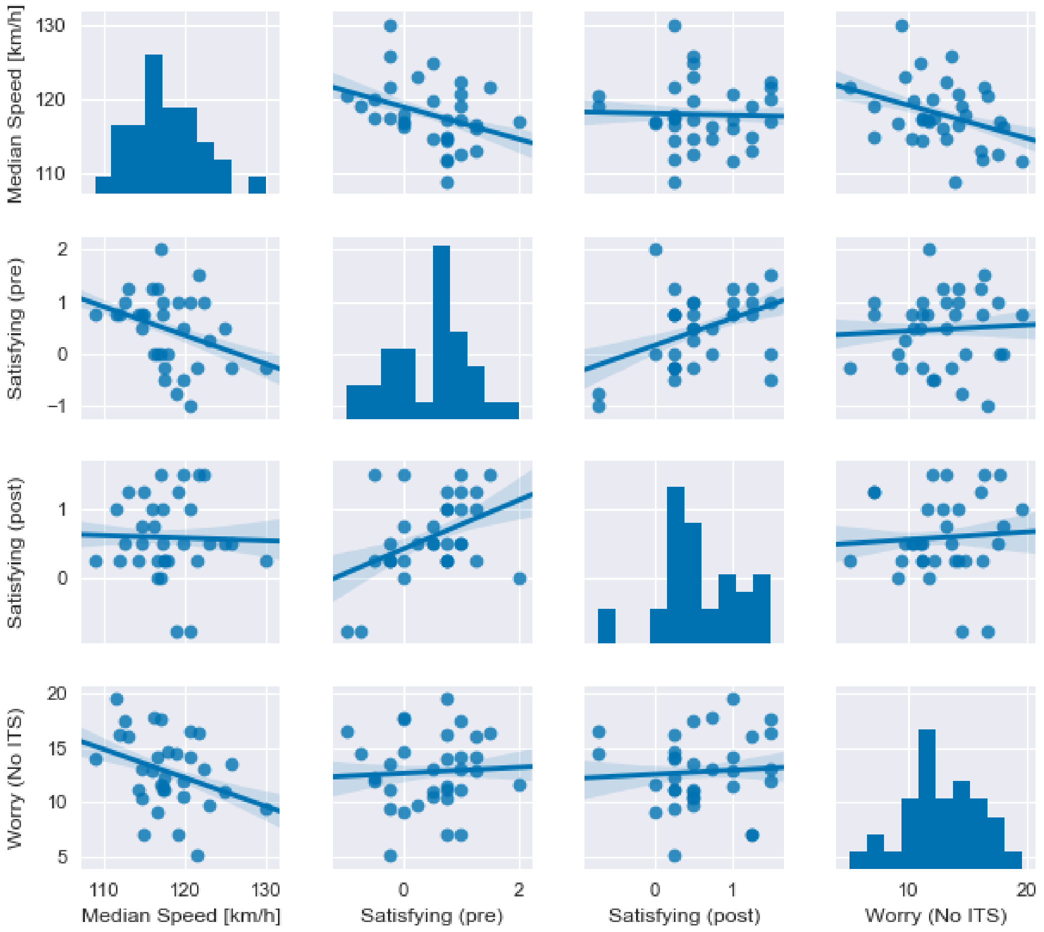


Figure 30. Comparison of speed, satisfaction and worry

5.3 Heart Rate

After subjective workload, physiological measures of workload were analysed: Heart rate and heart rate variability. These analyses were performed for data of 32 participants as heart rate logs for participants 3 and 4 were lost during the experiment. These numbers are calculated per zone part, so it is not possible to make distance plots of these indicators. Statistical analyses of beats per minute (BPM), standard deviation of beat-to-beat intervals (SDNN) and standard deviation of successive beat-to-beat interval differences (SDSD) do not yield statistically significant results for ITS or interaction effects with ITS. SDSD is on average 12% lower in work zones compared to the pre-work zone area (Table 12, residuals in Figure 49, App. P, p. 86).

Table 12. Estimated effects for st.dev of successive beat-to-beat intervals (SDSD)

Parameter	Estimate	Sign.	Number of	
Intercept	35.370	.000	**Drivers**	32
Work Zone	-4.148	.022	**Observations**	372
Pre-ann. Zone	0	-	**Levels**	16

5.4 Driving Performance

In this section, various measured indicators for personal performance are considered, two indicators for group performance: The number of collisions and the difference in the 85th percentile speed for zones with and without ITS support. Only a single rear-end collision happened, this happened in a scenario with ITS support. Due to the low occurrence, this is not considered a meaningful statistic to measure driving performance. Table 13 shows the 85th percentile peak speed and standard deviations under different circumstances. Looking at the data of all zones, a decrease of around 3 km/h in the work zones as well as the part after the pre-announcement is visible, however with fairly large standard deviations.

Table 13. 85th percentile peak speeds (km/h) and standard deviations under different circumstances

		All Zones		Selected Zones	
		No ITS	**ITS**	**No ITS**	**ITS**
Before Zone	v_{85}	119.57	116.57	119.85	116.85
	σ	11.17	10.76	11.64	11.14
In Zone	v_{85}	112.14	109.17	101.70	101.74
	σ	9.99	9.20	8.51	7.29

A speed-distance plot of the average speed of participants grouped by zone location (Figure 31) shows the course of driving speed in the slow-down area of the first zone of each segment is different to that of the other zones. LMM estimations of median driving speeds reveal that median driving speed between the 300 m and 500 m marks in zone location A1 was not significantly different to the other zones, but it did have the highest standard error in the model estimation (s = 3.04, see Table 33 and Figure 50 in App. N, p. 86). Between the 800 m to 1000 m marks of zone location B1 the median speed of participants is on average 3.1 km/h higher compared to other zone locations while the plot suggests a lower median speed in this part of the experiment (see Table 34 and Figure 51 in App. N, p. 87). The high variation for zone location A1 and the significant difference for zone location B1, indicates participants behaved different in these zones compared to the other zones in this experiment. This may be explained by participants getting used to driving in the simulator and or getting used to the HUD warning system. A1 and B1 are considered unreliable and are removed from further analyses.

A comparison of the 85th percentile in the warning and work zones is included in Table 13. At the work zone, this speed difference was not significant.

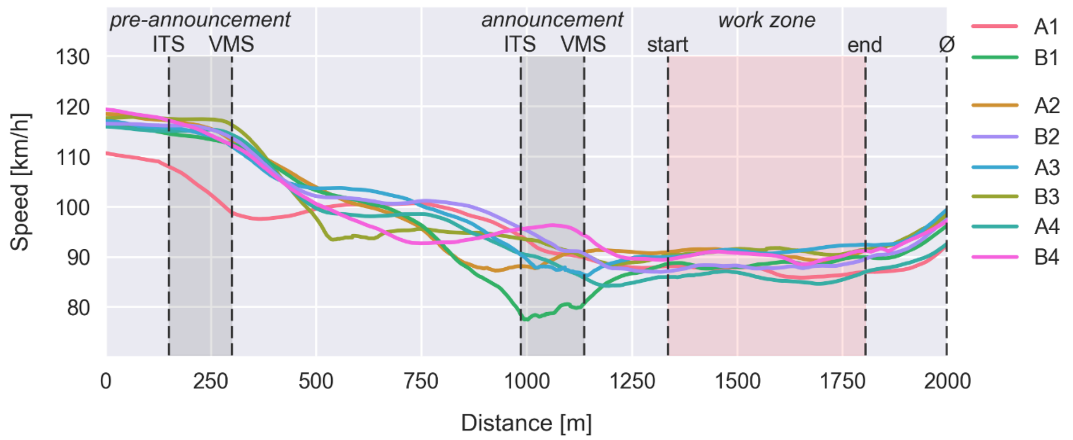


Figure 31. Speed vs distance per zone location (coloured lines)

Figure 32 shows a plot of all speed data in the experiment, this time grouped by ITS availability rather than zone location. Participants could see VMS signs clearly at 100 m to 150 m before the VMS location indicated in the plots. While the 68% confidence interval bands do not overlap in the section after the pre-announcement, the difference in speed is relatively small. Also, no speed difference is visible within the work zone. While this suggests the ITS system does not succeed in reducing speed in the work zone, effects may be larger when only participants who drove above the speed limit 100m before the pre-announcement is visible are considered, as these speeding drivers are more likely to speed in the work zone as well.

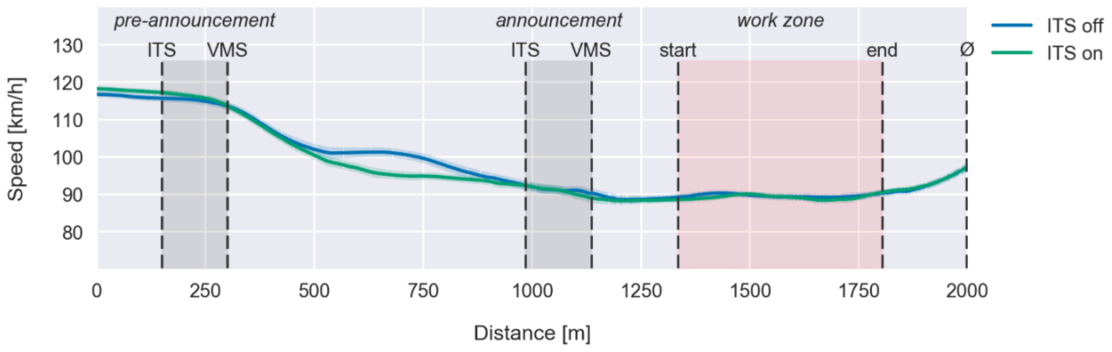


Figure 32. Speed vs distance by ITS availability, selected zones only

The gap between the ITS on/off lines in the slow-down area increased in this plot (Figure 33). 200 m after passing the pre-announcement VMS, drivers could not yet see a sign of the work zone and stopped their speed decline until traffic slowed down and the work zone items were visible. Average speeds inside the work zone are still similar.

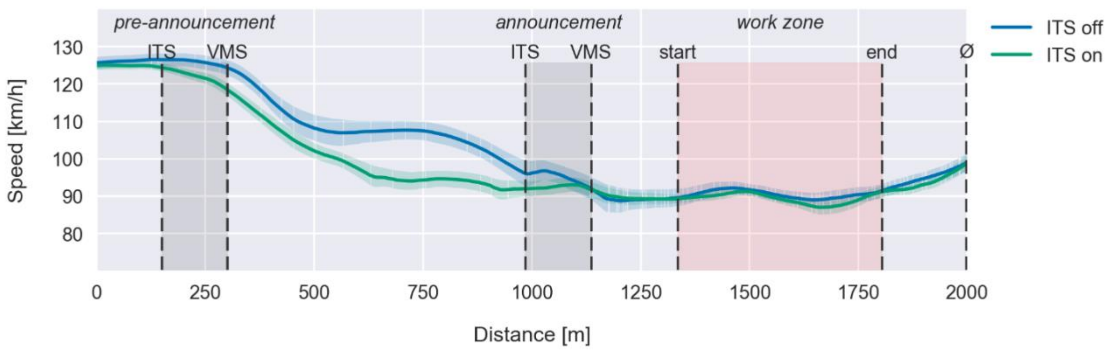


Figure 33. Speed vs distance by ITS support, 30% fastest drivers in selected zones only

When drawing individual lines for each level of traffic speed (Figure 34), scenarios with simulated traffic driving at high speeds show a higher average speed at work zones. In the slow-down area, scenarios with no ITS support show a rapid decrease in speed with an increase shortly thereafter, while scenarios with ITS support show a smoother speed reduction. Speed reduction seems more rapid when surrounding traffic is driving at a lower speed, which can be explained by the closing distance headway to the vehicle ahead.

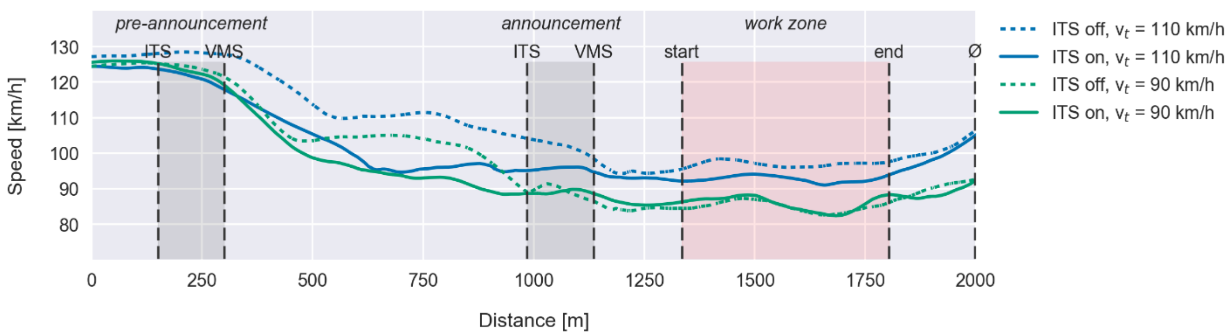


Figure 34. Speed vs distance by ITS support and traffic speed, 30% fastest drivers in selected zones

Aggregated indicators (medians, variances and extremes) per participant per zone are estimated for two parts of each scenario: The part in the slow-down area (300 to 1000 m in the speed-distance plots) and the work zone part (1350 to 1800 m). Traffic speed and (ITS availability) * (part of scenario) are significant factors in the linear mixed model, average speed 100m before the pre-announcement ITS is a significant covariate in this model. Table 14 shows parameter effects per level. The model results indicate ITS decreases average speed in the slow-down area significantly by 4.54 km/h (p = .001). At the work zone, the effect of ITS is only 0.7 km/h. Figure 35 visualises these effects for different traffic speeds (green/blue) and different speeds of participants before the pre-announcement. A histogram of residuals is presented in Figure 52 (App. P, p. 87).

In a similar fashion, the peak speed was found to decrease by on average by 3.6 km/h in the announcement area of work zones when ITS was enabled compared to measurements with ITS disabled (Table 35, Figure 53 and Figure 54 in App. P, pp. 88-88). In models for speed variance and total deceleration, the estimated effect of ITS and interaction effects with ITS were not significant.

Table 14. Estimated effects on median speed

Parameter	Estimate (km/h)	t-statistic	Sign.	Number of	
Intercept	76.638	13.572	.000	**Drivers**	34
Traffic 90 km/h	-6.094	-7.672	.000	**Observations**	408
Traffic 110 km/h	0	-	-	**Levels**	21
Speed Before	0.183	3.877	.000		
ITS Off * Zone	-5.184	-4.346	.000		
ITS Off * Pre	4.542	3.298	.001		
ITS On * Zone	-5.976	-5.019	.000		
ITS On * Pre	0	-	-		

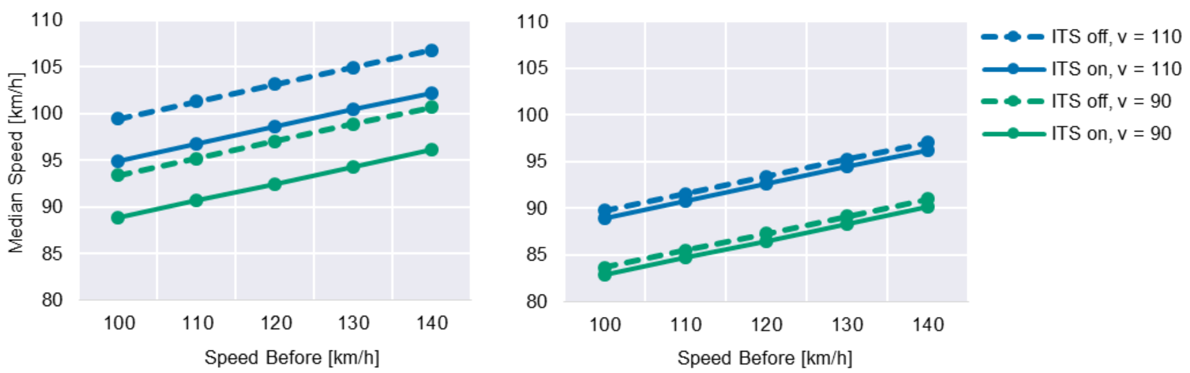


Figure 35. Estimated effects of ITS on median speed in slow-down area (left) and work zone (right)

Total deceleration in the slow-down areas was not significantly different in scenarios with ITS support was not significantly different compared to scenarios without ITS support. The course of deceleration displayed in Figure 36 shows an interesting effect of ITS. Throttle input of participants in the simulator shows roughly the same trend over distance (Figure 37). Due to the lack of speed feeling in the simulator, throttle input is considered a better indicator for driver intentions compared to acceleration. Furthermore, throttle input does not include excessive braking or interference of engine braking and collisions. The most interesting part of this graph is again in the slow-down area. With ITS turned on (green lines), throttle is released sooner and longer, resulting in smoother deceleration. At the 700 m point the lines cross, indicating that on average, participants without ITS support now apply less pressure on the throttle pedal.

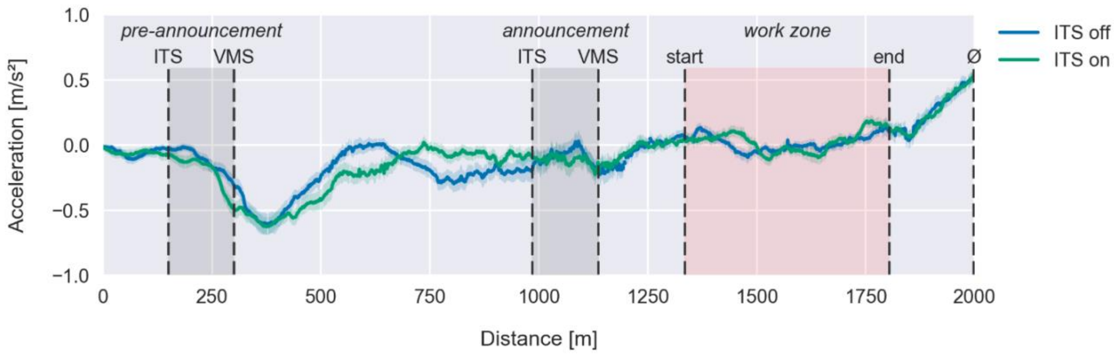


Figure 36. Acceleration vs distance by ITS support, selected zones only

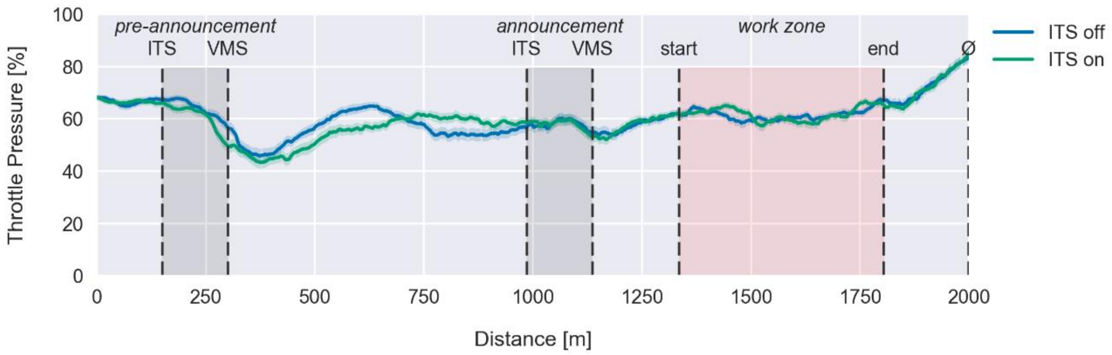


Figure 37. Throttle vs distance by ITS support, selected zones only

Average throttle pressure was analysed for two parts: between the pre-announcement VMS and the 700 m mark, and the 700 m mark and the announcement ITS location. In this model, ITS reduced average throttle pressure by 5.9% in the first part (Table 15). Vehicle speed before the pre-announcement has no significant effect on throttle pressure. The residuals plot (Figure 55 in App. P, p. 89) shows violations of the normality assumption, mainly on the left side of the distribution. Removing these cases and re-estimating the model has a small effect on the estimated effects, see Table 36 and Figure 56 (App. P, p. 89). Throttle variance between the 300 and 1000m marks was not significantly different for scenarios with ITS support compared to scenarios without ITS support.

Table 15. Estimated effects on throttle pressure

Parameter	Estimate (%)	t-statistic	Sign.	Number of	
Intercept	62.134	46.538	.000	**Drivers**	34
ITS Off * part1	-0.231	-0.120	.902	**Observations**	408
ITS Off * part2	-3.196	-1.826	.070	**Levels**	18
ITS On * part1	-6.142	-3.172	.002		
ITS On * part2	0	-	-		

Different speed and throttle patterns for scenarios with ITS and scenarios without ITS,suggest there may be an effect on lane changing behaviour as well. Figure 57 (App. P, p. 89) shows the share of participants in the left lane, grouped by ITS availability. Even though a difference of on average 50 m is visible, the space between the standard deviations of these two lines is small, and the results may be insignificant. Testing this number statistically requires intensive data processing steps and does not provide additional insights in speed behaviour at work zones, thus this was not performed.

6 Conclusions and Discussion

This chapter contains the concluding remarks on this research in four sections: Section 6.1 describes the substantive conclusions by using experiment results to answer research questions. Section 6.2 discusses these conclusions and draws the line to results in literature. Then, Section 6.3 presents research recommendations and recommendations to Advin. Finally, limitations of this study are presented in Section 6.4.

6.1 Substantive Conclusions

In this section, conclusions are drawn based on the results which were presented the previous chapter. While the results (Chapter 5) present quantitative results from the experiment, this does not provide answers to the research questions. This section presents each of the sub research questions in separate subsections and provides an answer to these questions based on the results of the experiment. Finally, the answers to subquestions are combined in order to answer the main research question and form a final conclusion for this study.

6.1.1 Speed Compliance

Do HUD speed limits and warnings improve driver compliance with the speed limit?

Analysis of simulator data indicates compliance with the speed limit at the work zone is not significantly different when HUD speed limits, merge indicators and road work warnings are enabled compared to situations with no in-vehicle warnings. Plots for different traffic speeds do suggest that for scenarios with higher traffic speeds there is a slight effect of speed reduction inside the zone when ITS is enabled, however these results were not significant.

The speed at which work zones are approached however, is significantly lower when HUD warnings are enabled: Median speed in the slow-down areas of work zones decreased by 4.5 km/h on average, peak speed decreased by 3.6 km/h on average at this point.

In conclusion: *Yes, HUD speed limits and warnings improve driver compliance with the speed limit.* This effect is however only significant in the slow-down area of work zones. The hypothesis for this sub question was that driver compliance with the speed limit improves in the slow-down area and at work zones. The hypothesis was confirmed for the slow-down area of work zones. However, despite extra warnings for those who were driving above the speed limit at the work zone, the expected improvement in speed compliance at this point was not confirmed in the simulator driving experiment.

6.1.2 Control Level Indicators

Do HUD speed limits and warnings influence vehicle controls related to speed behaviour?

The course of the speed-distance plots suggest that participants started decelerating ca. 100m sooner when ITS was enabled, and do so more smoothly when they are driving close to the adjusted speed limit. Acceleration is an indicator for this aspect of speed behaviour, and it is closely linked to the control measured by pressure on the throttle pedal. In the slow-down area, throttle in scenarios with ITS support was lower until the middle of this slow-down area (700 m mark). From this point to the second work zone announcement, average throttle was slightly lower when ITS support was enabled, but this difference is not statistically significant.

Other indicators for speed behaviour, like braking and standard deviations of vehicle measurements and pedal inputs were not significantly affected by the HUD warning system. In conclusion: *Yes, HUD speed limits and warnings do improve vehicle controls related to speed behaviour.* More specifically: Throttle pressure and deceleration improved in the first part of the slow-down area. Variations of speed, acceleration and pedal input were not different when ITS support was enabled. This is somewhat in line with the hypothesis that other aspects of speed behaviour improve when HUD warnings are enabled, although the significant effect of throttle pressure is closely related to speed compliance as addressed in the previous subsection.

6.1.3 Stress and Workload

Do HUD speed limits and warnings influence driver stress and workload?

Heart rate indicators did not differ for scenarios with HUD warnings compared to scenarios without these warnings. Similarly, stated stress after driving past work zones with the in-car warning system was similar to stated stress after driving past these work zones without the warning system.

In contrast to this, stated mental effort measured through RSME was 5 points lower when driving past work zones with the system enabled compared to stated mental effort in unassisted drives. Although this difference is statistically significant, it is a small difference on the full scale of 150 points with scores ranging from 2.5 to 95 (*absolutely no effort* to *great effort*) in this experiment. The average scores with ITS support (37.8) and without ITS support (42.7) are both at or slightly above the level labelled *some effort*.

Therefore, the answer to this subquestion is: *Driver stated workload decreased by the HUD warnings, but stress and physiological measures of workload were not different.* These effects are not in line with the hypothesis of this subquestion, which is that mental effort and stated stress do not decrease as the result of participants paying attention consciously when presented with in-vehicle warnings.

6.1.4 Usefulness and Satisfaction

What is the attitude towards usefulness and satisfaction on HUD speed limits and warnings?

Before participants experienced the HUD warning system, attitude towards *satisfaction* and *usefulness* was measured. Before the experiment, *satisfaction* of the system was on average 62.1% of the maximum score, labelled as neutral to high. Participants who drove above the speed limit in an unmarked measurement zone (at the start of the second set of scenarios) rated pre-experimental *satisfaction* closer to the neutral score (56.6% of the maximum) while those who drove at or below the speed limit were on average closer to the *high* score (67.2% of the maximum). Moreover, a significant negative correlation between median participant speed in the measurement zone and pre-experimental *satisfaction* was found. In similar fashion, a correlation between median speed and stress component *worry* after driving past work zones without ITS assistance was found. This indicates that while attitude towards the system on average is rather positive, but those who would benefit it most and those who are less worried about driving past work zones are more sceptical of the system and might be less likely to use it when given the opportunity to do so.

At the end of the experiment, *satisfaction* of the system was 64.7% on average but not significantly different to the pre-experimental score. However, the group of drivers who exceeded the speed limit reported an increased *satisfaction* score of 65.4% of the maximum score.

The *usefulness* scale was not internally consistent, indicating that this combined score is not reliable. *Usefulness* scores were slightly higher compared to *satisfaction* scores for all groups, although the dip in pre-experimental score for speeding users was not observed in this case. Comparisons of pre- and post-measurements of individual items in the *usefulness* score did not show significant differences, but did reveal that participants thought the system was good (86% of maximum score), but useless and not assisting (15.5% and 18.5% of maximum scores respectively).

In conclusion: *Attitude towards attitude towards satisfaction of HUD warnings is medium. A negative correlation between driving speed and satisfaction attitude was found.* This conclusion is in line with the hypothesis which stated that participants who drive faster have a less positive attitude towards the system and may show an increase after personally experiencing this warning system.

6.1.5 Final Conclusion

To what extent can HUD speed limits and warnings change speed behaviour?

HUD speed limits and warnings positively change speed-related driving behaviour when approaching work zones. Highly educated young male drivers have a good attitude towards the system and show higher compliance with the speed limit in the slow-down area when these warnings are present. These results hold for high and low traffic speeds and no penetration of the system in simulated traffic. Speed compliance at the work zone and other indicators of speed behaviour were not affected by these warnings. There was no significant effect of an in-vehicle road work warning in comparison to only a speed warning and merge warning.

Stated mental effort slightly decreased after introduction of the HUD assistance system, stress scores and heart rate measurements could not confirm the suspicion of a reduction in workload. Pre-experimental satisfaction of the system is good, but shows a negative correlation with driving speed in a non-work part of the experiment. Using the system further increased satisfaction of the system for this group.

Together, these properties show the potential HUD speed limits and warnings have on improving speed behaviour in the slow-down area of work zones. At work zones, behaviour is not significantly different when the HUD warning system is present. This is in line with the main hypothesis of this study.

6.2 Discussion

The previous section provided answers to the research questions, and compared each answer to the hypothesis of that research question. This section goes a step further in comparing and discussing the conclusions of this study, by comparing it to literature findings and by mentioning the similarities and differences between the conclusions of previous studies as found in literature, and the results of this study. Different from the previous section this section contains a single subsection to discuss both speed compliance and control level indicators, as there is an overlap in the discussion on the different aspects of speed behaviour.

6.2.1 Speed Behaviour

Speed behaviour in the slow-down areas before work zones improved which is in line with literature: In-vehicle warnings helped in slowing down participants ahead of dangerous zones (Farah & Koutsopoulos, 2014; Driel, Hoedemaker, & Arem, 2007). These two studies covered more advanced assistance systems: Multiple warnings and active assistance systems under various circumstances, whereas this study focused on speed behaviour of Dutch young male passenger car drivers after work zone pre-announcements. Another difference in comparison to what was found in literature is that this time, warnings were shown at the same point where road-side warnings were located. This shows the effect of adding a HUD to road-side warnings is similar to the effect of a HUD in situations with no road-side warnings. Nevertheless, in-vehicle warnings significantly improved speed behaviour in the slow-down area, presumably via increased awareness of the zone and or decreased deliberate speeding.

Deceleration behaviour was different when surrounding traffic drove at the adjusted speed limit compared to when surrounding traffic drove above the adjusted speed limit although there was a positive effect for both traffic types. This suggests the system is effective at improving speed behaviour for high as well as low penetration rates of these in-vehicle warnings.

Within work zones, no effect of ITS was found. This does not necessarily mean in-car warnings were ignored at work zones. For instance, this could mean drivers do slow down because of the warnings, but only up to 15 km/h below the regular speed limit. Also, it might be that the threshold for the repeated warnings presented to speeders should be lowered compared to the current design (5 km/h). Speed compliance at the work zone shows more similarities with the effects of congestion warnings and active congestion assistance systems in literature: These warning systems decreased mean speed when approaching congestion by 5 km/h, but had no effect on vehicle speed inside the congested road segment or in scenarios with low vision at night or due to weather conditions (Driel, Hoedemaker, & Arem, 2007).

Looking for other signs of driving behaviour improvement, following gaps usually increase by introduction of basic in-car information systems (Mazureck & Hattem, 2006, pp. 34-36; Farah H. , et al., 2012, p. 51). In this experiment, this could not be confirmed due technical limitations (see Subsection 6.4.3). Furthermore, no effects on driving smoothness were found, similar to conclusions of Farah et al. when estimating the acceleration noise of drivers for different levels of driver assistance (2012, pp. 49-50). Comparing smoothness on a larger scale, the throttle pressure results suggest the HUD system improves speed behaviour on this indicator, similar to results of Mazureck & Hattem (2006, p. 37).

Other indicators for safe driving were not significant in this study, and could not be not found in literature. This suggests these indicators were either not tested before or these indicators were tested but not mentioned by researchers.

Results of the experiment furthermore suggest drivers change lanes sooner when presented in-vehicle warnings, though these results were not statistically verified as explained in the limitations (Section 6.3.3). The last point of discussion is how several participants indicated they associated the HUD and warning sound system with speed camera warnings given by navigation systems when driving above the speed limit. This information was acquired while speaking with participants, and could thus be analysed like the formally stated feedback and quantitative measurements were analysed.

6.2.2 Stress and Workload

No meaningful differences were found in stated and measured indicators for stress and workload other than stated mental effort. Stated stress associated with taking part in a driving simulator study was mainly present in the stress factor *engagement*, where participants on average indicated to be highly engaged (80%). Pre-experimental *worry* was on average in the middle of the scale, *distress* below 10% of the maximum score. In addition, tere was no significant effect of the driver support system on stated stress indicators.

The lack of effect on heart rate and heart rate variability suggests the effects of a warning system on heart rate are different in a driving simulator compared to real road situations. In a COOPERS field test, ITS increased various measures of heart rate variability, indicating a decrease in driver stress (Farah H. , et al., 2012, p. 54). Driel and Van Arem also found a difference in mean heart rate when using a congestion assistant in a driving simulator experiment compared to driving without the congestion assistant, and showed that while the task load of driving in congestion was lower in foggy weather conditions, this did not require extra physiological effort when the congestion assistant system was active (2006, pp. 61-68). In addition to these results, Hoogendoorn et al. measured heart rate of 36 participants in a simulator driving experiment with different methods of presenting dynamic speed limits on the road-side (2012). Although there were some differences in mean heart rate for the different implementations of these dynamic speed limits, these differences were not significant (Hoogendoorn, Harms, Hoogendoorn, & Brookhuis, 2012, pp. 51-52).

In contrast to this congestion assistant system by Driel and Van Arem, Hoogendoorns dynamic speed limits did not significantly effect RSME scores (2007, pp. 61-68; 2012, p. 52). In this experiment on speed behaviour at work zones, stated mental effort did significantly decrease when HUD warnings were enabled. Through its easy interpretation, RSME is an indicator which is very sensitive to response bias. This should be taken into account when drawing conclusions on perceived mental effort associated with the HUD.

6.2.3 Satisfaction

At the start of the experiment, drivers on average stated they thought the warning system was satisfying. This is in line with results of the congestion assistance system by Driel et al. (2007, p. 149). Other studies on acceptance of intelligent driver assistance systems show similar results. Farah et al. concluded users are generally positive about co-operative warning systems, however the effect on intentions to purchase such a system is still unclear (2012, p. 51).

The various indicators for usefulness of the HUD warning system were not internally consistent, indicating that the questions did not represent a common concept. This is in contrast to previous studies using Van Der Laan acceptance scale (Driel, Hoedemaker, & Arem, 2007, p. 149; Laan, Heino, & Waard, 1997). Possible causes for this inconsistency are:

- The system in detail before handing asking participants for their opinion, this resulted in a low understanding of the system, causing a high variation between the components of usefulness.
- The target audience of this study had a different understanding of usefulness compared to those studied by Van Der Laan in 1997.
- Participants in this experiment legitimately thought in-car warnings are a good thing in general, but that these warnings are not effective or assisting to them personally.

The negative self-selection illustrated by the correlation between driving speed and pre-experimental satisfaction of the system is in line with literature findings: SWOV reported about the issue of negative self-selection for voluntary systems (2015, p. 4). As intelligent speed assistance is a more radical way of providing driver assistance and requires a financial investment in the vehicle, integration of speed advice in navigation systems is seen as a first step for implementation of intelligent speed adaptation (SWOV, 2015, p. 5). Though, it was previously revealed that I2V systems improve safe driving behaviour even for those who had low acceptance of the system, and that simulator results for attitude field test experiments yield results similar to simulator driving studies (Farah H. , et al., 2012). Combined with the increased satisfaction score after experiencing the system, this indicates in-car assistance at work zones can surely improve speed behaviour of fast drivers, although it may require some effort to ensure these people use the system.

Kroon et al. wrote that for compliance and acceptance, it is important to be credible and to provide an argument (2016). On first sight, this seems in conflict with the results of this simulator study: The effect of worker presence combined with a road work warning sign on the HUD was not significant. However, this insignificance could be due to the physical road work warning sign which was visible at the pre-announcement location (Figure 38). Furthermore, after the first work zone with ITS support, participants could expect the system to provide accurate warnings in future scenarios. As these first zones were excluded when estimating effects, users may have assumed system credibility in the scenarios that were used to estimate effects.

Figure 38. Pre-announcement of simulated work zones

6.2.4 Conclusion

Speed behaviour in this study only improved in the slow-down area of work zones. This is together with the work zone the part of work zones where most crashes occur (Yang, Ozbay, Ozturk, & Xie, 2014). Even though the lack of effect on speed compliance at the work zone may limit the advantages of these in-car warnings on traffic and worker safety, speed behaviour is influenced by HUD warnings. According to a literature study by Arem et al., in-car speed limits can lead to an 8% to 25% reduction of fatalities dependent on the type of warning and situation (Arem, Jansen, & Noort, 2008, p. 38). This is in line with Finch in Mazureck and Van Hattem who found that a 1 km/h reduction in average speed roughly relates to a 3% reduction in the number of injuries associated with that group of drivers (Mazureck & Hattem, 2006, p. 37). If these results hold for the slow-down areas of work zones, in-car warnings have the potential to significantly improve traffic safety at highway work zones. Furthermore, the improved speed reduction can reduce the number of head-tail collisions at work zones, although no quantifications of this effect were found in literature.

Pre-experimental attitude towards the system is sufficient when compared to attitude towards active driver support systems, however attitude of fast drivers is low compared to attitude of those who are not fast drivers

(Brookhuis, Driel, Hof, Arem, & Hoedemaeker, 2009, p. 6). This asks for a proper implementation plan for these warnings, to ensure the right drivers use the system.

6.3 Recommendations

The results and conclusions of this study, and their relations to previous research projects provide insights in speed behaviour. It was shown that in-vehicle warnings at work zones significantly reduce the speed at which young male drivers approach these work zones, and smoothens the course of deceleration. While there is no sign of negative effects of the system, the goal of improved speed compliance at work zones was not realised. This suggests that implementing the at future work zones can improve traffic safety, but only by a limited amount. The effects of information presentation and effects on drivers with different backgrounds are not yet known. The following subsections are devoted to implementation recommendations of this study, recommendations for future driving simulator experiments, as well as content recommendations for future research.

6.3.1 Implementation of Results

This study has shown that it is possible to reduce traffic speed sooner and smoother in the slow-down areas of work zones by presenting HUD speed and merge warnings. This increases traffic safety in this area, and potentially reduces the number of head-tail collisions and the number of vehicles driving into work zones by accident. On the contrary, the main goal of improving speed compliance at work zones is not fulfilled with the HUD system of this study. The HUD warning system does not show potential to achieve this goal.

Should further steps for implementation nevertheless be made, attitude towards this voluntary system is a key aspect. In general, attitude towards the system was good, but those who would benefit most from using the system had a lower attitude towards satisfaction compared to those who drove more slowly. However, combining the system with something which provides users with a directly perceivable benefit helps to increase acceptance (Kroon, et al., 2016). Navigation and speed camera alert systems are examples of systems which are used for direct personal benefit. Flitsmeister provides over 1 million Dutch road users with real-time speed camera warnings on mobile phones and as of recently provides location-based warnings for upcoming incidents, ambulances and work zones (Flitsmeister, 2016). Working together with Flitsmeister to add the right type of warnings for highway work zones to their system brings these warnings to a large number of road users who choose to use an application to avoid speeding tickets. This experiment and previous studies showed that even these fast drivers slow down when presented in-vehicle warnings, and satisfaction of the system increases to levels between medium and high after using the system.

As stated in guidelines for design of in-car information design, it is important to present drivers with accurate and reliable information in order to avoid confusion and to maximise acceptance and compliance (Kroon, et al., 2016). Furthermore, literature research revealed that providing proper information about work zone when drivers are still in the ability to avoid driving past a road work zone can improve safety by effecting strategic decisions of drivers. To use these benefits, the possibilities to share detailed and up-to-date road work information with the different private parties involved in route planning and in-car traffic information systems should be researched, and yield many potential benefits at low effort. Furthermore, it is suggested that the possibility of including the real time in-car warning system in existing navigation and traffic information devices is explored.

Solutions that bring head-up displays to currently existing vehicles are available; however, this currently requires drivers to purchase and install this system, something which (fast) drivers are not likely to do (HUDWAY, 2016). The HUD system was received positively by participants in this study, and the safety benefit of a HUD is clear: Drivers do not need to move their eyes off the road to look at information. Furthermore, a device which uses a mirror so the mobile phone display turns into a HUD requires drivers to place their mobile phone on the dash board with the display set to mirror mode. A mobile phone set to HUD mode and laid down on the dash board cannot be used for messaging or social media distraction of the driver, which is seen an increasing threat to road safety (SWOV, 2016a, p. 6). In order to remove the barrier of using a mobile phone as a HUD, these simple devices may be distributed by road construction companies or a joint effort with Rijkswaterstaat as a promotional item or as part of a campaign.

It may be however, that companies involved mainly with infrastructure are not looking to get more involved with current in-car assistance systems as this is too far away from their core business. In this case, a speed reduction in the slow-down area of work zones can be realised by placing more signs in the slow-down area. In this experiment, when drivers had no HUD warnings most of the speed reduction happened close to a VMS, with little to no speed reduction in between. This suggests that it is not just the in-car aspect of the system that improves speed behaviour, but also the fact that these warnings are presented to drivers throughout the entire slow-down area. Furthermore, visibility of danger has shown to slow drivers down, and visible safety stimulates compensatory speeding. Therefore, speed compliance at the work zone may be improved by ensuring this area is clearly visible to drivers, or by at least making an effort to reduce the amount of protection and safety measures that are visible at work zones.

6.3.2 Research Recommendations

Additional to the recommendations made for implementation of an in-car warning system and other suggestions for reducing traffic speed at work zones, several recommendations for future research are made in this subsection. These recommendations are not limited to any specific company or researcher, but instead aimed at all involved in traffic safety, road work and or in-car warning systems.

Road Users

This study focused on speeding behaviour by young male drivers, and most participants in the experiment were highly educated. While previous studies suggest similar effects for other groups of passenger car drivers, it would be good to focus on different groups of drivers in future studies. For instance, elderly drivers and truck drivers are two groups of drivers which may respond in a very different way to in-vehicle warnings compared to the young males in this experiment.

For truck drivers, the vehicle properties and their location on the road might play an important role as well. While truck drivers are less likely to speed at work zones, they are currently more often involved in crashes at road work zones compared to passenger car drivers (SWOV, 2010). Thus, possibly truck drivers respond better to different warnings.

Road Conditions

Different road and traffic conditions require more research as well. This study looked at very specific conditions: Daytime work zones on a highway, while in reality work activity is often performed at night. This has effects on user attention, and visibility of road-side warnings, and may thus alter the effect of warning systems. Again, the best type and timing of warnings might be different in these situations, and it may be beneficial to present different warnings in different conditions.

Furthermore, the effects of the current warning system at work zones on provincial roads remains unknown. While work zones on this road type are relatively safe compared to highway work zones, improvements can probably be made at these zones. As the design of these work zones can be very different to the design of highway work zones, current results may not hold in these situations.

Work Zone Design

Work zone design choices unrelated to in-vehicle warnings are currently designed based on experience and literature, but no specific scientific testing of scenarios is conducted. It is suggested that CROW 96a guidelines are experimentally tested for safety, and that future changes to these zones are based on research. For safety of all involved in these work zones, it is suggested that experiments of new work zone design modifications are first performed in a driving simulator, however collecting data at real work zones provides the opportunity to expand the insights in these guidelines and in validating driving simulator experiments at road work zones.

Furthermore, from the viewpoint of hasty road users it is suggested to investigate the effects of increasing the adjusted speed limit to 100 km/h in case no workers are present in the work zone. When using in-car and VMS warnings, it is technically possible to adjust the speed limit when the work zone is inactive. While higher traffic speeds in itself do not improve traffic safety, this adjustment may lead to more homogenous speed behaviour and increased acceptance and compliance of the adjusted speed the work zone. This change can also be made without the application of in-vehicle warnings, if all road-side signs are VMSs or DRIPs.

Warning Presentation

The previous parts of this subsection already suggested to investigate the effect of in-vehicle warnings in other conditions and on other groups of road users. In such tests, it would be good dive deeper in to the effects of different warning presentations and presentation locations too, as this is one of the advantages of HUD ITS warnings over road-side warnings.

This might yield further benefits, as the warning presentation at work zones in this experiment might not have been pressing enough to some drivers, while personalisation of warnings is something ITS excels at. but also because current design guidelines for work zones and in-vehicle warnings are based on the needs of the average road users. Intelligent in-vehicle systems have the possibility to present personalised warnings to drivers, which creates the opportunity to present each driver with a warning design which is optimal to him or her. In this direction, more research is needed in the direction of personalised warnings and possibly the application of machine learning algorithms and traffic safety.

6.3.3 Driving Simulator Experiments

This simulator study focused on a specific combination of road, work, drivers and ITS, so its effects may not be valid under all circumstances. For increased validity in different circumstances, it is suggested to conduct more research on traffic safety at work zones. To automatically present drivers with the warnings that best suit their needs.

For such future studies, simulator research shows good potential. While only relatively valid, simulators provide a highly controllable environment with high safety and low cost. Acquiring a full driving simulator would not be required to compare traffic safety for different work zone situations or to study the effects of different implementations of assistance systems. The use of a virtual reality headset in these studies should be investigated, as this may improve the feeling of reality in the driving simulator while limiting the costs associated with the driving simulator experiment.

In-house knowledge about traffic, infrastructure and 3D cannot only be used to test future scenarios, but it could also be applied to expand the 3D views of projects which are currently presented to clients with a driving experience in an early stage of projects.

6.4 Limitations

In the **de**limitations (Section 3.2), constraints on location, road type, road conditions, time scope, ITS and drivers were discussed. These delimitations still hold, however the design of this experiment and technical imperfections result in additional limitations. This section discusses these additional limitations.

6.4.1 Experimental Design

Most limitations resulting from the experimental design of this study have already been addressed in Chapter 4: A simulator is different compared to driving in a real vehicle on a real highway, and repeated measures experiments are more susceptible to the influence of learning and exhaustion effects compared to experiments with multiple samples. A counterbalanced design in which participants are tested under multiple conditions with ITS support as well as multiple conditions without ITS support was used to minimise these effects, furthermore LMM attempts to deal with remaining imbalance in the experiment.

As stated by Bella, all driving simulators need to be thoroughly validated before being used in experiments (2009, p. 125). No such validation for the Green Dino driving simulator used in this study was found. However, results of speed behaviour in the experiment are in line with previous driving simulator experiments and field studies on the effects of in-vehicle warnings on driving speed (Driel, Hoedemaker, & Arem, 2007; Farah & Koutsopoulos, 2014). While this does not show full relative validity of this driving simulator experiment, it can be seen as a first step in this validation process. This assumption of relative validity of results means that effect and direction of effects dependent variables would be the same in a repetition of this experiment as a field test.

Regarding the design of scenarios in the driving simulator experiment, there are some limitations to this study: To start with, only one type of work zones was tested on a two-lane highway. More specifically: The A67 between Eindhoven and Venlo. While this highway as well as the work zone were designed following the Dutch standards, several aspects limit the validity of this experiment. First of all, the virtual A67 is not representative of its real-world equivalent in terms of road-side details and speed limit at parts with no work zone. Second, to fit eight work zones into this short experiment, the density of work zones was quite high: On average, each work zone scenario had a length of 1718 m ($\sigma = 22$ m), the space between zones was 2213 m on average ($\sigma = 152$ m). Several VMSs had to be relocated or added, resulting in a high number of VMSs in the experiment compared to actual road situations. Third, the width and design of work zones on this highway section is quite specific and provides a small barrier between traffic and the work zone. The unsafe appearance of these zones is likely to initiate less compensatory behaviour by drivers compared to work zones with more thorough protection and wider lanes (Reyes, 2008; Akerstedt & Kecklund, 2001). Work zone designs with more compensatory speeding behaviour might therefore show larger effects of the ITS system as drivers are more likely to speed in these work zones.

The simulated work zones have several properties that form limitations for the experiment. The first of these properties is the variation of distances between zones and zone parts (coefficient of variation of 8% or less) when compared over the eight different zones (Table 19, App. D). The second simulated work zone limitation are the slight lateral differences between the zones, most importantly the pre-announcement of work zone 1 which is placed shortly after the exit of a 15° bend in the road. However, this zone was excluded in the data analysis phase as it showed unreliable driving behaviour by participants.

Another limitation related to the design of this experiment is traffic. Traffic in this experiment was modelled to make decisions based on the same criteria as human drivers. However, these models simplify real human behaviour drastically. A result of this is that on- and off ramps are not used by modelled traffic. Another implication of this traffic model is that these vehicles follow instructions designed by the researcher at work zones. This results in absence of certain actions encountered on the real road (such as overtaking on the right) and limits the model to a single level of moderate traffic intensity.

A limitation related to the experimental design but not to the simulator set-up, is that results in this study follow from a repeated measures experiment. While compensating for learning effects by a counterbalanced design and LMM data analysis, no clear trend was found in speed behaviour over the different work zone locations. However, as speed behaviour is significantly different for the second, third and fourth time drivers used the system compared to driving, it can be concluded these warnings are effective quite quickly after deployment. As the work zones and traffic behaviour were similar, but not equal for the different work zone locations, no learning effects of the ITS system were estimated.

Most of these limitations are well-fit for an experiment set-up with consistent scenarios and participants, leading to high reliability. However, the homogeneity of the experiment limit the validity of results at real work zones.

6.4.2 Participants

This research was targeted at young male drivers, as discussed in Section 3.2. This limits the external validity to other groups of potentially slower drivers. 34 participants took part in the experiment. For reference: Other driving experiments had between 15 and 80 subjects (Farah & Koutsopoulos, 2014; Knapper, Christoph, Hagenzieker, & Brookhuis, 2015; Brookhuis, Driel, Hof, Arem, & Hoedemaeker, 2009). While this may seem on the low side compared to other types of research, a larger sample is not feasible because of the effort required by researcher and participants when conducting a driving simulator study. As larger samples are more likely to have normally distributed residuals, LMM may perform better on larger datasets and an increase in the number of participants may result in finding more significant effects.

Looking at the distributions of driver properties, it becomes clear most participants in this study received their licenses at age 21 or below. This is in line with expectations as both the age of participants as well as the year in which they have received their licenses are bound to an upper limit. When these two distributions are combined, it results in a distribution which is thin towards the top. Another large effect here is the possession rate of drivers' licenses in the Netherlands: As Figure 39 shows, it is very common for people in the Netherlands to receive their drivers' license before the age of 25.

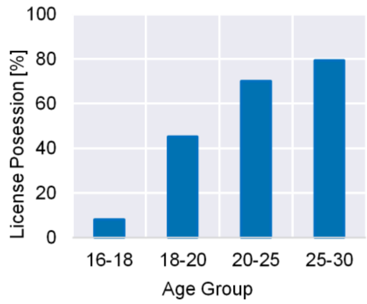


Figure 39. Dutch drivers' licenses by age group (CBS, 2016b)

Participants were not financially compensated for taking part in the experiment, so most successful recruitment was performed at TU Delft campus and amongst acquaintances of the author. As a result of this, most participants in this experiment were highly educated. All but three participants indicated they drove 10,000 km or less last year, this seems in line with the low car ownership rates of young drivers and in special students in the Netherlands.

Familiarity of participants with driving simulators or the A67 was not asked in the questionnaires provided to participants during the experiment. Therefore, it is not possible to control for these factors when analysing the data. Yet some participants mentioned using a driving simulator for their first driving lessons and one participant said to be an enthusiast racing simulator driver.

In conclusion, the participants in this study are a fairly homogenous group, which increases the experiment reliability but limits external validity of this study. There are no specific indications that educational level in young males can be used to predict driving speed, but there are indications that intelligence is inversely correlated to vehicle accident mortality (O'Toole, 1990). Finally, as familiarity of participants with driving simulators or the A67 is unknown, the bias of these factors on driving performance and its effects on the outcome of this study remain unknown.

6.4.3 Technical

When conducting the experiment and analyses some technical issues were encountered, resulting in additional limitations to this study. Most of these issues were the result of using a driving simulator which was still under development and was not used in an experimental setting before. Some of these obstacles were identified during the pilot experiment, however not all obstacles could be adequately fixed in time. These technical limitations can be divided into two groups: simulator limitation and data limitations.

Drivers experienced several technical limitations while participating in this experiment. While the exact effect of these limitations on the outcome of the study remain unknown, these limitations did not seem critical to the experiment. Although the steering wheel did not push back as the drivers moved the wheel more quickly, this was not immediately obvious to those operating the simulated car. Yet, an effect of this limitation is that it was harder to drive in a straight line and steer slowly at high speeds. The second technical simulator limitation was directly noticeable: Glitches in the traffic model caused odd behaviour of simulated vehicles in some situations. Two types of odd traffic behaviour were noticed in the experiment: Abrupt lane changes, and cases in which simulated traffic lost track of the virtual lane and drove away from the road through the guardrail between the two carriageways. This happened at least once for most participants, but always outside of measurement zones. Participants were informed about the possibility of encountering this glitch before driving in the simulator. In one case the participant's vehicle was rammed from behind by one of the vehicles which had lost track of the virtual lane. Except for this collision, participants did not visibly panic when these glitches occurred, this it is assumed that this decreased the level of empathy of participants in the smiulator.

During the experiments, the simulator logged vehicle information at a rate of 50 Hz. One aspect of each log entry is the distance headway between the subject vehicle and the vehicle ahead. This headway value is based on the virtual lanes in which the subject and simulated traffic were driving at the moment that log entry was being created. The issue is not in the lane numbers 0 and 1, but rather the point at which a virtual lane starts or ends when a work zone is near. The merging of lanes at the start and end of work zones was mimicked by a virtual on- or off ramp as displayed in a scenario editor picture in Figure 40. The lane number of these intersections was -1. This is an integral design choice by Green Dino and cannot be changed without redesigning the simulator software. It resulted in the data logging component of the driving simulator logging distance headway wrongly. Namely, this log was based on the nearest vehicle in the same virtual lane as the participant's vehicle. In case an intersection interrupts this virtual lane, distance headway was not logged. This limitation could be worked around by adding a 'lane is closed' sign to the virtual lane at work zones instead of removing the virtual lane. The lane closure sign was however not fully implemented at the time of conducting this experiment. A way to work around this issue would be by analysing the detailed information of all simulated vehicles in the simulator log files, however this requires a large effort in terms of data analysis and does will not provide more than a rough estimation of the distance headway.

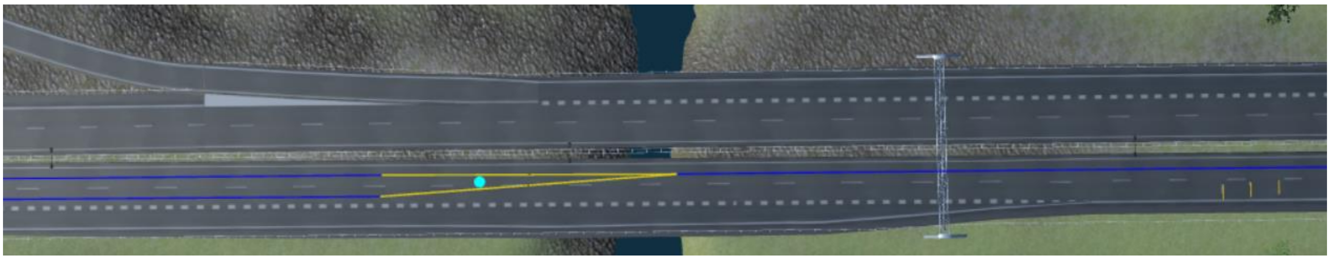


Figure 40. Virtual intersection (yellow) and lanes (blue) near work zone announcement

In conclusion, some technical limitations in the experiment may have slightly influenced driving behaviour, although conditions were equal for all participants (a lack of steering force feedback) or at random (traffic glitches). Regarding the measurement and analysis of data, the simulator and the design of its code limited the analysis of headway. It is suggested for future research to resolve these shortcomings before conducting experiments.

7 Reflection

This chapter provides a reflection on the work done in this project. The reflection covers two aspects: Section 7.1 reflects on the research performed in this project, the methods and results. This includes retrospective suggestions to improve this study should it be repeated. In Section 7.2 I will provide my personal reflection on the journey this project has been.

7.1 Reflection on Research

As part of designing this study, interviews were conducted as part of the literature review phase. These interviews were useful to get a feeling of the topics relevant to this study, although some interviews were held too late in the literature review phase as performing this interview at an earlier stage would have helped in finding a well-defined direction for this research more quickly.

After defining the objectives of the study, a research methodology was designed. Though this was a proper design for drawing conclusions on the topic of interest, several details can be improved at this stage. In retrospect, the effects of simulator driving and learning to drive in the simulator may have been underestimated, with an overestimation of the effect of in-car warnings on the indicators for safe driving behaviour. This was fixed by moving the focus of the study back to speeding behaviour at a late point, however a more deliberate decision on the direction of this research would likely have resulted in a more useful outcome.

Another aspect of the research methodology which should be changed in future studies is the design of the warning system. When the main goal is to study effects of this warning system, it would be wise to vary the design of these systems on several aspects. This way, better conclusions can be drawn on the presentation of personal warnings, this advantageous feature of in-car ITS is left unused in this study.

Furthermore, when using a new simulator and especially when the researcher is unfamiliar with performing simulator driving experiments, it is recommended to conduct a serious pilot study in an earlier phase of the research project compared to what was done in this study. This gives the researcher a feeling of the possibilities and difficulties of a driving simulator experiment. Now, the pilot experiment was mostly used to confirm the experiment design and data collection shortly before conducting the real experiment. It should be noted though, this was partly due to issues with the new simulator.

In the end, the experiment went well and returned some useful insights in HUD warnings at road work zones. Though, the main client goal of reducing traffic speed at work zones has not been reached. Recommendations to the client are limited to mainly a negative advice and some additions which are only slightly related to the goals and activities of this client. While the course of scientific experiments cannot always be predicted at the start of the experiment, a more cautious design of the experiment may help to return results that are more relevant to the client even when the results of the study are not in line with the expectations beforehand.

7.2 Personal Reflection

I would like to devote this final section to give my personal reflection on this project. After the previous reflection on traffic safety, simulator data, conclusions or the process of conducting research, this section is about me and my opinion on how I performed in this project.

In short, I think I have worked well. Focussing on a single task and working well used to be one of my biggest challenges as a student. Besides my personal efforts in this area, I think I succeeded in this task by having access to the good working environment at the office of Advin, as well as the useful and motivating feedback I received from the members of my committee. Of course, the interesting versatility of performing a research project on human subjects in a driving simulator helped a lot, as this allowed me to combine a wide variety of topics I am interested in: traffic, technology, data research and social/psychological aspects.

However, I do not want to give the impression everything went perfectly. In retrospect, it was not a good idea to start this project in August: The summer holiday proved to be a difficult time to start a project, due to limited availability of people to work with when defining the research goals and plan. Also, I really could have used another month of rest given my physical and mental state at the time. Despite knowing about these objections beforehand, I chose to start this project in the summer in order to save time. However, due to inefficient progress at the start most if not all of this 'head start' was lost.

Then, the designing of the actual experiment started. At this point, I really started to enjoy the project, as this allowed the combination of the personal interests mentioned before. When moving away from defining the experimental design and working on the actual design task, this is also where some weaknesses showed: I had limited coding and 3D skills at this point. While this allowed me to learn a lot by working on the project and made me extremely dedicated, many hours were lost at this stage of the project. More practice beforehand would have definitely increased my efficiency at this stage of the project.

These delays and my inexperience were visible through the planning and planning updates I made. At the start, I made an underestimation of the time required for designing and conducting simulator driving experiments, and conducting data analysis afterwards. Every feedback session, or when close to a personal deadline in the planning, I did not make it and would believe that I was very close. At this point, I would add extra time for some stages of the research to the planning in a conservative way, but usually not enough. I think this underestimation of the time required for certain tasks was due to:

- Inexperience in performing the tasks, resulting in making unrealistic time estimations.
- Inexperience in performing the tasks, resulting in requiring extra time for tasks.
- Being one of the first to work with the new simulator.
- Personal health and immune system issues, limiting the amount of work I could perform.

Because I decided at the start of this project that I would work well, and because the on-going health issues had an unclear start and end, tried to reduce its effect on my performance. However, by doing so I may have slowed the recovery down further, and reduced the quality of my personal life. In retrospect, I should have taken some time off and adjusted my schedule to my physical and mental conditions. I think current inefficient working delays and the delays due to taking it easy otherwise, are similar while recovery may take a higher pace when taking time off. Thus, it seems the work-life balance I tried to achieve during this project was once again unbalanced, and I still need to improve on this aspect. Even though I developed many hard skills during this project, I think this lesson on soft skills is the most important personal result of this project.

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Appendix A. Work Zone Safety

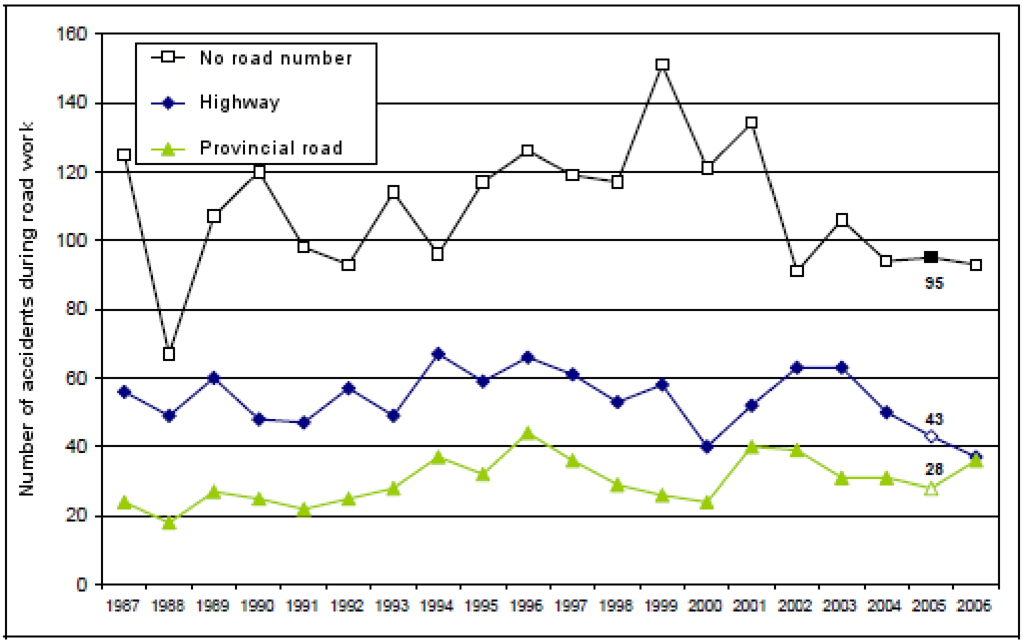

Figure 41. Serious accidents during road work per road type (Janssen & Weijermans, 2008)

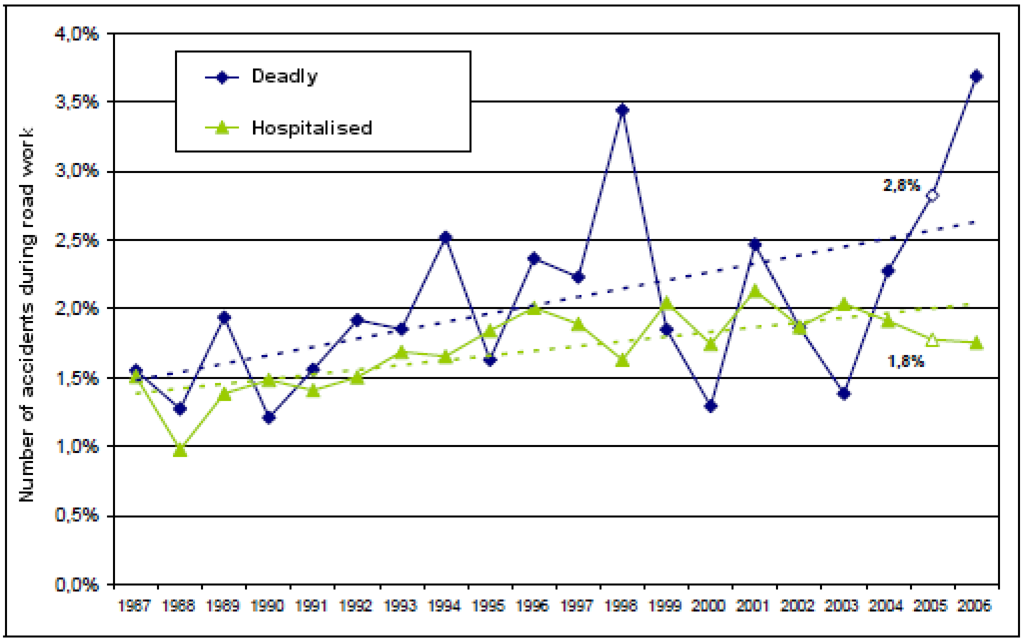

Figure 42. Share of serious accidents during road work in relation to all serious accidents by severity (Janssen & Weijermans, 2008)

Appendix B. Experimental Design of Scenarios

A uniform design is a more specific version of a Latin square where each treatment occurs only once within each sequence and once within each period (PennState, 2016a). These designs yield an equal number of columns and rows. Each row represents a participant, each column represents a scenario (PennState, 2016a). For a given number of experiments, multiple Latin squares can be formed. Williams introduced a more balanced design which ensures that not only each scenario occurs equally frequently at each position, but also each scenario is preceded by each other scenario equally frequently (1949, p. 151). For these properties to hold, each square should be completely used.

Table 16. Scenarios in the simulator experiment

	A	B	C	D	E	F	G	H
Work activity		✓	✓			✓	✓	
ITS support					✓	✓	✓	✓
Traffic speed [km/h]	90	110	90	110	90	110	90	110

Table 17. Balanced 4x4 Latin square (Merser, Miller, & Weiner, 2016)

Zone:	1	2	3	4
Participant 1	A	B	D	C
Participant 2	B	C	A	D
Participant 3	C	D	B	A
Participant 4	D	A	C	B
Participant 5	Continue at the first row of this table.			

Table 18. Combination of two 4x4 Latin squares, counter balanced.

Zone:	A1	A2	A3	A4	B1	B2	B3	B4
Participant 1	A	B	D	C	H	E	G	F
Participant 2	H	E	G	F	A	B	D	C
Participant 3	B	C	A	D	G	H	F	E
Participant 4	G	H	F	E	B	C	A	D
Participant 5	C	D	B	A	F	G	E	H
Participant 6	F	G	E	H	C	D	B	A
Participant 7	D	A	C	B	E	F	H	G
Participant 8	E	F	H	G	D	A	C	B
Participant 9	Continue at the first row of this table.							

Appendix C. Work Zone Layout and ITS

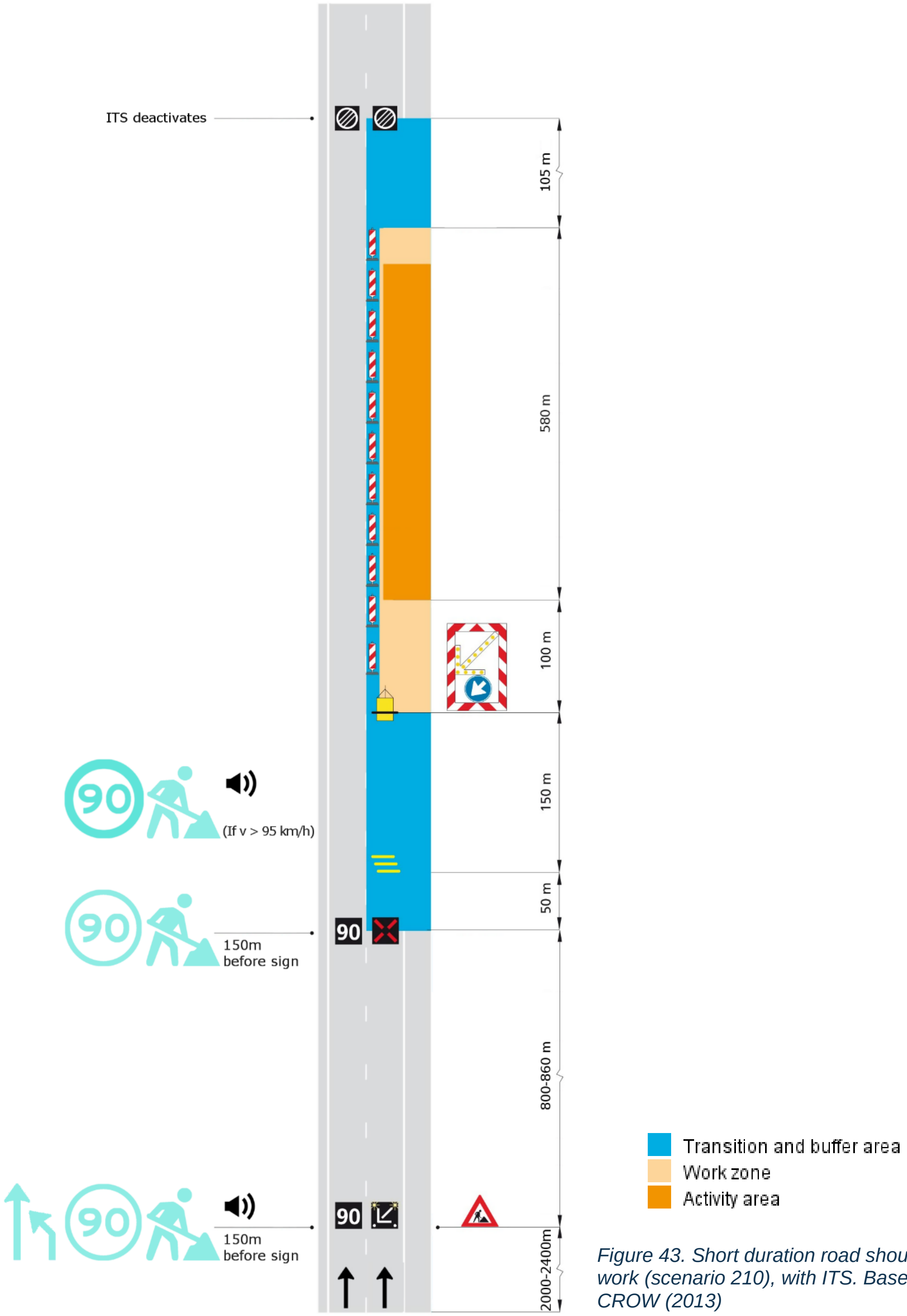

Figure 43. Short duration road shoulder work (scenario 210), with ITS. Based on CROW (2013)

Table 19. Distance between zone parts in simulator scenarios, in metres

Distance to	A1	A2	A3	A4	B1	B2	B3	B4	μ	σ / μ
Pre-Ann	1900	2399	1993	2215	2300	2280	2320	2270	2213	6.7%
Announcement	861	860	800	831	834	830	833	832	835	2.0%
Sign Car	201	201	197	200	201	200	199	200	194	8.2%
Last Beacon	585	588	604	582	583	583	581	579	585	1.2%
Zone End	100	100	111	100	105	107	106	105	104	3.8%
ZONE TOTAL	*1747*	*1749*	*1712*	*1713*	*1723*	*1720*	*1719*	*1716*	*1718*	*1.3%*

Appendix D. Screenshots of Work Zone in Simulator

Figure 44. Driver view at a work zone pre-announcement

Figure 45. Part of an active work zone

Figure 46. Side view of an inactive work zone

Appendix E. Full Questionnaire

Table 20. Full version of the questionnaire

#	Question				Scale
1	Wat is je geboortejaar?				Ratio
2	In welk jaar heb je je autorijbewijs (B) gehaald?				Ratio
3	Van welk niveau is je hoogst voltooide opleiding?				Ordinal
4	Hoeveel kilometre heb je het afgelopen jaar ongeveer gereden?				Ratio
5	Geef alsjeblieft aan in hoeverre ieder woord beschrijft hoe je je voelt op dit moment voelt.				Likert 1-5
	A	Ontevreden	**F**	Ongeduldig	
	B	Alert	**G**	Geërgerd	
	C	Ontmoedigd	**H**	Boos	
	D	Verdrietig	**I**	Geïrriteerd	
	E	Actief	**J**	Humeurig	
6	Geef alsjeblieft aan in hoeverre iedere stelling beschrijft hoe je je in de afgelopen tien minuten hebt gevoeld.				Likert 1-5
	K	Ik ben vastberaden mijn prestatiedoelen te bereiken.			
	L	Ik wil slagen in het uitvoeren van de taak.			
	M	Ik ben gemotiveerd de taak uit te voeren.			
	N	Ik probeer mezelf te begrijpen.			
	O	Ik reflecteer op mezelf.			
	P	Ik dagdroom over mezelf.			
	Q	Ik ben verzekerd van mijn kunnen.			
	R	Ik ben zelfbewust.			
	S	Ik maak me zorgen om hoe anderen over me zullen denken.			
	T	Ik ben bezorgd om hoe ik op anderen over kom.			
	U	Ik verwacht goed te zijn in rijden in de simulator.			
	V	Ik heb het gevoel dat ik dingen onder controle heb.			
	W	Ik heb gedacht over hoe anderen presteerden in de simulator.			
	X	Ik heb gedacht over hoe ik me zou voelen wanneer ik te horen krijg hoe ik heb gepresteerd.			
7	"Ik vind een system in mijn voertuig dat waarschuwingen geeft over actieve wegwerkzaamheden en het bijbehorende snelheidslimiet…"				Likert 1-5
	Y	Nuttig		Zinloos	
	Z	Plezierig		Onplezierig	
	AA	Slecht		Goed	
	AB	Leuk		Vervelend	
	AC	Effectief		Onnodig	
	AD	Irritant		Aangenaam	
	AE	Behulpzaam		Waardeloos	
	AF	Ongewenst		Gewenst	
	AG	Waakzaamheidsverhogend		Slaapverwekkend	

#	Question	Scale
9	Rating Scale Mental Effort (Appendix H)	Ordinal 0-150
10	Geef alsjeblieft aan in hoeverre ieder woord beschrijft hoe je je tijdens het rijden voelde.	Likert 1-5
11	Geef alsjeblieft aan in hoeverre iedere stelling beschrijft hoe je je tijdens het rijden voelde.	Likert 1-5
12	Rating Scale Mental Effort (Appendix H)	Ordinal 0-150
13	Geef alsjeblieft aan in hoeverre ieder woord beschrijft hoe je je tijdens het rijden voelde.	Likert 1-5
14	Geef alsjeblieft aan in hoeverre iedere stelling beschrijft hoe je je tijdens het rijden voelde.	Likert 1-5
15	“Ik vind een system in mijn voertuig dat waarschuwingen geeft over actieve wegwerkzaamheden en het bijbehorende snelheidslimiet…”	Likert 1-5
16	Ben je benieuwd naar de resultaten van dit onderzoek? Laat dan in dit veld je e-mailadres achter.	Text

Appendix F. Short Stress State Questionnaire

Table 21. Validated SSSQ model (Helton, Validation of a Short Stress State Questionnaire, 2004)

#	Original Item	Dutch Translation
1	I feel dissatisfied.	Ik ben ontevreden.
2	I feel alert.	Ik ben alert.
3	I feel depressed.	Ik ben ontmoedigd.
4	I feel sad.	Ik ben verdrietig.
5	I feel active.	Ik ben actief.
6	I feel impatient.	Ik ben ongeduldig.
7	I feel annoyed.	Ik ben geërgerd.
8	I feel angry.	Ik ben boos.
9	I feel irritated.	Ik ben geïrriteerd.
10	I feel grouchy.	Ik ben humeurig.
11	I am committed to attaining my performance goals.	Ik ben vastberaden mijn prestatiedoelen te bereiken.
12	I want to succeed on the task.	Ik wil slagen in het uitvoeren van de taak.
13	I am motivated to do the task.	Ik ben gemotiveerd de taak uit te voeren.
14	I'm trying to figure myself out.	Ik probeer mezelf te begrijpen.
15	I'm reflecting about myself.	Ik reflecteer op mezelf.
16	I'm daydreaming about myself.	Ik dagdroom over mezelf.
17	I feel confident about my abilities.	Ik ben verzekerd van mijn kunnen.
18	I feel self-conscious.	Ik ben zelfbewust.
19	I am worried about what other people think of me.	Ik maak me zorgen om om hoe anderen over me zullen denken.
20	I feel concerned about the impression I am making.	Ik ben bezorgd om hoe ik op anderen over kom.
21	I expect to perform proficiently on this task.	Ik verwacht goed te zijn in deze taak.
22	Generally, I feel in control of things.	Ik heb het gevoel dat ik dingen onder controle heb.
23	I thought about how others have done on this task.	Ik heb gedacht over hoe anderen presteerden op deze taak.
24	I thought about how I would feel if I were told how I performed.	Ik heb gedacht over hoe ik me zou voelen wanneer ik te horen krijg hoe ik heb gepresteerd.

Table 22. Factor structure of SSSQ (Helton & Näswall, 2015)

#		Pre Driving			Between / After	
	Distress	Engagement	Worry	Distress	Engagement	Worry
1	0.62			0.70		
2		0.36			0.59	
3	0.54			0.59		
4	0.60			0.55		
5		0.36			0.46	
6	0.52			0.53		
7	0.74			0.83		
8	0.75			0.76		
9	0.85			0.88		
10	0.56			0.65		
11		0.70			0.76	
12		0.70			0.65	
13		0.74			0.75	
14			0.67			0.62
15			0.64			0.72
16			0.54			0.54
17		0.54			0.53	
18			0.64			0.65
19			0.71			0.75
20			0.73			0.77
21		0.58			0.55	
22		0.45			0.50	
23			0.32			0.57
24			0.39			0.48

Appendix G. Van Der Laan Acceptance Scale

Table 23. Van Der Laan Acceptance Scale (Laan, Heino, & Waard, 1997)

#	Left extreme (0)	Right extreme (5)
1	Useful	Useless
2	Pleasant	Unpleasant
3	Bad	Good
4	Nice	Annoying
5	Effective	Superfluous
6	Irritating	Likeable
7	Assisting	Worthless
8	Undesirable	Desirable
9	Raising Alertness	Sleep-inducing

Table 24. Van Der Laan Acceptance Scale in Dutch (Laan, Heino, & Waard, 1997)

#	Left extreme (0)	Right extreme (5)
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

Guide for scale users (Laan, Heino, & Waard, 1997):

1) Describe the system to be evaluated in terms of “what is your judgment about a system that would…”, and present the items (before-measurement).
2) Present the items again after experience with the system under evaluation with the description: “what is your judgement about the system… you just finished driving with”.
3) Items are coded from +2 to -2 from left to right, items 3, 6 and 8 are coded from -2 to +2.
4) Perform reliability analyses on the before-measurement. Use items 1, 3, 5, 7, and 9 for the usefulness scale, and items 2, 4, 6, and 8 for the satisfying scale.
5) If reliability is sufficiently high (Cronbach’s $\alpha > 0.65$), compute per subject the end score for the two scales by averaging scores on items 1, 3, 5, 7, and 9 for the usefulness score, and averaging scores on items 2, 4, 6, and 8 for the satisfying score.
6) The usefulness scale is averaged over subjects to obtain an overall system practical evaluation. The same is done with the satisfying scores.
7) Compute difference-scores per subject by subtracting the before-measurement score form the after-measurement score per scale. The difference scores show whether and in which direction subjects’ opinion was altered as a result of experience with the system.

Appendix H. Rating Scale Mental Effort

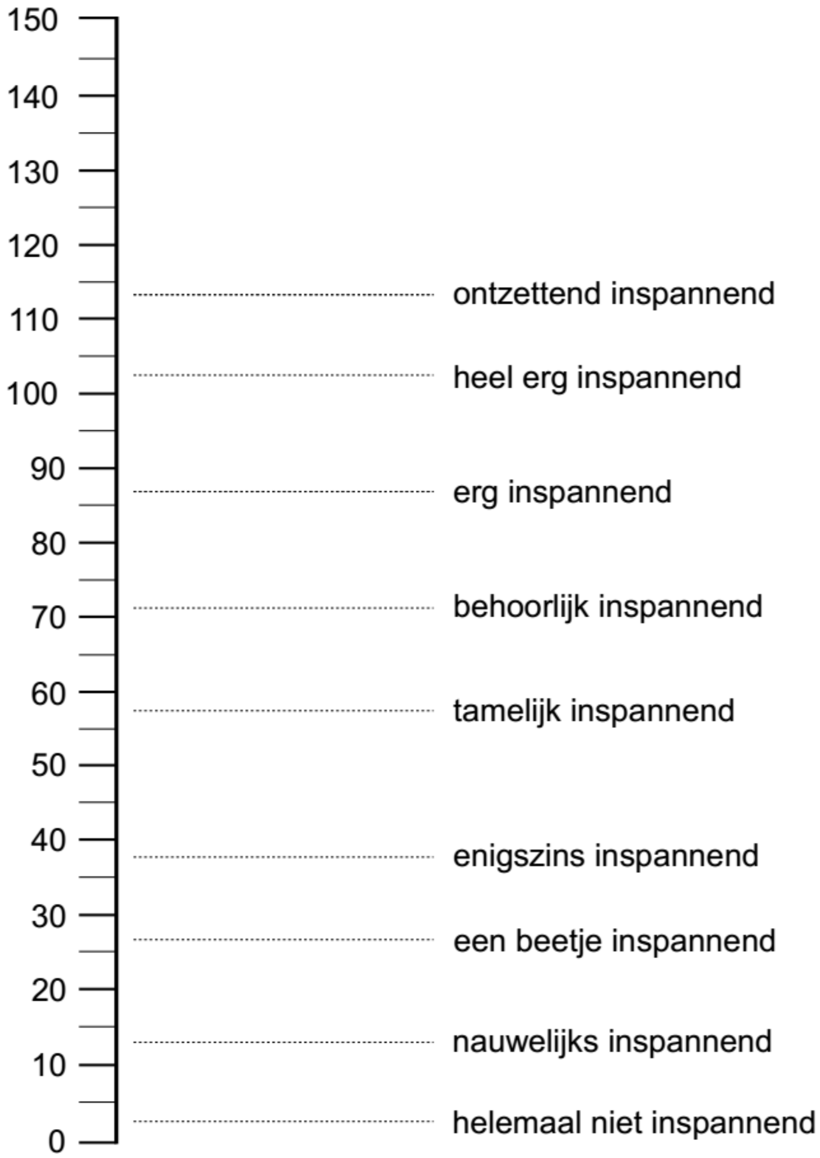

Figure 47. Rating Scale Mental Effort at true size (Zijlstra, 1993)

Table 25. Translation of RSME items (Zijlstra, 1993)

Dutch	English
ontzettend inspannend	extreme effort
heel erg inspannend	very great effort
erg inspannend	great effort
behoorlijk inspanned	considerable effort
tamelijk inspannend	rather much effort
engiszins inspannend	some effort
een beetje inspannend	a little effort
nuwelijk inspannend	almost no effort
helemaal niet inspannend	absolutely no effort

Appendix I. Experiment Promotion Flyer

Ben jij een man tussen de 18 en 24 jaar en heb je een autorijbewijs?

Doe dan mee aan een experiment in de rijsimulator voor het afstudeerproject van Bram Bazuin (b.n.bazuin@student.tudelft.nl)

Duur: Minder dan 1 uur
Locatie: Civiele Techniek TU Delft, ruimte 4.28

Meld je aan via: http://bit.ly/2hi9FCn

Figure 48. Simulator driving experiment promotion flyer (Hoogdalem, 2017)

Appendix J. Informed Consent Form

Toestemming deelname aan onderzoek naar rijgedrag

Ik doe mee aan een onderzoeksproject van Bram Bazuin, master student Transport, Infrastructuur & Logistiek aan de TU Delft. Ik begrijp dat dit project bedoeld is om informatie te verzamelen over het rijgedrag van bestuurders van personenauto's. Ik ben een van ongeveer 40 deelnemers aan dit onderzoek.

1. Mijn deelname aan dit onderzoek is vrijwillig. Ik begrijp dat ik niet betaald word voor mijn deelname en geen vergoeding krijg. Ik kan op ieder moment zonder verdere consequenties mijn deelname aan dit onderzoek beëindigen.
2. Indien ik me oncomfortabel voel op wat voor manier dan ook, heb ik het recht een vraag niet te beantwoorden of mijn deelname aan het experiment in het geheel te beëindigen.
3. Deelname aan dit onderzoek bestaat uit:
    a. Vragen beantwoorden over hoe ik mij voel.
    b. Vragen beantwoorden over het simulator-experiment.
    c. Het maken van twee ritten in de rijsimulator.
4. De vragen van deel a en b zijn verdeeld over drie delen van een online vragenlijst. Het invullen hiervan duurt per deel tussen de 5 en 10 minuten.
5. In deel c wordt een rijsimulator gebruikt om een verkeerssituatie met verkeer na te bootsten. Voertuiginformatie wordt verzameld en een hartslagsensor wordt aan één van je vingertoppen verbonden. Iedere rit duurt tussen de 10 en 15 minuten.
6. Ik begrijp dat de onderzoeker mij op geen manier zal identificeren door middel van mijn naam, en dat mijn vertrouwelijkheid als deelnemer van dit onderzoek gewaarborgd wordt. De datasets die worden verzameld in dit onderzoek worden op basis van deelnemernummer aan elkaar gelinkt en zullen anoniem worden bewaard en verwerkt.
7. Ik begrijp dat dit onderzoek is goedgekeurd door het Human Research Committee van TU Delft. Voor problemen met dit onderzoek is het Human Research Committee bereikbaar via hrec@tudelft.nl.
8. De uitleg die over dit onderzoek is gegeven door de onderzoeker is duidelijk, en ik begrijp de inhoud van het onderzoek. Er zijn geen onduidelijkheden en ik ben akkoord met deelname aan dit onderzoek.
9. Bij akkoord teken ik dit formulier in tweevoud, één van deze formulieren is voor de onderzoeker, het andere formulier voor mij.

____________________________	____________________________
Datum	Locatie
____________________________	____________________________
Deelnemer nr.	Handtekening

For further information, please contact Bram Bazuin: bram.bazuin@advin.nl / 06 46 49 09 58

Appendix K. Annotated Simulator Data Log

```
"Frame2977":{                                          frame number
      "TimeStamp":63.45862,                            log entry time stamp [s]
      "worldTime":"11/27/2016 6:14:22 PM.559",         real-world time
      "Player":{
            "Pos":{
                  "x":-1238.028,                       x location of player position [m]
                  "y":20.95079,                        y location of player position [m]
                  "z":-508.3616                        z location of player position [m]
            },
            "Vel":{                                    player velocity [m/s]
                  "x":-37.68589,
                  "y":0.01319389,
                  "z":1.723794
            },
            "Acc":0.6500244,                           player acceleration [m/s²]
            "Heading":{                                direction from -1 to 1 [rad/π]
                  "x":-0.9989909,
                  "y":-0.001127074,
                  "z":0.04489825
            },
            "Throttle":1,                              throttle input from 0 to 1
            "Brake":0,                                 brake input from 0 to 1
            "Steer":0,                                 steer input from -1 to 1
            "Clutch":0,                                clutch input from 0 to 1
            "SteerAngle":0,                            steer input in degrees
            "MamualGear":4,                            player vehicle gear
            "RPM":3743,                                player vehicle rpm
            "SignalLeft":true,                         left indicator is on
            "SignalsRight":false,                      right indicator is off
            "Human":true,                              is player human or not
            "Headway":999,                             no vehicle ahead
            "Backway":10.2,                            distance to vehicle behind 0 to 999 [m]
            "Lane":{
                  "LaneGroup":0,                       current lane number (left lane)
                  "StartVec":{                         start location of current lane part
                        "x":-1150.559,
                        "y":20.55523,
                        "z":-512.1302
                  },
                  "EndVec":{                           end location of current lane part
                        "x":-1509.647,
                        "y":20.55522,
                        "z":-494.8727
                  },
                  "SpeedLimit":120,                    speed limit at current lane
                  "AdvSpeedLimit":120,                 advisory speed limit at current lane
                  "OnIntersection":false               is the current lane an intersection
            }
      },
      "Agents":[]                                      if agent present, agent vehicle info
}
```

Appendix L. Python Data Resampling Function

Table 26. Description of variables in data resampling function

Variable	Description
df	Simulator data frame of a single zone part
pre	Identifier of zone part (before or after 2nd VMS)
zone_cnt	Position of zone in experiment

```python
import numpy as np
import pandas as pd

def resample_sim(df, pre, zone_cnt):
    """Resample data for all zones, idividual per type pre or ann."""
    pre_dist = 1135
    ann_dist = 889

    df.reset_index(inplace=True)
    start_dist = df.real_dist_int.iloc[0]
    df['real_dist_int'] = df.real_dist_int - start_dist  # Calculate dist in zone part.
    zone_dist = df.real_dist_int.iloc[-1]  # Get length of zone in [dm].

    # Scale zone parts, build index with equal spacing and interpolate data.
    df.loc[(df.pre == 1), 'real_dist_int'] =  (df.real_dist_int / zone_dist *
                                               pre_dist).astype(int)
    df.loc[(df.pre == 0), 'real_dist_int'] =  (df.real_dist_int / zone_dist *
                                               ann_dist).astype(int)
    new_idx = df.index.join(pd.Index(np.arange(df.index.min(), df.index.max())),
                                               how='outer')
    df = df.reindex(new_idx).interpolate('slinear')

    # Make sure tag for zone part is set correctly and remove any duplicates.
    df.loc[:, 'pre'] = pre
    df['zone_cnt'] = zone_cnt.astype(int)
    df.drop_duplicates('real_dist_int', keep='last', inplace=True)
    return df
```

Appendix M. LMM SPSS Syntax

```
MIXED dependent BY zone_cnt [independents] WITH speed_before
 /CRITERIA=CIN(95) MXITER(100) MXSTEP(10) SCORING(1) SINGULAR(0.000000000001)
   HCONVERGE(0, ABSOLUTE) LCONVERGE(0, ABSOLUTE) PCONVERGE(0.000001, ABSOLUTE)
 /FIXED=zone_cnt [independents] | SSTYPE(3)
 /METHOD=REML
 /PRINT=SOLUTION
 /RANDOM=INTERCEPT | SUBJECT(ppid) COVTYPE(VC)
 /REPEATED=zone_loc | SUBJECT(ppid) COVTYPE(DIAG)
 /SAVE=RESID.

GRAPH
 /HISTOGRAM(NORMAL)=RESID_1.
```

Appendix N. Questionnaire Analysis

Table 27. Descriptive statistics for satisfaction of fast drivers

	N	Minimum	Maximum	Mean	St.dev
Satisfaction (pre)	18	-1.00	1.50	0.31	0.79
Satisfaction (post)	18	-0.75	1.50	0.61	0.68

Table 28. Wilcoxon signed-rank test for satisfaction (pre - post) of fast drivers (α = 0.05)

	N	Mean Rank	Sum of Ranks	Z-score	Sign.
Negative ranks	10	6.85	68.50		
Positive ranks	2	4.75	9.50		
Ties	6				
Total	18				
Test statistics				-2.342	***.019***

Table 29. 2-tailed test statistics of Wilcoxon signed-rank results for usefulness items (α = 0.01)

	Useful Useless	Bad Good	Effective Superfluous	Assisting Worthless	Alertness Sleep Inducing
Z	-1.476	-1.507	-1.068	-1.076	-0.881
Sign.	.140	.132	.286	.282	.378

Table 30. Descriptive statistics for RSME

	N	Minimum	Maximum	Mean	St.dev
RSME ITS	34	5.0	80.0	37.78	20.06
RSME No ITS	34	2.5	95.0	42.68	23.80

Table 31. Wilcoxon signed-rank test for RSME (No ITS - ITS) (α = 0.05)

	N	Mean Rank	Sum of Ranks	Z-score	Sign.
Negative ranks	11	13.09	144.00		
Positive ranks	20	17.60	352.00		
Ties	3				
Total	34				
Test statistics				-2.039	***.041***

Table 32. 1-tailed Pearson correlations (α = 0.05)

		Satisfaction (pre)	Satisfaction (pst)	Worry (No ITS)
Median Speed	**Correlation**	-.344	-.029	-.344
	Significance	***.050***	.437	***.050***

Appendix O. Performance Analysis

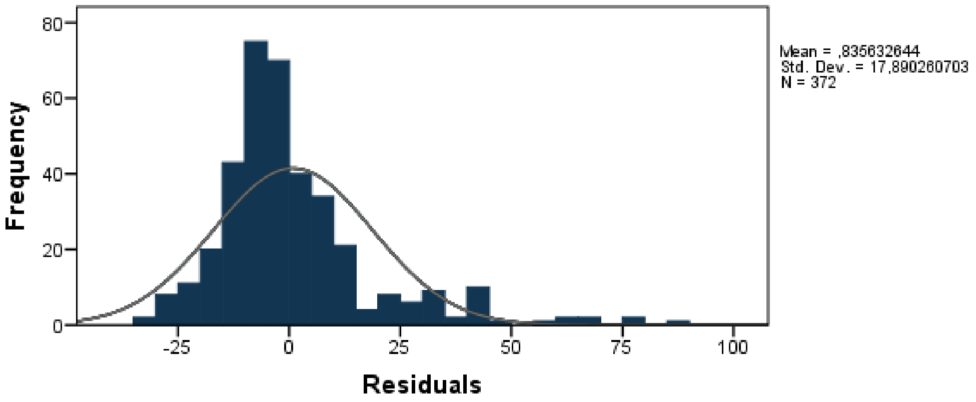

Figure 49. Distribution of residuals of 'standard deviation of successive beat interval differences'

Table 33. Estimated effects on median speed from 300 m to 500 m

Parameter	Estimate (km/h)	t-statistic	Sign.	Number of	
Intercept	108.880	43.073	.000	**Drivers**	34
Traffic 90 km/h	-4.140	-3.298	.001	**Observations**	272
Traffic 110 km/h	0	-	-	**Levels**	20
Zone A1	1.841	0.606	.547		
Zone A2	-5.154	-1.724	.090		
Zone A3	-3.663	-1.336	.188		
Zone A4	0.384	0.138	.891		
Zone B1	-1.670	0.577	.567		
Zone B2	-0.065	0.022	.982		
Zone B3	0.357	0.121	.904		
Zone B4	0	-	-		

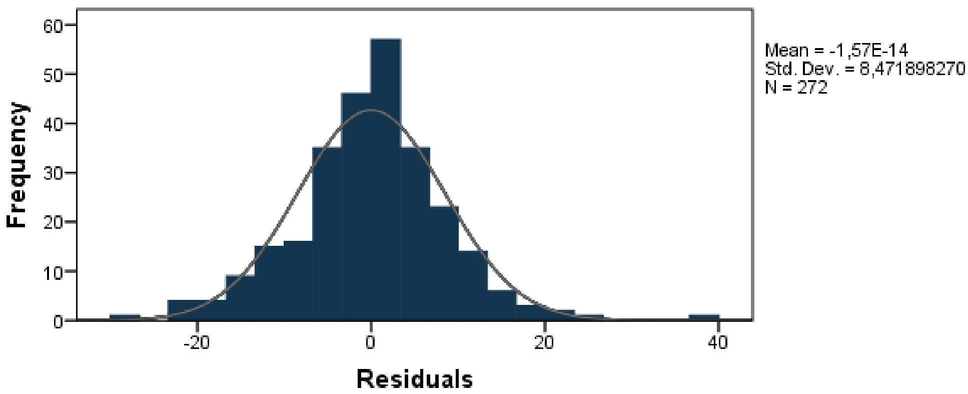

Figure 50. Distribution of residuals of median speed from 300 m to 500 m

Table 34. Estimated effects on median speed from 800 m to 1000 m

Parameter	Estimate (km/h)	t-statistic	Sign.	Number of	
Intercept	94.277	76.022	.000	**Drivers**	34
Traffic 90 km/h	-4.825	-4.757	.000	**Observations**	272
Traffic 110 km/h	0	-	-	**Levels**	20
Zone A1	-0.460	0.223	.825		
Zone A2	0.019	0.011	.991		
Zone A3	0.147	0.081	.936		
Zone A4	-2.710	-1.512	.137		
Zone B1	3.057	2.082	.043		
Zone B2	-3.262	-1.529	.134		
Zone B3	-1.268	-0.651	.519		
Zone B4	0	-	-		

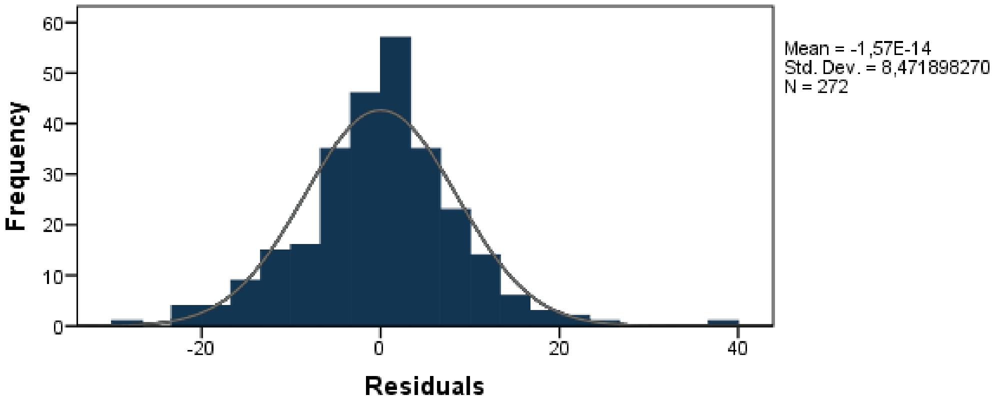

Figure 51. Distribution of residuals of median speed from 800 m to 1000 m

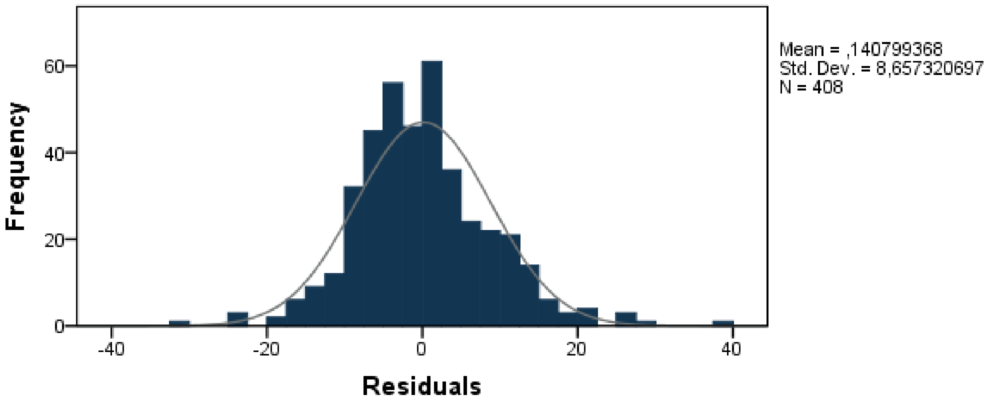

Figure 52. Distribution of residuals of mean speed in km/h

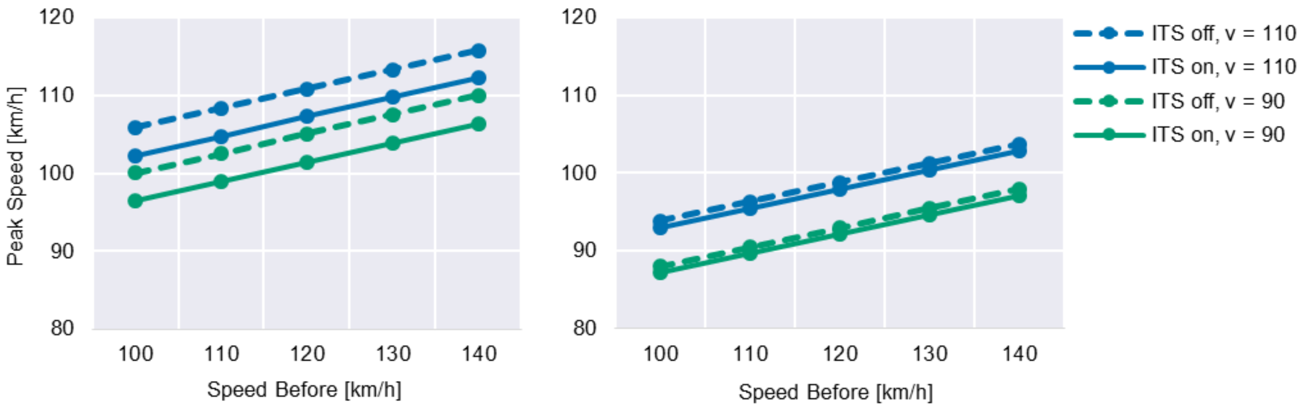

Figure 53. Estimated effects on peak speed after pre-announcement (left) and in work zone (right)

Table 35. Estimated effects on peak speed

Parameter	Estimate (km/h)	t-statistic	Sign.	Number of	
Intercept	77.509	12.852	.000	**Drivers**	34
Zone	-9.342	-7.738	.000	**Observations**	408
Pre	0	-	-	**Levels**	23
Traffic 90 km/h	-5.794	-7.474	.000		
Traffic 110 km/h	0	-	-		
Speed Before	0.248	4.930	.000		
ITS Off * Zone	0.864	0.943	.347		
ITS On * Zone	0	-	-		
ITS Off * Pre	3.578	2.475	.014		
ITS On * Pre	0	-	-		

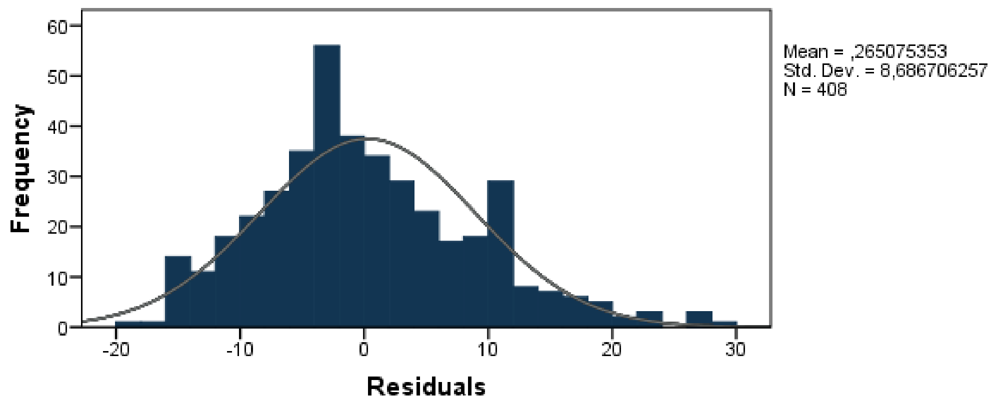

Figure 54. Distribution of residuals of peak speed in km/h

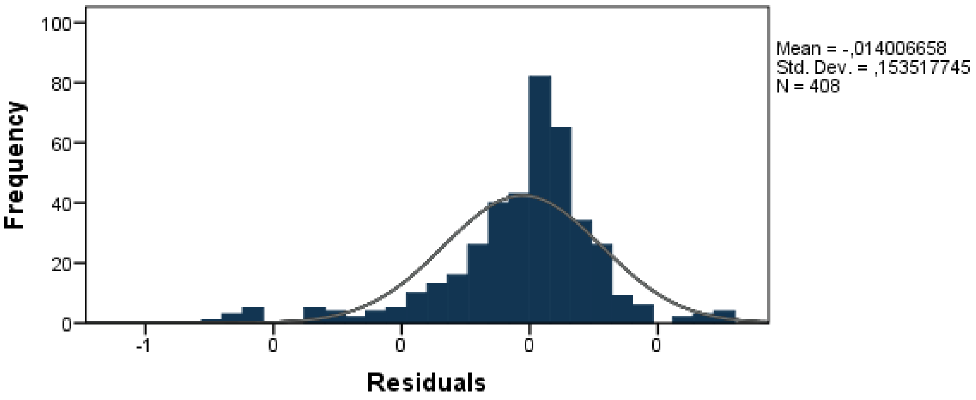

Figure 55. Distribution of residuals of throttle pressure percentage

Table 36. Estimated effects on throttle pressure, outliers removed

Parameter	Estimate (%)	t-statistic	Sign.	Number of	
Intercept	64.393	108.222	.000	**Drivers**	34
300-700 m (part1)	-5.941	-3.994	.000	**Observations**	403
700-1000 m (part2)	0	-	-	**Levels**	22
Traffic 90 km/h	-3.323	-5.220	.000		
Traffic 110 km/h	0	-	-		
ITS Off * part1	5.051	2.556	.011		
ITS Off * part2	0.324	0.484	.629		
ITS On * part1	0	-	-		
ITS On * part2	0	-	-		

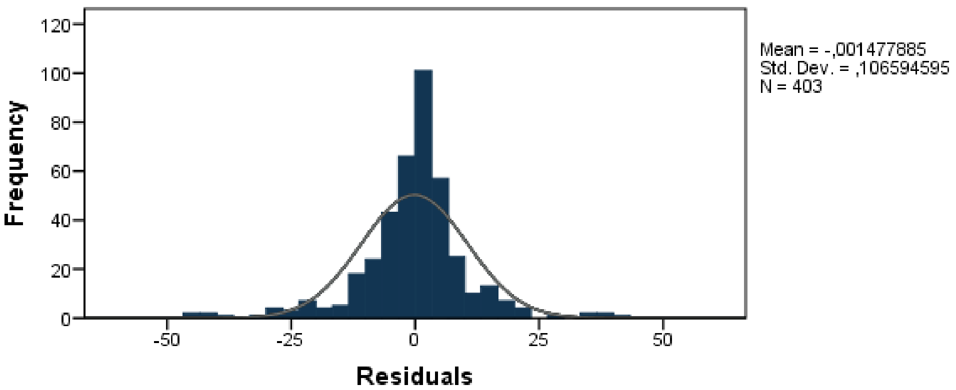

Figure 56. Distribution of residuals of throttle pressure percentage, outliers removed

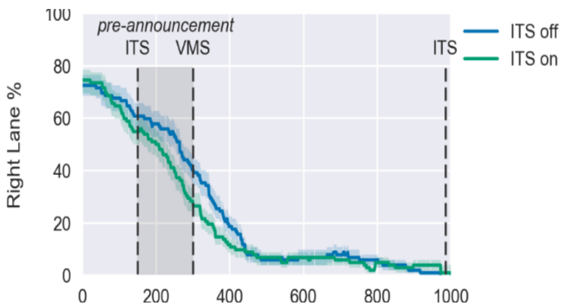

Figure 57. Share of drivers in right lane vs distance by ITS support, selected zones only