The final part of Masters of Transportation Sciences program, concludes with a Master’s thesis, in which student, does a research on a topic, do literature review, performs his experiment and concludes with results and recommendations. I present my Master’s Thesis, the title of the dissertation is “Evaluation of effectiveness of different temporary traffic control measures on work zone areas on highways”. The experiment was conducted by means of driving simulator, which examined the driving behaviour, along with assessing mental work load. I would express my gratitude to some people, who have always been helping me and supporting me, throughout various stages of the thesis. Firstly, I would like to give a word of special thanks to Mr. Kristof Mollu (supervisor) who has helped me and guided me throughout the procedure from first to the very last step. Whenever I lost track, he came with positive ideas, comments and feedback. Special appreciation also goes out to Prof. Dr. Tom Brijs (promotor), who provided feedback, discussion and recommendations about the topic, which led me today to present my thesis in a good qualitative shape.

A word of thanks also goes to Miss Judith Urlings, for introducing me to the world of statistics, explaining the data analysis procedure, and giving her tips for the data analysis.

I would also like to thank, Mr. Marc Geraerts who gave me introduction to driving simulation language, and also did the data extraction for me from the raw output files.

Special appreciation to the 46 participants, who came up and became a part of the experiment.

Last but not the least, I wanted to thank my family members, fiancé and friends. Who have given me extensive support the whole year, whenever I needed gave me a real inspiration and motivation, when I lost track and got disappointed. Without their help and support, I would not have being able to present this report.

Zain Ul Abdin, Hasselt, Belgium

26th December 2015
This thesis is done to assess the driving behaviour inside work zone area of highways, while different TTC measures are present. This study was done in context with work zone area on highways in Flanders, Belgium. Since work zone areas are considered to be vulnerable and project good level of threat to traffic safety. When maintenance activities are carried out in work zone areas of highways, traffic flow capacity reduces, chances of tail gaiting and bottleneck rise up suddenly. This further leads to congestion, frustration and which leads drivers to make errors. For traffic accidents in Belgium, only Flanders contributes of about 63.74% of the accidents occurring. A generic trend of 7.8 % reduction in number of injuries is noted. Road safety states general, Belgium has the goal to reduce the number of injuries to 420 fatalities by 2020. Whereas in the year 2013, in work zone areas on highways 52 accidents occurred out of which 42 were slight injuries and 6 were heavy injuries resulting in hospitalisation. Therefore focus of this study is to review current work zone signalisation scheme in Flanders, evaluate the effect of different TTC measures inside work zone highways. The study is done by means of driving simulator, which is regarded as an effective and valid tool for research. This experiment studied the driving behaviour of 46 different test subjects coming from different age groups, from Belgium.

In this driving simulator experiment, a within subject design was used which consisted of six different conditions. It was decided to avoid to introduce any sign board or TTC measure which results in any confusion. For this experiment one condition was considered as reference scenario which was default signalisation scheme for work zone highways. Further other five scenarios were designed which experimented removal of left hand side sign boards except speed limit, remove all left hand side boards, speed camera sign board, police presence and speed limits in yellow background.

This study with its comparative statistical analysis concludes that, removing left hand sides sign board’s results to show significant differences, and higher speeding averages with other scenarios. Therefore using this sign is not recommended, since it may prove to be vulnerable in dense traffic conditions, when driver work load is high. Whereas yellow background speed limits sign resulted in significant differences among different scenarios, while presence of sign C 43 70 km/h, speed camera sign and police presence. Whereas significant comparative differences were also noted for speed camera signs and police presence inside work zone areas with other driven scenarios.

The findings of this study tell us that use of newly adopted TTC measures resulted in a positive outcome. The C 43 speed sign limits (90 km/h, and 70 km/h), resulted in significant speed reduction of 5.84% and 11.06%, after the sign occurrence. The speed camera sign, also resulted in reduction in mean speed reduction of 12.076% and deceleration rate of 0.2963. Police presence also resulted in speed reduction by 5.74 % and deceleration 0.5382. Whereas C 43 sign (70 km/h) at centre of work zone, did not had any significant effect, but was noted that test subjects abided by the speed limits. Finally end of work zone sign, also resulted in sudden increase in speed by 16.11% and acceleration rate of 0.900, which concludes that appropriate information was carried out to drivers and hence resulting in expected reaction. Finally at the end of this experiment recommendations are given, and proposal is outlined for possible future studies.

**Keywords:** Driving simulator, driving behaviour, subjective workload, work zone safety, speed enforcement.
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<table>
<thead>
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<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TTC</td>
<td>Temporary traffic control measure</td>
</tr>
<tr>
<td>ANOVA</td>
<td>Analysis of variance</td>
</tr>
<tr>
<td>MANOVA</td>
<td>Multivariate analysis of variance</td>
</tr>
<tr>
<td>CMS</td>
<td>Changeable message sign</td>
</tr>
<tr>
<td>PCMS</td>
<td>Portable changeable message sign</td>
</tr>
<tr>
<td>FHWA</td>
<td>Federal highway administration</td>
</tr>
<tr>
<td>MUTCD</td>
<td>Manual of uniform traffic control devices</td>
</tr>
<tr>
<td>VSL</td>
<td>Variable speed limit</td>
</tr>
<tr>
<td>ITS</td>
<td>Intelligent transportation systems</td>
</tr>
<tr>
<td>JLM</td>
<td>Joint lane merger</td>
</tr>
<tr>
<td>CLM</td>
<td>Conventional lane merger</td>
</tr>
</tbody>
</table>
1. INTRODUCTION

Traffic queuing and congestion are important elements and have major influence on highways. Congestion and tail gaiting in highways are major factors which lead to accidents due to driver’s error when construction or maintenance is going on highways. To increase traffic infrastructure construction/maintenance activities are carried on highways which have detrimental effect on traffic safety of highways resulting in accidents. Temporary traffic control (TTC) measures, are used and deployed in work zone areas on highways to improve traffic conditions on highways (FHWA, 2009). The basic aim of providing TTC measures on highways is to provide improved safety levels to automobiles, construction workers, machinery at place where construction work activities are being carried. TTC measures includes such as traffic sign boards, dynamic vehicles carrying electronic boards, speed enforcement methods, stop/sign signals, pavement markings, construction barrels, speed limits, and lane closures. All over the world, legislations are done by law enforcing agencies/governments and certain budget is allocated for improving of traffic safety conditions on highways.

In USA, approximately 40,000 people have being injured each year on highways in the period of 1999 to 2003 due to major road and bridge projects for enhancing the capacity of traffic infrastructure. The number of fatalities raised from 872 to 1028 from 1999 to 2003 (Li & Bai, 2009).

Condition of Flanders, Belgium is not different from other parts of world in terms of highway safety. In Belgium, highway maintenance/construction work is carried out on regular basis on highway which are also known as work zone area on highways. Construction/maintenance activities are carried on lesser frequency on highways than other infrastructural developments, but have a high impact on traffic conditions of highways, resulting in congestion and tail-gating which eventually leads to frustration among drivers, and thus stimulates them to make errors, which leads to traffic accidents on highway due to presence of work zone areas. Mainly two types of accidents happen on highways due to presence of work zones, in the first type driver inside the passenger car is injured by having contact with equipment /machinery and in the second of type accident, worker on site experiences injuries by having encounter with other vehicles.

Belgian road safety institute reported 767 deaths on Belgian roads in all three regions in the year 2012. Only in the year 2012, 381 deaths were recorded on Flemish roads. In work zone sites about 94 accidents occurred on Flemish highways in the year 2010. Increase in the trend of accident rates were noted on Flemish highways from year 1991 to 2000, but after that a general gradual decrease was seen which was interrupted by year of stagnation (2007). In 2010 number of deaths have being reduced by 10.8 % (Moens, 2013).

To improve the traffic safety situation, researchers, practitioners have being looking into several measures, such as experimenting on TTC. However it is still yet not clear which measure should be implemented and which will produce maximum safety out of it. Therefore in-order to evaluate the effectiveness of TTC on construction/maintenance activities on Flemish highways, experiments are to be done, to give conclusions and recommendation for improving the traffic safety situation in work zone areas of highways.
2. PROBLEM DEFINATION

Traffic accidents and situation all over the world is of utmost importance. Statistics show that traffic accidents are being rated as the top 10 reasons of death ranging about 1.21 million deaths (Centre, 2011). Since 1981 in USA, traffic crashes have been the number one killer in most age groups (Newswire, 2005). Even in developing countries like Turkey, traffic accidents are top causes of death between the age group of 15 to 29. Moreover, over 1.2 million people have died because traffic accidents (Xinhua, 2013). Surprisingly accidents do not happen only due to mechanical error/failure but, almost 90% of accidents on road happen due to human error, such as driving recklessly, speeding, lane changing without adequate signalling, driving on shoulder and violating red lights (Olarte, 2011).

In U.S.A high rate of work zone accidents indicates significant percentage increase in accidents (48%), since 1997 recorded by Federal highway administration (FHA). Alone in 2003, the data show that around 1,028 persons died and 41,239 persons were injured. Thus the FHA has issued advisory tips of driving safe in work zones which is slowing down, obeying flaggers, avoiding tail-gating and etc (F.H.A, 2005). Increase in road accidents due to presence of work zones causing law makers to focus more on traffic safety situation in work zone activities. During the time period 1997-2002, there was a significant increase in work zone accidents by 55%. In U.S.A, only in the year 2002, there were about 117,567 accidents due to work zone sites, committing 52,000 injuries and 1,181 fatalities (DOT, 2004).

Facts and statistics of 2010 collected in U.S.A show that 70% of accidents happen in day time from 8:00 am to 4:59 pm. Injury occurrence rates tells that one injury occurs per 14 mins, about 4 people injured in every hour. More trend of rear end collisions is seen of about 46.9% and side sweep collision of about 13.6% (FHWA, 2010).

Work zone crashes on highways have more impact, as compared to inner city roadways work zone. Crashes happen due to some critical factors such as vehicle type, speed and reaction time. In Florida, U.S.A data was collected for work zone crashes on freeway (highway), which showed that factors like roadway geometry, weather, driver age and lighting conditions play a significant role in crashing (Harb, Radwan, Yan, Abdel-Aty, & Pande, 2008). Most accidents in work zones on highways, happen due to human errors like diverting, changing lane, speeding, braking, misjudgement and also not being adopted to a new environment (Bella, 2005).

Studies conducted on this topic show various results focussing on different parameters which lead to construction work zone accidents. About 21.4 % increase in crash rates occur as compared to pre-work zone period for long term construction projects (Juergens, 1972). There is also a significant increase in crash rates of about 88% for work zone period as compared to before pre-work zone period. Short term work zone having a lower crash frequency of about 0.8 accidents/mile-day. It was also noted that sites containing lesser information such as short tapers, missing arrow boards, and signs exhibited higher speed variations in work zone sites (Rouphail, Yang, & Fazio, 1988). In case of multi lane urban highway work zone sections, traffic control devices plays a significant role in crash rates, in work zone highways crash rates most often depend upon type of control devices. Accidents rates during work zone periods also depend upon accident rates prior to work period (Garber & Woo, 1991). It should be noted that presence of work zones has a negative effect on traffic safety. Crash rate during work zone periods is 21.5 % higher than pre-work zone period. More comparison shows crash rates comprises of 17.3% injury, and 23.8 % non-injury accidents. By using negative binomial models, increase in frequency of crashes when there was increase in work zone duration, length and average daily traffic. Time period, length and average annual daily traffic (AADT) of work zone also
influence injury & non-injury crash frequencies too, the longer the work zone time, length and AADT, more is the possibility of crash occurrences (Khattak & Council, 2002).

The target area of this study is work zone areas on Flemish highways. Since it is present Europe. The European Union (E.U) commission plays a significant role in policy making and policy implementation. The policies in Europe are formulated by E.U commission and followed by its member states. Belgium (Flanders) is also following its key policies in various sectors such as environment, economy, education, and traffic safety related focus areas. The commission is also looking after the traffic safety issues, formulates its key policies and targets in the European Zone. Traffic safety and accidents seems to be worrying problem and a major societal threat in Europe. In 2009, about 35,000 fatalities & 1,500 persons were injured on road in the Europe, the numbers are also equivalent to a small town. In Europe, occurrence of number of fatalities in rural areas is 56% and on urban areas is 46%. The E.U commission has addressed the situation of traffic safety by introducing a target based goal, which aims at traffic safety and mobility issues. The goal incentive program is also known as “Europe 2020- A strategy for smart, sustainable, & inclusive growth”. This program aims at providing sustainable transport to the citizens with better accessibility and mobility. It focuses on lowering the number of road casualties, improving the performance of transportation sector and thus meeting its citizen’s requirements and expectations. The European commission aims to reduce the overall number of road deaths by 2020 starting from 2010 (Nugent, 2010).

In Belgium, traffic safety situation is also not in the good shape, a lot of traffic incidents happens on Belgian roads. In the year 2012, there were about 44,193 accidents & 58,474 traffic injuries were recorded in Belgium. It is also seen that Flemish region is the largest contributor to traffic accidents having contribution of 63.74%, region of Wallonia contributed about 27.74% ad region of Brussels adding about 8.78%. General trend of 2012, in comparison with 2011 tells us that there is reduction in number of accidents and injuries by 7.8% and 8.2%, respectively. In Belgium, Road safety general is responsible for formulating & implementing its key policies for traffic situation in Belgium. It has set the target of reducing the number of accidents by half between the period 2010 and 2020. The goals for 2015, are to reduce the number of fatalities by 630 and by year 2020 is 420 fatalities. The Table 1 indicates the accidents and casualty data on Belgian highways. A general downward trend can be seen in number of accidents, casualties, deaths, serious injury, and slight injury by 14.7% & 7.5% respectively (Moens, 2013).

**Table 1 Accidents and casualty data on Belgian highways year 2011-2012 (Moens, 2013)**

<table>
<thead>
<tr>
<th>Accident and casualty data on Belgian highways</th>
<th>2011</th>
<th>2012</th>
<th>2011-2012</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of impact &amp; year</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Number of accidents</strong></td>
<td>47946</td>
<td>44193</td>
<td>-0.08%</td>
</tr>
<tr>
<td><strong>Number of casualties</strong></td>
<td>63723</td>
<td>58474</td>
<td>-0.08%</td>
</tr>
<tr>
<td><strong>Number of deaths 30 days</strong></td>
<td>861</td>
<td>767</td>
<td>-0.11%</td>
</tr>
<tr>
<td><strong>Number of serious casualties</strong></td>
<td>6169</td>
<td>5261</td>
<td>-0.15%</td>
</tr>
</tbody>
</table>
The Figure 1 tells us the relationship between numbers of fatalities, deaths occurred and the target sets by the year 2005 to 2020. It can be visualized from the figure that number of deaths increased by 11.9 % and 10.8 % by year 2008 & 2010, respectively. The below data was collected by the Police services, so quality of figures are more or less reliable & stable.

**Figure 1 Evolution of number of deaths on Belgian highways year 2005-2012 (Moens, 2013)**

The figure no.2, shows the total accidents on Flemish highways consisting data of number of accidents and number of fatalities. Looking into the figure further reveals the total amount of accidents, number of fatalities, number of accidents with serious and light injuries in Flemish highways from year 1991 to 2013 excluding year 2003. There is a general downward trend number of accidents occurring from year 2006. Most accidents have led to light injuries.
The figure 3 shows the number of accidents occurring in the construction work zone site from the year 1991 to 2003. This does not include the data from 2003, due to its reliability/authenticity. It should also be noted that in the year 2010, there were enormous amount of construction/maintenance works on Flemish highways. The following figure shows the detailed description of number of accidents on construction work zone sites having slightly injured and serious injury.
3. OBJECTIVES

Construction and maintenance work are going around the world on different roadway segments. All over the world, investments are being made to make transportation infrastructure better, by investing more and more on infrastructural development. Countries where there is more vehicle occupancy per population, face the issue of poor traffic safety situation in work zone areas in highways. It is seen vehicle occupancy is high in developed countries and low in under-developed countries.

Objective of this study, is to adapt the existing signalisation scheme for highway works by experimenting with the TTC measures in work zone area of Flemish highways. This involves designing the scenarios, randomizing, testing and analysing the results. At the end give recommendations that help drivers in better compliance & reduction of errors in work zone areas of highways.

3.1 Method selection

For research purpose the effect of a particular measure in a work zone area is to observe effects on driving before & after work zone scenarios. Thus for ideal situation, the similar way of practice can be done. However taken in consideration, the budget and time constraints for the study, the driving simulator was selected to perform the study, which is also a way to produce indoor results by simulating on-field behaviour of driver. The driving simulator study is used as a research tool for prediction of possible results. For this study, the driving simulator at Transportation research institute (I.M.O.B) of Hasselt University was used. This simulator scenarios were programmed on M500 series STISIM 3 (Systems & technology, 2013).

3.2 Parameters

Since this study is new, presents a novice look into driving performance of Belgian drivers on highways where work zones are present. The study is made in the simplest manner in order to avoid any confusion and complexity. The research aims at reaction of drivers (test subjects) while they encounter different temporary traffic control measures (TTC). Thus scenarios were designed in a manner that did not had any interaction with other vehicles in driving in the same direction.

The visualization of the simulation, reflects highway driving culture of Flanders, Belgium. A three lane highway was designed with a speed limit of 120 km/h, separated from other lane by median, with traffic also coming in the opposite direction. To be noted that this study preliminary aims at providing preliminary results, which can also be validated later on with a field study.

3.3 Simulation Parameters

The aim of this study is to examine Flemish driving behaviour facing work zone construction activities while driving through Flemish highways. There were some limitations to be considered while programming, otherwise experiment would be too complex. The research is conducted on driving behaviour of drivers while driving through construction work zone areas of highways, encountering different temporary traffic control (TTC) measures. To simply the driving process and avoid work load on drivers, traffic moving in the same direction with the simulated car was avoided. The base assumption of appropriate traffic flow is lacking, due to the reason that driver’s responses could be influenced. Therefore interactive traffic was not be present inside the simulated environment. But for giving a realistic approach to driver, two vehicles were added in the lead and two vehicles in the tail of drivers. The vehicles are programmed to stay 400 meters behind the simulated driving car and 300 meters ahead of the driver. The speed of vehicles is programmed to be intelligent speed (following...
test subject vehicle). Vehicles, both the vehicles in the front and behind are supposed to follow speed of the subject’s vehicle.

The visualization of the simulation scenarios are propagated to look alike the work zone construction schemes used at Flemish highways. Therefore a three lane highway separated by a median was programmed. The simulation also consisted of traffic coming in opposite direction separated by a median of highways in order to give a realistic look. This study is aimed to provide preliminary results of driving behaviour. Further the driving simulator is used keeping in mind the fact that it stressed verification of results in naturistic conditions.

4. RESEARCH QUESTIONS AND HYPOTHESES

The research questions have being formulated, covers the aspect of driver’s behaviour and actions which lead to accidents while driving in a work zone area on Flemish highway. The research domain of this study is focusing on construction work zone on Flemish highways, causing congestion, narrowing, diversion, confusion among drivers and thus contributing to accidents.

The following hypothesis is formulated in accordance with the research domain:

“Would the implementation of different signs typology, using signs boards, removing sign boards, providing extra sign boards i.e. speed camera sign, yellow speed limit signs and police presence strategies have a positive impact on general safety in work zone areas. Which sign board will give appropriate information to increase drivers understanding of the situation at site, without further confusing them in work zone highways. Which signs would result in compliance of drivers?”

Thus this study will indeed help to investigate whether or not speed management, speed enforcement, speed limits, lane closures, provide solution to issues of work zone conflicts in highways where speed regulated in sufficient manner. Mostly accidents occur due to drivers error i.e. speeding, overtaking, manoeuvres, braking and misjudgement. This research focuses in providing better driver compliance, sign recognition and understanding through providing temporary traffic control devices i.e. signs boards, speed limits, speed cameras, traffic management and speed enforcement strategies.

In this thesis report, attention is made to see driver behaviour in work zone areas where maintenance, construction is taking place, with respect to driving in day time environment. This research will be focusing in deep that how drivers behave while presence of temporary traffic control devices i.e. speed camera’s, police car presence, speed limits, sign boards and other important work zone components present in work zone scenario.

The main research question is formulated as following:

**Question: What are the effects of adaptation of different sign typology, sign boards in all different scenarios while observing driving behaviour in construction work zone highways?**

Since it is the aim of the study to the compare the effects of normal (implemented) signalization scheme in Flemish highways. Which is also taken as the reference scenario, comparing with manipulated signalisation schemes in Belgium, which consists of extra signs, speed limits, speed camera’s and additional temporary traffic control devices.

To be noted that reference scenarios and other scenarios are explained in detail in the methodology section.
The other research questions are formulated as follows:

1. What are the effects in driving in removing all signs except speed limits from left hand side in comparison with all other scenarios?
2. What are the effects in driving in no left hand sign board, in comparison with all other scenarios?
3. What are the effects in driving in a yellow background speed limit sign board, in comparison with all other scenarios?
4. What are the effects in driving in speed camera sign board, in comparison with all other scenarios?
5. What are the effects in driving in speed camera sign with police enforcement car presence, in comparison with all other scenarios?
6. What is the effect of end of work zone sign on mean speed and acceleration?
7. What is the effect of speed limits sign boards, before and after its occurrence?
8. Which sign results in higher deceleration speed camera sign or police car presence combined with speed camera sign?
9. Is there any effect of sign on standard deviation of mean speed and standard deviation of lateral position?

Here in this study comparison will be done and results will be tabulated, by comparing effect of implemented TTC measure in comparison with all other scenarios. The driving simulator parameters will be calculated by comparing every scenario with a set of temporary traffic control measure such as speed signs, lane closures, sign boards, and other traffic devices used while going through driving simulator scenarios. Other variables (i.e. filler pieces) are not taken in account. Adequate attention, has being given to mean speed, maximum acceleration/ deceleration and standard deviation of lane position of vehicle driven by a test subject. Although it is not expected to happen, but crash occurrence has also being monitored.

4.1 Research method

The main objective of this study, is to provide answers to formulated research questions in adequate manner, with the help of driving simulator. In recent years, a driving simulator has being used due to number of advantages and also has proven itself in contributing in research experiments. It is also considered as economical way of conducting research as compared to real world driving/field experiments. Apart from conducting experiments on driving simulator, field studies and surveys are also conducted for validation of results with real world environment obtained from the study. A driving simulator experiment is also considered to be safer then real world experiment, since it does not consist of possibility of accident.

During the course of experiment, the researcher is involved, who executes and monitors the experiment. The researcher has designed the scenarios himself. Thus the researcher can emphasize on certain variables to assess the effects and impact of that measure/variable.

Driving simulator research is considered valid and appropriate research methodology for driving behaviour assessment. Other factors of using driving simulator is that it also possess the dimension of safety and easiness compared to field study. Thus, proves itself to be a useful experimental tool into those situations which are considered vulnerable in real life.
4.2 Research development
The research questions itself helped to emphasize on assessment of driving behaviour while certain measures are present, and to foresee their prominent effects.

The key distinct design feature in work zone areas in Europe are approximately same, only the signalisation implementation may differ depending on country origin. Almost every country has its own set of rules and procedures for implementation of work zone activities on highways. Thus driving in work zone area in USA or UK is not the same as driving in work zone highways in Flanders.

Flemish highways consists of drivers coming from diverse backgrounds due to the country’s strategic location. Therefore emphasis is made to assess behaviour of drivers coming from different background possessing a valid Belgian/European driving license in order to generate healthy results. One could argue about the implementation difference of work zone areas in highways in other parts of the world. Different countries follow different guidelines for implementation of TTC measures in work zone areas. Focus in this study is made to assess the possible practical implication of TTC measures on Flemish highways. Therefore scenarios were designed in a manner to check the effect of good practices adopted in other countries on Flemish drivers. The scenarios for the experiment are designed by following the traffic sign typology guidelines set by the Flemish authorities.

5. LITERATURE REVIEW
This section provides the review of past literature and summaries of different researches studies around the globe on work zone areas on highway. This section consists of definition of work zone present on highways, its different elements/components and other related articles described in detail in ensuing paragraphs.

5.1 Work Zone Area
It can be defined as “Area of a highway where construction and maintenance related activities are carried out”. The work zone areas entail different sign boards, channelizing devices, barriers (both median and side), pavement markings and machinery/equipment for carrying out the construction activities. The work zone area normally starts from first warning sign to end of road work sign (FHWA, 2009).

5.1.1 Components of work zone area
The work zone area is further divided into four sections, which are described below:

5.1.1.1 Advance warning area
The advance warning area is the section where road drivers are informed about the upcoming construction and utilities activities see figure 4 for graphical details. It should be properly placed on a highway where road users can easily recognize the information and act accordingly. The advance warning area may comprise of a single warning sign or series of multiple signs including, but not only limited to inclusion of high intensity flashing, oscillating and rotating light. The distances for placement of the signs shall be given utmost attention and should be placed neither too close nor too far. Moreover, the signs should be placed at a nominal distance, so that drivers can easily perceive the information and react to situation in given time without disturbance (H. Yang, Ozbay, Ozturk, & Xie, 2015).
5.1.1.2 Transition area
The transition area is the section where drivers are informed to change their path and enter into the work zone activity area (Figure 4). The re-direction to the normal path is done via channelization devices, vehicle mounted traffic control devices i.e. sign boards, arrow boards, changeable message sign boards, flashing, intense rotating and oscillating lights. In transition section, portable devices are preferred over static channelization devices due to nature of application (Yilei Huang & Bai, 2014). Nature of application refers to dynamic nature of construction activities which are continuously shifting from one point to another over a large span of area on highway.

5.1.1.3 Activity area
The section where construction, maintenance and utility activities are conducted is generally termed as activity area (Figure 4). The activity area comprises of components related to construction such as workers, equipment, material and on-going activities. For authorities to respond quickly a staging place is provided to vehicles, for quick response in case of emergency.

5.1.1.4 Termination area
It is the section of the highway where road drivers are informed that they can resume their normal driving operations of the highway (Figure 4). The termination area extends from end of work zone activity area to last TTC device place i.e. end of work zone sign. In business as usual cases, a traffic sign i.e. speed limit, end of work sign or other sign may be used to inform drivers that they can now drive on normal speed and use the other blocked/prohibited lane.

Figure 4 Different components of work zone construction area of highway (FHWA, 2009)

5.2 Traffic calming measures in work zone highways
Various research works indicated the use of different type of traffic measures as per requirement of work zone highways i.e. speed limit signs. Apart from regular TTC measure specified by governmental agencies, numerous researches revealed the experimentation and adoption of newly developed TTC
measures. The ensuing paragraphs describe the most recent developed and adopted traffic signs used around the globe.

5.2.1 Changeable message signs/ Dynamic message signs

It is an electronic traffic control device which is capable of showing multiple messages to road users. They are also known as dynamic message sign or variable message sign. This sign is further classified into permanent changeable message sign (CMS) and portable changeable message sign. Generally portable message signs are smaller than permanent message signs, and are used on highways at special occasions such as accidents, disaster, warning, advisory and taking alternative route messages. CMS can be used for providing real time information to road users. Those message may also contain advice about a certain problem and proposed solution (Dudek, 2004). CMS is used in the field for a long time since 1960s. CMS is helpful in reducing speed by 11% after going through the sign board. It is also seen that drivers with vulnerable attitude i.e. teenagers drive with high speeds through work zone areas (Yunchen Huang, Strawderman, & Garrison, 2013). In general, CMS is regarded more effective in reducing speeds and influencing drivers in work zone when compared to static speed signs. It is also seen that CMS helps in reducing mean speeds by 12.86 km/h in work zones of lengthy duration (Garber & Srinivasan, 1998).

1. Permanent changeable message sign

Permanent changeable message signs are those signs which cannot move and are statically placed at one location. Researchers find reduction in speed due to implementation of CMS. In Virginia USA, CMS were used at seven work zone places, compared with situation which had manual of uniform traffic control devices (MUTCD) static advisory, warning signs and results concluding that drivers reduced their average speed (Garber & Patel, 1995). In 2014, a study was conducted to check the effectiveness of changeable message signs on driver’s behaviour by comparing different aggregate analysis using a set of empirical data. The results indicated that CMS do not have an important effect on diversion of driver, whereas congestion (visible by normal eye vision) found to have significant impact on diversion of driver (Xuan & Kanafani, 2014). Stated preference surveys showed an interesting aspect of driver’s perception of CMS. Studies conducted by stated preference surveys revealed that driver’s decision is effected by flexibility of schedule, travel distance, familiarity of alternative routes, previous experiences and available information (Ben-Elia, Di Pace, Bifulco, & Shifman, 2013).

Figure 5 An impression of changeable message sign
CMS signs are installed near work zone entries contributing by help lowering the speeds. By doing so drivers are already prepared for lowering their speed limits, as they will drive through work zone area and will be inclined to maintain their speed too (McMurtry, Saito, Riffkin, & Heath, 2009a).

2. Portable changeable message sign
A PCMS (portable changeable message sign) is temporary traffic control sign which can be moved from one location to another in work zone areas of highway usually mounted on a large truck, dumper or on back of a large vehicle (FHWA, 2009).

PCMS has raised as a significant technology for temporary traffic control devices used in work zone areas on highways to convey advisory and warning message sign in a given sequence. A simulator study was performed in Texas, USA on 32 participants to test the effectiveness of compliance rate of unit of information for PCMS. Referring to the guidelines set by FHWA, and other research studies conducted earlier suggest that pieces of unit of information shall be kept below 5 units. The results also revealed that keeping 5 unit of information while even using sequential PCMS, the compliance rates remain low. However by keeping message length to four units spread over 2 portable changeable message signs gives better compliance than keeping information concentrated at one location visible by a large changeable message sign (B. Ullman, Ullman, Dudek, & Williams, 2007).

![Commonly used portable changeable message sign](image)

Figure 6 Commonly used portable changeable message sign

Graphics aided changeable message signs proved to have a better understanding among highway drivers. Graphics aided signs have advantages like they are more recognizable under severe visual conditions, information quickly extracted by drivers, and more understanding than reading out a long text. On the other hand traditional text based signs have limitations such as difficulty to read among less educated drivers. Field simulation study were conducted in USA, for checking the effect of mean speed of presence of graphics aided portable message signs placed on work zone area on highway. The data was collected for about 1600 vehicles and data analysis showed reduction in mean speed by 17% in upstream part of work zone (Yilei Huang & Bai, 2014).

A study conducted in Texas, USA about truck mounted changeable message sign (TMCMS) in work zone operations tells us that, they can be used for short, unplanned, sudden, and unscheduled operational control in work zones for informing road users about unexpected conditions. The TMCMS can be used as a successful tool for giving appropriate information with a small amount of time for immediate actions to be carried out by drivers. The results revealed that TMCMS yield in revealing better recognition and recalling among drivers. The best reaction time of participants was noticed by “Man working figure”. Reaction time for this study was recorded for text was 23 seconds and for symbol 33 seconds. TMCMS were also used successfully for carrying out lane changing conditions to drivers (B. Ullman, Trout, & Sun, 2012).
5.2.2 Variable speed limit

VSL (Variable speed limits) are those electronic sign boards which have varying characteristics of speeds limits according to roadway and environmental conditions i.e. congestion and snowy weather. They are used for increasing traffic safety during extreme roadway and environment conditions (DOT, 2014).

The concept of variable speed limit is not as common in USA as it is studied theoretically without any practical implementation. VSL can be used an important tool for regulation of traffic and reducing speeds on highways. Some limitations regarding implementing this technology are system's operational deficiencies, compliance, compatibility and configuration. VSL can be useful tool on relieving from ongoing congestion and offers instance recovery too in case of demand volumes not being so high. If demand volumes are high, VSL does not seem to be useful tool. Whereas location of VSL is of utmost importance as they should be located at nodes, where drivers can act accordingly once going through bottleneck (Fudala & Fontaine, 2010). VSL has a positive impact on mobility and safety of highways. The crashes were reduced from 10-30% after installing them on highways of Germany and Netherlands (Robinson, 2000). The highways in Finland showed reduced mean speed of 3.4 km/h in case of free flow traffic after installing VSL. These highways posted speed were reduced from 100 to 80 km/h (Rämä, 1999). VSL is often used along with automated speed enforcement methods which can also be an influential factor.

![An impression of variable speed limit](image)

Figure 7 An impression of variable speed limit

Ohio state department studied the effect of motorist speed responses to variable and non-variable speed limits. In this study variable speed limits are helpful in reducing mean speed by 3-11 mph. It reveals that motorist reduce their speed of vehicles. Thus recommending to use the first speed limit for work zone, when the work zone area is clearly visible to the driver (Finley, Jenkins, & McAvoy, 2015).

5.2.3 Lane closures

Lane closure sign boards guide and give information to drivers on highways that lane on left side (high speed vehicles lane) or right side (slower speed vehicles lane) is going to close and driver has to change lane and merge into another lane (FHWA, 2009). This sign board is used to maintain traffic flow, avoid congestion and accidents by giving information to drivers prior to the occurrence of work activities. Lane closures can be static and dynamic (electronic) as well.

For lane closures two safety indicators are used for measurement of expected increased of likelihood of crashes i.e. (1) Uncomfortable deceleration (2) Speed variance. Uncomfortable deceleration applies...
to rates exceeding 3.048 m/s² (Nemeth & Rathi, 1985). The number of frequency of uncomfortable deceleration at some specific points increases chances of crash occurrence.

Pigman et al. (1988) concluded that 95% drivers usually change their lane in advance warning area prior coming to transition area, less than 5% of drivers change their lane in transition area.

In 2004, safety analysis study was conducted to check which lane closure (left or right) fallout in occurrence of more conflicts, de-acceleration and crashes. The study concluded that left lane closure results in higher declaration values and resulting in increased collision risk in work zone areas. This is due to the fact that vehicles travelling on left lane are faster than vehicles on right lane. Uncomfortable deceleration rates for left lane are higher than right lane closure (Zhu & Saccomanno, 2004).

With improved ITS technology used in work zone, issues/problems can be assessed and addressed. Grillo et al. (2008) evaluated the effectiveness of dynamic late lane merge systems (DLLMS) on highway work zones. The aim of using DLLMS is to specify one point of merging for drivers, in order to improve traffic flows, ultimately reducing queue lengths. The use of DLLMS has shown positive results, thus laying a positive shade on traffic flows. Calculations based on saved travel time reveal that DLLMS has a benefit cost ratio of 1 and saves time of $5/h giving positive monetary benefits.

Use of ITS technologies, provide positive outcomes such as better compliance, better traffic flow, reduction in occurrence of injuries, improved safety and mobility in work zone areas of highways. Radwan et al. (2011) found late SDLMS (standard dynamic lane merge system) with and without VSL in high traffic scenarios (2500 vehicles per hour) produce higher mean throughputs and compliance rate of 60%. Thus use of ITS technologies produces better mobility performances than existing static sign boards systems in case of work zone configurations.

Literature suggests (Nemeth & Rathi, 1985; Pigman & Agent, 1988; Zhu & Saccomanno, 2004) that lane closures have an effective impact on traffic safety situation. Hence in the experiment, static lane closures are used, at different locations to guide drivers. The static lane closures are adopted in the scenarios at location of 5000 m, 6500 m, 7000 m, and 7750 m.

5.2.4 Speed camera signs

Speed camera signs are installed at various locations of highways having purpose to record/make photographs of vehicles, and inform authorities who violate the speed limit laws on highways. There are three types of speed cameras. 1. Mobile, which traffic officers carry from one location to another to check speed. 2. Is fixed, which is located at one point and cannot be moved. 3. Speed cameras are controlling speed over a section of roadway, and speed is measured on average over the whole section.

While speeding is considered as a critical factor which plays an influential factor on traffic related conflicts, especially resulting serious injuries (Elvik, 2005). Speeding results in frequency and occurrence of crashes. Thus to improve work zone safety, speed compliance can be maintained by speed cameras and automated radar speed enforcement. Thus research has been carried out on this topic for predicting its effectiveness on different parameters. It has been seen that speed cameras influence over traffic flow, average speed, crashes type i.e. rear end or side sweep crashes. To foresee the effect of fixed speed camera, it was installed on a 6.5 mile route of highway in Arizona, for a period of 9 month. The effects were measured for period-after and termination period of cameras. The results suggested that speed camera can be used as an effective tool for reduction of mean speed of 9 mph was recorded after installing it, crashes types were also reduced, and after removing the camera’s speeding frequencies were increased by 10.5 (Shin, Washington, & Van Schalkwyk, 2009).
Figure 8 Good practices for speed camera devices

Speed enforcement devices (SEDs) such as cameras, laser and radar devices are considered as effective in reducing speed and injuries. SEDs have a sound effect in proportion of speeding vehicles ranging from 5 to 70% in a pre/post scenario respectively. In case of over speeding vehicles, travelling more than speed limit, 50% to 65% reductions were reported for pre/post scenarios (Wilson, Willis, Hendrikz, & Bellamy, 2006).

In Washington, U.S.A speed cameras were evaluated by implementing at 7 different sites in year 2001, data was collected 1 year before enforcement and 6 months after enforcement began. Results suggested that there was significant reduction in mean speed by 14%, amount of vehicles speeding also declined by 82%. Thus recommended to use as an effective tool for speed reduction, severity and frequency of crashes (Retting & Farmer, 2003).

Automated speed photograph radar enforcement (SPE) is also seen as an emerging technology for compliance of speeds and reduction in frequency of violation of speed limits. SPE has proved itself as a useful traffic indicator to regulate, control, maintain speed on work zone highways especially before and during work zone areas of highways. SPE has speed reduction effect on light vehicles of 4 to 8 mph, whereas 3 to 7 mph on heavy vehicles. SPE has also a positive effect on number of vehicles speeding. It did not any remarkable impact on post work zone of vehicles (Chitturi, Hajbabaie, Wang, & Medina, 2010).

5.2.5 Police enforcement

Police enforcement is considered to be effective, efficient way of reducing speed and controlling traffic laws violations. Studies conducted in past revealed that police enforcement plays a significant role in speed reductions. Police enforcement can be covert or visible. There are different methods of police enforcement such as circulating patrols, stationary, aerial enforcement, and automated enforcement technology (G. L. Ullman et al., 2010).

Miller et al.(2009) analysed the effect of police presence in work zones at night time. Police presence resulted in mean speed reduction of 5.3 mph in work zone area of highway. Effect of rumble strips in combination of police presence was also studied, showing mean speed reduction of 4-6 mph, also with standard deviation of speed by 25% (Zech, Mohan, & Dmochowski, 2005).

In Indiana, USA study was conducted to identify and tabulate the effects of traffic volume, work zone specific features, police presence, and road way configuration on crash frequency in work zones. Findings revealed that police presence caused 41.5 % reduction in frequency of crashes (Chen & Tarko, 2012).
Speed flow relationship curves were studied in work zone with presence of police and speed cameras. The reference scenario which did not have any police or speed camera had a free flow speed (FFS) of 61.3 mph and capacity of 1850 per car per hour per lane (pcphpl). Due to police presence FFS was reduced by 6.3 mph and capacity reduced by 50 pcphpl. While for speed camera FFS and capacity was reduced to 6.8 mph and 100 pcphpl (Avrenli, Benekohal, & Ramezani, 2012).

**Figure 9 Impression of police enforcement**

The combined presence of speed camera sign and police presence may have a significant impact on driving behaviour due to “deterrence theory”. Deterrence theory comes from behavioural psychology explains that actions can be controlled by fear of punishment. Deterrence theory exists for both general and specific. General deterrence means, any punishment which is made public to make people refrain from certain activity. Specific deterrence means any punishment made to a particular person over violating a certain law in order to refrain that action in future (Apel, 2013). In driving specific deterrence can be applied to control driving behaviour.

### 5.2.6 Effect of Colour on sign board and pavement markings

For better compliance, signs are designed in a manner which help to understand the information given to the drivers. If sign boards are in-appropriate and drivers cannot visually sight it properly thus it will ultimately lead to crash occurrence and traffic safety issues. In-appropriate use of colour will lead to poor visual recognition, visual discomfort and ultimately resulting in a problem (Matthews & Mertins, 1987). Colour plays an important characteristics in visual performance of an individual driving on a roadway segment. In 2005, a study was conducted to evaluate the driver response recognition time of 4 different colour schemes in a randomized order in dynamic message sign. Amber colour scheme resulted in a shortest amount of response time. Drivers took more time to recognize red colour. Younger drivers were quicker in colour recognition than old age drivers. Participants respond more quickly to two colour scheme than three colour scheme (C.-M. Yang, Waters, Cabrera, Wang, & Collyer, 2005). Attentional cognitive processing of location and colour cues while driving were assessed. Aim of this study was to explore the effect of colour and location on response time. At long distance colour gives more recognition, locating a sign takes more time so colour attraction helps in vision. At short duration location cues are valid and colour cues are prevalent such as they have insufficient time for detection (Xia, Fukushima, Kimura, & Miura, 2009). Literature further suggested that in UK signs to be used in work zone area should have a high visible acceptance i.e. yellow, amber, white background, having font in colours which are in contrast i.e. black(Department, transportation, Gov, & UK, 2015). Work zone areas on highways in Belgium, use traffic signs in yellow background, except for speed limits.
For better visual recognition in work zone areas on highways, Howell, Pigman, and Agent (2015) conducted a study, to foresee which colour type result in better compliance. Revealing that all participants rated amber colour as an effective measure for visual recognition on highways.

Method of making pavement and signs more visible is by retro-reflection. Retro reflection is a phenomenon that happens when “light hits a particular surface and comes back to source of light”. Imperfect nature of retro-reflected material causes the light to reflect in a cone around the source of light, directing drivers eyes a slight portion of light and hence making it more visible (McGee & Mace, 1987).

For better visibility and durability, proper application of retroreflective materials is needed. Bead application in pavement markings results in more visibility and recognition, even at night time among all pavement materials (Montebello & Schroeder, 2000). This study used amber markings on roads in transition area, in-order to inform drivers of late lane merging. Glass beads, standard and snow plow-able retroreflective pavement markers are useful for good recognition especially in night conditions (Migletz, Graham, Harwood, & Bauer, 2001).

5.3 Driver work load
Driver work load is the amount of level of effort input. In total there are four methods to assess the driver’s work load in a particular situation. The following are the four methods:

1. Standalone performance measure.
2. Subjective estimates of workload.
3. Secondary task performance
4. Physiological measure.

Secondary task performance measures are used for research purposes. Amount of work load generated is seen by calculating difference between primary and secondary task (Rudin-Brown, Williamson, & Lenne, 2009). Work load among drivers is measured by filling out a paper based questionnaire or a software based applications. Most common subjective work load assessment is done by NASA Task load index (TLX). NASA TLX is available in both paper and software format. NASA TLX uses six dimensions for calculating work load index, which are of following nature (Cao, Chintamani, Pandya, & Ellis, 2009):

1. Mental demand
2. Physical demand
3. Temporal Demand
4. Performance Level
5. Effort level
6. Frustration Level

Literature suggest that NASA TLX can be used in an effective manner to assess work load among different sample of drivers. NASA TLX has proven its use in various fields i.e. medicine, nursing and psychology.

NASA TLX has also being used to assess the effect of changing work zone configurations on performance variables. A study emphasis its impact on self-reported ratings on drivers task. Here Conventional lane merger (CLM) and joint lane merger (JLM) were used, which were assessed by NASA TLX while driving in a simulator based experiment. The analysis of results show no significant increase/decrease in mean speed, acceleration between JLM and CLM. Whereas self-reported work load ratings by participants show that JLM have 15.3 % lower work load. Thus JLM proving to be a
useful merge configuration in terms of providing safety and optimizing traffic flows (Shakouri, Ikuma, Aghazadeh, Punniaraj, & Ishak, 2014). For examination of drivers behaviour in complex virtual environment. A study was conducted to assess different level of simulator fidelity impacting subjective and physiological work load among drivers. ANOVA analysis of results reveal that scenario complexity and secondary tasks had a direct effect on work load. Whereas simulator fidelity had no effect on work load. Thus proving low fidelity simulators to be useful research tool (Mueller et al., 2014).

5.4 Studies related to work zone areas on highways

A field study was conducted in Texas USA, to foresee the effect of compliance rate, effect on speed for three different signs, such as speed display trailer, changeable message sign with radar, and orange background speed limits. Results revealed that orange background speed limit signs improve visibility, but can only have a positive effect when used with other temporary traffic control device. CMS with radar with posted speed limit of driver show better driver compliance and speed reduction. But drivers tend to drive at their normal driving speed if their speed limit is not realistic and no active work is going on. This is only possible without active enforcement (Brewer, Pesti, & Schneider IV, 2006).

In South Carolina, USA study was conducted to evaluate speed activated sign in reduction of speeds in work zones. Innovative message signs are considered as expensive and also impractical. Therefore speed activated signs are used for speed reduction strategies in work zone area of highways, due to their economical and ease of handling reasons. The results showed reduction in mean speed by 3.2 to 9.7 km/h. Thus it can be seen as a useful tool for speed reduction on short term basis in work zone area of highways (Mattox III, Sarasua, Ogle, Eckenrode, & Dunning, 2007).

In USA, effect of work zone crash occurrence on safety performance measurement program was assessed. This was done to observe the effect of work zone on level of severity of crashes. Examination of collected crashes data, crash trends and also safety improvement measures were observed. Results showing that only 23% of crashes occurred in the vicinity of work zone could have an influence, and can be related directly to work zone (Clark & Fontaine, 2015).

A study for vehicle intrusion crashes tell that intrusion crashes made up of about 7.5-12.4% of crashes in work zone areas. Whereas lane closure had the largest proportion of operations. Moreover it was seen that vehicle intrusion crashes also resulted due to driver’s decision of ranging about 25% to 64% to enter work zone area (G. Ullman, Finley, & Theiss, 2011).

In recent years, good amount of research has being conducted on work zone areas, to determine relationship of various factors on crash occurrence and causal factors. To be noted that there is a significance increase in crash rate has being observed, rear end crashes are seen to occur more frequently if work zone areas on highways are present. No specific location in work zone area is observed with more frequent crashes. Here no relationship is found to be among crashes and factors such as time, severity, facility type, weather and opted TTC measure. Furthermore for better assessment of work zone crashes, focus shall be more tended towards data collection, advanced modelling technique, and creating a systematic data analysis framework (H. Yang et al., 2015).

In work zone areas, half of injuries of construction workers occur due to vehicle and equipment of vehicle. Vehicle is backing appropriate communication shall be maintained for safety purposes for the workers on foot. The workers shall also be provided adequate amount of safety training to perform their difficult duties. This also includes in developing in a procedure or a set of mechanism to minimize the exposure of workers on being foot. Installation of traffic guiding devices will also result in better compliance. Lastly vehicles shall incorporate newer technologies for detection of workers presence on foot in blind areas (Romano, Fosbroke, & Ruff, 2008).
To address the issue of speed management in work zones, a project known as ASAP (Appropriate speed saves all people) was conducted in context of Europe. The aim of this study was to provide set of possible solutions for increasing safety on different type of road types and work zone layouts, independent on the country they travel through. This project evaluated the effectiveness of different sign boards, speed reduction measures, and speed enforcement in different European countries. This main analysis of this project was that inside work zone there is uniform speed distribution, while added dynamic measures help in reduction of speed (Thomson, Saleh, La Torre, Cocu, & Tucka, 2014).

5.5 Driving simulation studies

In USA, validation studies for TTC devices in work zone area on highways was done for night time. Data for real life driving through work zone highways were accumulated. The simulator experiment on 127 different test subjects were performed. To foresee different effects, results were concentrated on three points at beginning near transition area, in middle and in the end of the work zone area near stream tapper section. The statistical results were analysed, concluding that due to perception of risk in real life while driving, driving simulators represent mean speed observed to be significantly different from real life (McAvoy, Schattler, & Datta, 2007).

To investigate the effects of primary, secondary factors of work zone on driving behaviour and crashes a study was done using driving simulator. In this study primary factors are roadway type, density of traffic, lane closure, and shoulder closure. Whereas for this study considered secondary factors were driving behaviour, potential for crash, and environment. 45 participants were tested for this study. Those participants drove through 24 different configurations, using crash frequency, speed, lane deviation as variables for performance. The results tell us that traffic density, roadway type do not have any novel effect. This study concludes that most vulnerable roadway configuration is the one which consists of divided roadway with high traffic density, and vehicles which are suddenly braking or stopping (McAvo, Duffy, & Whiting, 2011).

In research, driving simulator can also be used to evaluate safety audits of highway configurations and design operations. Safety of roadway geometry can also be measured by driving simulator research.

5.7 Validation of driving simulator

Driving simulators are used to evaluate the driving performance and environment, of those situations which are considered vulnerable, not possible in real life situation. For validation of driving simulator with various other factors, many relevant studies have being conducted.

In order to give a positive outcome and prove to be useful research tool. A validation of driving simulator must be done with relevant work. Thus taking in account validation, a study was done in Italy to validate the work zone configurations with field study highway work zone areas of medium duration. Thus results concluded that differences between speeds in real life and simulation experiment were not statistically different. Thus proving the simulator experiment to be relative valid with on field real life driving in terms of work zone design configurations (Bella, 2005).

A validation study of type and mean driving errors were done by driving simulator. Driving behaviours in real life and in simulated environment were monitored by occupational therapist and train researchers by using assessment form. Statistical analyses was done by paired t-tests to assess the difference between these two environments i.e. real life and driving simulated environment. For assessment of driving errors performance measures like mirror checking, left, right, forward observations, speed and traffic signal compliance are relative valid. Whereas as differences were found and are not considered valid performance measures like, speed behaviours, gap selection, and
lane position of simulator on road. The proving driving simulator to be relative valid to real life situation, but are not absolute valid to real life (Meuleners & Fraser, 2015).

Driving behaviour questionnaire are also considered as a relative, valid and useful tool for behavioural analysis of drivers, in both simulated and real life environment. DBQ shows meaningful correlations in accordance with speed measures with driving simulator. DBQ is considered to be valid measure for both real life and simulated driving (Helman & Reed, 2015).

Two concurrent pair of studies were conducted to foresee validation of real life and simulated experiment for driving performance. The first study focused on young novice drivers, revealing a degree of concordance in terms of driving errors, for both environment. The second study considered participants from three different categories having different level of experience of driving. Results showing that drivers having lesser driving experience performed more of driving errors. Concluding that more the experience, lesser is the chance of accident. These findings support using driving simulator as a valid tool and relatively valid for research purpose (Mayhew et al., 2011). Furthermore simulators validation for hazard perception in roadway geometry and environmental conditions tell us that it is an effective tool for training and testing purpose. Simulator experiment show earlier fixation on hazardous objects for experienced drivers (Underwood, Crundall, & Chapman, 2011).

6. METHODOLOGY

This study focuses on using driving simulator to investigate driving behaviour of Flemish drivers while passing through work zone areas of highways encountering different traffic control devices. This study examines the driving behaviour in six different simulated conditions. One control condition is set as reference scenario which is traditional signalization scheme adopted on Flemish highways. In other five scenarios the behaviour of drivers towards other temporary traffic control devices are examined encountered at different location of scenario. This ensuing section also elaborates testing of one control condition and five different uncontrolled conditions.

6.1 Scenario

The simulation consisted of total six different scenarios which were encountered once by every participant. These scenarios were developed from signalisation schemes used in work zone areas on Flemish highways in Belgium. The signalisation scheme specified by the Flemish government for work zone area on highways are used as reference scenario in this study.

Every individual programmed scenario, comprises of temporary traffic control devices of reference scenario, thus one condition of temporary traffic control device are introduced and tested in that manipulated scenario. In this study, focus was remained to avoid to give any information that lead to confusion for participants while driving. Therefore in other 5 simulated driving scenarios, it was avoided to introduce any combination of different traffic control device. Therefore 5 simulated scenarios had its distinct condition i.e. temporary traffic control device. In short the following scenarios were developed.

The following table elaborates, the details of the simulated scenarios, which were tested among the participants.
6.1.1 Scenario 1 (Reference Scenario)
Figure 11 Description of reference scenario and placement of TTC device
The reference scenario consists of different temporary traffic control devices for work zone areas on highway as specified by the Flemish government. The length of scenario is in total 11 km. Whereas width, number of lane, shoulder width, divided line type and grade percentage were made according to the standard practice. The first three kilometres are acceleration zone, 1 km congestion zone, 1 km congestion tail zone, 3 km of signalisation scheme, 2 km work zone area and 1 km post work zone area. The reference scenario consists of following TTC sign boards and device:

1. Overhead bridge changeable message sign
2. Lane closure
3. Speed limit sign board
4. Portable changeable message sign
5. Attention sign board
6. Man at work sign board
7. Retroreflective pavement marking
8. Delineators
9. Construction barrels for lane separation
10. Construction zone end sign

The detail description of used TTC signs and devices can be found in annexes.

To be noted that reference scenario was used as a base assumption for creating all other manipulated/rest scenarios. The manipulated/rest scenario consists of adding or replacing a TTC device i.e. speed limits and speed camera.

For uniform outcome of results, every TTC measure is tested before and after 250 meters of its presence. For example if assessing the effect of speed limit of 90 km/h at a location of 500 m, the mean speed is taken in account before and after 250 m, which is 250 m and 750m of the location of sign (Jongen, Brijs, Mollu, Brijs, & Wets, 2011). Use of VSL has a good impact on traffic flows, but due to limitations of the STISIM software, this Master’s thesis experiment has not adopted the use of VSL in the simulation experiment. Literature by (Migletz et al., 2001; Montebello & Schroeder, 2000) suggest the use of retroreflective material, along with standard glass bead markers, which improve the visual recognition specially at night due to their sharp reflection. Thus in this Master’s thesis experiment, amber colour pavement markings are used specifically at one location, which indicates lane change occurring just before start of work zone area. The amber colour pavement marking is used in all 6 designed scenarios, at one location at 7975m. This Master’s thesis experiment study consists of overhead bridge, which consists of traffic information for stimulating efficient traffic flows on highway. The overhead bridge consists of a permanent changeable message sign, having 3 units pieces of information, which is motivated by the guidelines of roadway agencies i.e. FHWA (2009). Furthermore the use of changeable message sign (CMS) is inspired by (Ben-Elia et al., 2013; Garber & Srinivasan, 1998) suggest that CMS has a positive effect in terms of mean speed and traffic safety situation. The simulation experiment also test the effect of presence of graphic aided design inside the different scenarios programmed. Literature by Yilei Huang and Bai (2014), B. Ullman et al. (2007) suggests the use of graphic aided changeable message sign, and portable changeable message sign. Hence both technologies are taken into account. In the experiment combine use of graphics aided signs and portable message signs are adopted, which are present in the scenarios at the distance of 3800 m on right hand side and at 8000 m on left hand side.
6.1.2 Scenario 2 (Remove left hand side signs except speed limits)
This scenario were designed to focus on gathering data, about the driving behaviour when sign placement is in-adequate. Thus all signs were removed from left hand, except speed limit sign. The scenario is further elaborated in detail in the annexes I.

6.1.3 Scenario 3 (Remove all left hand side signs)
This scenario focuses on assessing driving behaviour when all signs from left hand side are removed including speed limit. The scenario is further elaborated in detail in the annexes II.

6.1.4 Scenario 4 (Speed camera sign)
Focus remains on this scenario about the instant reaction of drivers when they encounter speed camera. This scenario is elaborated in detail in annexes III. This thesis study evaluates the effectiveness of speed camera sign presence on a section of road. Literature by (Chitturi et al., 2010; Retting & Farmer, 2003; Shin et al., 2009; Wilson et al., 2006) suggest that it has positive effects in speed reduction, speed compliance and regulating traffic. The speed camera sign is used in only one programmed scenario at a distance of 7650 m on right hand side.

![Speed camera sign](image)

Figure 12 Speed camera sign used in Flanders, Belgium

6.1.5 Scenario 5 (Police with speed camera sign)
Focus remains on this scenario about the instant reaction of drivers when they encounter police presence before entering the construction work area of the scheme. To be noted that in this scenario comprises of combined use of speed cameras sign boards and police presence. This scenario is elaborated in detail in annexes IV. Relatively several studies by (Avrenli et al., 2012; Chen & Tarko, 2012; Miller et al., 2009; Zech et al., 2005) were conducted to foresee separate effects of police enforcement and SPE, on driving behaviour on highways. However effects of combined enforcement of police and speed cameras signs have not been studied extensively. Hence this Master’s thesis experiment has addressed this problem by carrying out simulation scenario to assess effect of combined enforcement of police enforcement and speed camera sign. In the experiment combine enforcement of police presence and speed camera signs are adopted, which are present in the scenarios at the distance of 8000 m on left hand side and at 7650 m on right hand side respectively.
6.1.6 Scenario 6 (Yellow speed limits)

This scenario examines in detail driving behaviour and reaction, while they encounter retroreflective material sign boards such as yellow background speed limit sign board. In general, in Flanders speed limits are posted in white background. This scenario is elaborated in detail in annexes V. Literature (Howell et al., 2015; Matthews & Mertins, 1987; Xia et al., 2009; C.-M. Yang et al., 2005) suggest positive outcome, of using amber background colour sign boards for visual recognition. Whereas in the literature emphasis has also being made that those sign boards shall be used which have better recognition at longer distance and night time giving a better sight for all age group drivers. But still literature has not yet identified the effects of using yellow colour sign boards, nor has it evaluated the effect of combine use of amber and yellow background sign board. Thus in this Master’s thesis experiment yellow background speed limits signs are used in combination with amber background sign boards (lane closure), to foresee possible effects both combine, and separate manner.

Table 2 Description of location of sign placement in reference and manipulated scenarios of experiment

<table>
<thead>
<tr>
<th>DRIVING SIMULATOR SCENARIOS IN THIS STUDY</th>
<th>WORK ZONE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIGNS TO BE USED AND THEIR LOCATION</td>
<td>SCENARIO 1 (REFERENCE SCENARIO)</td>
</tr>
<tr>
<td>SIGNS USED FOR MANIPULATED CONDITIONS</td>
<td>LEFT BLANK ON PURPOSE</td>
</tr>
<tr>
<td>DISTANCE 350 m, SIGN 15</td>
<td>YES</td>
</tr>
<tr>
<td>DISTANCE</td>
<td>SIGN</td>
</tr>
<tr>
<td>----------</td>
<td>------</td>
</tr>
<tr>
<td>8000 m</td>
<td>16</td>
</tr>
<tr>
<td>6600 m</td>
<td>17</td>
</tr>
<tr>
<td>6900 m</td>
<td>18</td>
</tr>
<tr>
<td>7500, 7850, 8250, 8750, 9250 and 9750 m</td>
<td>19</td>
</tr>
</tbody>
</table>

**Sign boards on both left & right side**

<table>
<thead>
<tr>
<th>DISTANCE</th>
<th>SIGN</th>
</tr>
</thead>
<tbody>
<tr>
<td>3000 m</td>
<td>1</td>
</tr>
<tr>
<td>3800 m</td>
<td>2</td>
</tr>
<tr>
<td>5000 m</td>
<td>3</td>
</tr>
<tr>
<td>5500 m</td>
<td>4</td>
</tr>
<tr>
<td>6000 m</td>
<td>5</td>
</tr>
<tr>
<td>6500 m</td>
<td>6</td>
</tr>
<tr>
<td>6600 m</td>
<td>7</td>
</tr>
<tr>
<td>7000 m</td>
<td>9</td>
</tr>
<tr>
<td>7750 m</td>
<td>11</td>
</tr>
<tr>
<td>8000 m</td>
<td>12</td>
</tr>
<tr>
<td>10050 m</td>
<td>13</td>
</tr>
<tr>
<td>10150 m</td>
<td>14</td>
</tr>
</tbody>
</table>

**Left blank on purpose**

<table>
<thead>
<tr>
<th>DISTANCE</th>
<th>SIGN</th>
</tr>
</thead>
<tbody>
<tr>
<td>3000 m</td>
<td>1</td>
</tr>
<tr>
<td>3800 m</td>
<td>2</td>
</tr>
<tr>
<td>5000 m</td>
<td>3</td>
</tr>
<tr>
<td>5500 m</td>
<td>4</td>
</tr>
<tr>
<td>6000 m</td>
<td>5</td>
</tr>
<tr>
<td>6500 m</td>
<td>6</td>
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<tr>
<td>7000 m</td>
<td>9</td>
</tr>
<tr>
<td>7750 m</td>
<td>11</td>
</tr>
<tr>
<td>8000 m</td>
<td>12</td>
</tr>
<tr>
<td>10050 m</td>
<td>13</td>
</tr>
<tr>
<td>10150 m</td>
<td>14</td>
</tr>
</tbody>
</table>
The detail list of sign of both reference scenario and manipulated (added/replaced) sign can be found in annexes table VI and VII respectively.

6.1.7 Scenario Development

Developing a scenario inside the simulator experiment is of significance, since it gives a detailed view of the scenario. In this study, time is considered as an important variable. Therefore appropriate time is given to every test subject for the simulation experiment. The scenario itself is further bifurcated into four different zones which are explained below:

6.1.7.1 Acceleration zone area

The acceleration zone is developed, for drivers to accelerate from 0 km/h to 120 km/h. The area occurs at the start of the experiment, gives drivers the opportunity to speed up, attain a normal driving speed which other vehicles are driving in highway, in order to avoid any rear end collision. The length of the acceleration zone is set to be 2 kilometres.

6.1.7.2 Congestion zone area

After acceleration zone area, occurs congestion zone area. Here drivers are allowed to drive, in a regular manner on highways. During this congestion zone area drivers encounter an overhead bridge, bearing changeable message sign and a portable changeable message, informing drivers about possible congestion ahead due to work activities. As described in the literature review section, permanent and portable changeable message sign helps drivers to reduce their mean speed, helps take a decision to change their lane, prepares drivers to lower and maintain the speed (McMurtry, Saito, Riffkin, & Heath, 2009b). The length of congestion zone area is set to be 1 kilometre.

6.1.7.3 Congestion tail zone area

Congestion tail zone area comes instantly after, congestion zone area. Whereas the purpose of this zone is avoid possible bottleneck due to congestion before entering the signalisation scheme area. Bottleneck can be avoided by creating additional discharge section immediately upstream of the bottleneck (Lu, Varaiya, Horowitz, Su, & Shladover, 2011). This zone does not consist any TTC devices. The length of this zone is set to be 1 kilometre.

6.1.7.4 Signalisation scheme zone area

This zone consists of various TTC devices, purposed and used in work zone area on highways by Flemish government. The TTC devices are speed limit, lane closure, possible congestion ahead, man working ahead sign boards, delineators, retroreflective pavement marking for lane change and barriers. The length of this zone is set to be 3 kilometres.

6.1.7.5 Work zone area

The work zone area consists of TTC boards, barriers, and whereas construction activities were proceeding in one lane. The traffic was allowed to travel between two lanes. The speed limit is set 70 km/h. The length of the work zone area is 2 kilometres.

6.1.7.6 Post work zone area

Post work zone area comes after end of work zone area. It consists of end of work zone sign board and project description sign board. The purpose of this zone is to foresee driver’s acceleration, reaction and speed after TTC sign boards. The length of this zone is 1 kilometre.
6.2 Set-up of the simulation

The final simulation programmed consists of total 6 scenarios, one controlled condition (reference scenario) and five uncontrolled condition (altered scenarios). The programming of the scenarios were done keeping in mind the requirements of the studies and layout of the work zone signalisation scheme adhered by the Flemish government. After completion of programming, the full randomization was carried out in such a way that every subject’s drive has different set of sequence from other driver. For familiarization purpose, test subjects drove through warm up scenario. The following sections describe in-detail about the different aspects of scenarios.

6.2.1 Randomization

In driving simulator research experiment, there is wide concern that test subjects can produce negative/biased results, with the help of effect of learning in sequence. In general, people can adapt their behaviour for the simulation experiment based on their experience with the previous one and asking other test subjects. One fixed sequence for all test subjects can negatively influence the results or point out that one of the TTC is not effective in improving traffic safety condition or has no effect. In order to exclude all of these concerns from the experiment, a full scale randomization sequence for the experiment is carried out. After application of randomization, every test subjects receives a unique sequence set of simulated conditions.

The driving simulator software STISIM DRIVE 3, lacks an in-built function of randomization. To ensure every test subject receives a different set of sequence, programming codes are to be created. The adopted randomization can be referred in annexes VIII.
6.2.2 Warm up scenario

In order to get familiar with driving simulator environment, test subjects drove through a warm up scenario (test drive). This is considered necessary since many simulator programs are not being able to represent the speed correctly with real life inside the environment. The test subjects also need time to adjust themselves with the brake and acceleration pedal. During the test drive, the test subject drove through 11 km length of highway. The warm up scenario environment resembled the configuration of actual simulated experiment. During the warmup scenario test subjects were given adequate time to get familiar with the environment.

6.2.3 Simulation design

The driving simulation environment are supposed to represent the highway driving culture of Flanders, Belgium. The driving speed of Flemish highways is 120 km/h, therefore in the simulation scenarios speed limit is also set at 120 km/h for the highway condition. Furthermore for realism purpose buildings, trees, and opposite traffic are also added to make driver feel more real. The following figure shows photograph of the simulation environment.

![An impression of driving simulator experiment](image)

Figure 16 An impression of driving simulator experiment

There are certain limitations while conducting driving simulator research, this master’s thesis experiment faced the problem that speed and distance were not represented correctly in the simulated experiment. The visibility of all the signs, buildings, and TTC measures was kept at a distance of 500 m in the experiment. For improving the feedback mechanisms and reaction time a manual gearbox was programmed and used in the experiment. The sound of engine was also added to the simulation experiment for improving the feedback mechanism to the test subjects.

6.2.4 Within-subjects design

The driving simulator research can be used between and within subject design. The within subject design is used when all participants face the same conditions and that one compares the different behaviour of all conditions for every participants, mostly used for relatively small sample size. In between subject design, the sample population is divided into various groups encountering different
conditions. Humans possess different and varied nature as they are not easy to compare, and thus negative results can be produced while using between subject designs (Rosenbloom & Pereg, 2012).

For appropriate and relative results, this study takes in consideration within subject design, since sample size of test subjects is 40 to 50 persons.

6.3 The experiment

Subjects were invited through an electronic mail invitation, with the invitation a web based link was also provided which had option of reserving time slot for experiment. The subjects after confirming their proposed time slot for participation in driving simulator were invited to come to the location of simulator. The conducted experiment was divided into four stages, which is given below:

1. Test subject information, brief questionnaire and introduction to the driving simulator

2. Warm-up trip

3. The driving simulation experiment

4. Questionnaire

**Figure 17** Different stages of how the experiment was carried out

During the first stage of the experiment, test subjects were welcomed at the facility, basic distinct individual data regarding the test subjects were collected such as age, gender, profession, education level, nationality, driving license type, driving experience, vision impairment, frequency of using highways, purpose of driving, time of driving, accident encountered, and use of mobile phone during driving. Brief introduction to the simulated experiment was provided, the test subjects were told that they would drive on a highway. No information regarding the work zone or temporary traffic control devices was provided nor were they told to experience them during the experiment. The test subjects were also inquired about any driving ailments, and experience of simulator sickness. Participants having driving ailments were not considered for the experiment. In appendices no. IX, the pre-questionnaire is included.

In the second stage test subjects, were introduced to the driving simulator, which consists of Ford Mondeo car, and projector screen. The test subjects were settled in the driving seat, information about power electronics of automobile was provided and were told to receive projections of driving environment on large 180° projector screen. Later test subjects drove through warm-up scenario. The test subjects drove through a highway segment having speed limit of 120 km/h, having multiple buildings and trees placed on sideways of road segment. They were asked to accustom themselves to the driving simulator environment.
In the third stage, subjects after a short break drove through the driving simulation experiment. The test subjects were given multiple scenarios to drive through. The process and procedure of scenarios is discussed previously. Immediately after performing every simulation, subjects were asked about the driving work load of the scenario. The driving work load was assessed on NASA task load index paper pencil form provided in English and Dutch, according to the preference of the test subject. The work load paper pencil form asked test subjects of how physically, mentally demanding was the task? Was the pace of the task in hurried manner? Success of subjects in performing the task, level of hard work done, and boredom/stress/annoyed feeling while doing the task (Connors & Chrestenson, 2006). The NASA task load index can be found in the appendices no. X.

At the fourth stage the subjects were asked open ended questions about the aim of the experiment. Their perception about the relevance of the simulated driving with real world driving. Did they encountered speed camera sign board, yellow speed limit sign, blue speed limit sign, orange speed limit sign, presence of police car, their comments and suggestions to improve signalisation scheme in work zone area on highways. The post questionnaire is included in the appendices no. XI.

6.4 Test subjects

Taking in a account the nature of the experiment and time limitations, the eligibility to participate in the experiment was possession of valid Belgian or European license. The basic target group of the test subjects were Flemish drivers, and other subjects who are familiar of Flemish driving behaviour. No filter of age, gender, driving experience and education was enforced during participation recruitment. But narrowing down the research to certain group can also be an interesting aspect for future research, if varied, interesting results are found.

For recruiting participants, a graphical poster and electronic invitation was sent to the students and staff members to University of Hasselt. As a result test subjects belonged mainly to age group of young drivers 18-25 years, nevertheless other age group drivers also participated in the study but with a low participation percentage.

6.5 Summary

This study examines the driving behaviour of Flemish test subjects, while driving through work zone areas on highways. Due to financial and time limitations, field experiments could not be carried out, thus driving simulator was considered to perform the research.

Six different set of simulated driving scenarios were used in this study. The first scenario is always taken as reference scenario. In this study a reference scenario is the signalisation schemed used and proposed by the Flemish government for work zone construction schemes on highways. Scenarios were designed in a manner to foresee driving behaviour of drivers, while removing left hand signs, using speed camera, police enforcement and yellow background speed limit. The designed/manipulated scenarios mainly consisted of information of reference scenario with addition of a certain TTC measure.

For avoiding the learning by sequence phenomenon for test subjects, all scenario conditions are fully randomized and within test subject design is used for this study.

A questionnaire survey was also designed to assess the test the knowledge and attitude of Flemish drivers in construction work zone areas of highways. Based on few multiple choice questions and open ended questions, participants were asked about aim, knowledge of speed cameras, and police enforcement on the highway. The table 4 shows overview of collected data during the experiment.
For recruitment for experiment, a graphical poster and e-mail was sent to students and staff members of University of Hasselt. Most test subjects belonged to the age group of 18-25 years, whereas other age groups are also included in this study.

![Diagram](image)

- Mean speed of vehicles
- Standard deviation of lateral position
- Lane position
- Maximum Acceleration and Deceleration of vehicle

- Work load index perception
- Speed Camera and Police enforcement Knowledge
- Personal data

Figure 18 Represents the important benchmarks of the data collected during the experiment

7. RESULTS

This part includes the results of descriptive and statistical analyses. MATLAB was used to extract the raw output data of the STISIM simulator software. After data extraction, descriptive analysis was done, for a general overview of the data in MINTAB 16. For detailed statistical analysis, one way repeated measures ANOVA and two way repeated measures of ANOVA were carried out in SPSS 22. Repeated measure of ANOVA was conducted to foresee possible effects of independent variables (different scenarios/conditions) in the driving performance measures. Here repeated measures of ANOVA is used to compare means when same test subjects participate in different conditions/scenarios. Whereas, ANOVA also helps to analyse to see the variance in mean values of dependent variables i.e. mean speed, acceleration and standard deviation of lane position. In this statistical analysis, assumption of sphericity is also taken in consideration, since violation of sphericity has a negative effect on F-ratio (loss of power), which can be compared to tabulated values of F-distribution, thus not producing valid f-ratio (Field, 2009). Assumption of sphericity is evaluated by Mauchly’s test, if p-value < 0.05 then variance differences are significant and assumption of sphericity is violated. If data violates sphericity assumption, corrected F-ratios are reported by Greenhouse-Geisser correction or Huynh-Feldt. If estimates of sphericity are greater than 0.75 then Huynh-Feldt correction should be used, if values are less than 0.75 or nothing is known about sphericity, Greenhouse-Geisser correction shall be used (Girden, 1992). In some cases, if data violates sphericity multivariate test statistics are reported, since it does not depend upon the assumption of sphericity (O’Brien & Kaiser, 1985). The corrected F-values and degrees of freedom are reported. All significant effects reported in this section were statistically significant with type I error p value less than 0.05.

The parameters for driving analysis are mean speed, acceleration/deceleration and standard deviation of lane position were averaged for section of 250 meters before and after location of different TTC
measure for every single participant. Whereas only in two cases driving parameters values were averaged for 500 meters i.e. control zone and middle of work zone. In this section, relevant statistical analysis are presented which serve the research questions. For verification of logged data some other analysis were also carried out, which have no concern with research questions i.e. control zone.

Detailed description of the test subjects is provided. First, descriptive analysis is done, for data interpretation in terms of age, gender, driving experience, car transmission and vision impairment. Secondly, outlier analysis is provided. Afterwards, statistical analysis were conducted and described at location placement of different temporary traffic control (TTC) measures.

7.1 Participants data

In this experiment, 46 test subject participated. From this 46 participants, 2 test subjects were excluded from analysis. One experienced sign of simulator sickness and one participant was classified as statistical outlier. Out of 46 test subjects 27 were male and 19 were females, having age from 18 to 66 years. Among test subjects 35 possessed Belgian driving license, 4 Netherlands, 4 German, 2 Italian and 1 Greek driving license. Based upon their own responses, the majority of test subjects (21) drove between 0 to 5000 kilometres per year, and only 7 drove more than 25,000 kilometres per year. Whereas 17 drove on highways per week, 10 daily, 13 monthly, 5 yearly basis and 1 never drove on highways.

Table 3 Descriptive Analysis of test subjects

<table>
<thead>
<tr>
<th>Content</th>
<th>Age</th>
<th>Driving Experience</th>
<th>Vision Impairment</th>
<th>Frequency of going on highways</th>
<th>Vehicle kilometres driven per year</th>
<th>Gender</th>
</tr>
</thead>
<tbody>
<tr>
<td>N valid</td>
<td>46</td>
<td>46</td>
<td>46</td>
<td>46</td>
<td>46</td>
<td>46</td>
</tr>
<tr>
<td>Mean</td>
<td>26.41</td>
<td>5.94</td>
<td>Yes</td>
<td>Daily 10</td>
<td>0 to 4999 km</td>
<td>21 Male 27</td>
</tr>
<tr>
<td>SE of mean</td>
<td>1.59</td>
<td>1.53</td>
<td>No</td>
<td>Weekly 17</td>
<td>5000 to 9999 km</td>
<td>7 Female 19</td>
</tr>
<tr>
<td>Median</td>
<td>23</td>
<td>2</td>
<td></td>
<td>Monthly 13</td>
<td>10 k to 14,999 km</td>
<td>6 Male 58.69 %</td>
</tr>
<tr>
<td>Std Deviation</td>
<td>10.78</td>
<td>10.35</td>
<td></td>
<td>Yearly 5</td>
<td>15 k to 19,999 km</td>
<td>2 Female 41.30 %</td>
</tr>
<tr>
<td>Variance</td>
<td>116.25</td>
<td>107.13</td>
<td></td>
<td>Never 1</td>
<td>20 k to 25 k</td>
<td>3</td>
</tr>
<tr>
<td>Coefficient of Variance</td>
<td>40.82</td>
<td>174.31</td>
<td></td>
<td></td>
<td>25k and more</td>
<td>7</td>
</tr>
<tr>
<td>Skewness</td>
<td>2.45</td>
<td>2.79</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td>18</td>
<td>0.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>66</td>
<td>44</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The average age of the participants was 26.41 years, having minimum age of 18 years and maximum of 66 years. Majority of test subjects (67.39%) had no glasses or contact lenses. Majority of test subjects (N=21), drove 0 to 4,999 kilometres per year. Test subjects often tend to drive on highways on weekly basis (N=17).

Figure 19 Histogram of Age

There are two ways to determine driving experiences (1) Number of years in possession of driving license (2) Number of kilometres driven per year. Here in this experiment, test subjects on average were in possession of driving license of 5.94 years (average value). Having minimum value of 0.08 years, and maximum of 44 years.

7.1.1 Outlier Analysis

Before data analysis, it was important to foresee any statistical outliers in the dataset. An outlier is an observation in the dataset which appears to be inconsistent with the remainder of the data set (Johnson & Wichern, 1992). Presence of values from outliers produces a biased in the dataset. Thus it is important to remove statistical outlier values. Different techniques exist to exclude outliers from data set. In this master’s thesis experiment outliers were determined by plotting box plots. Those data set values plotted outside the box plots were termed as outliers. As a result one test subject no.11 is termed as statistical outlier. This test subjects had extreme values of more than 1.5 and 3 times of the interquartile range, hence the values were removed. The box plot values can be found in appendices number XII.

7.2 Subjective work load assessment

In this experiment, NASA TLX is used to assess the subjective workload, of test subjects while driving through different conditions. NASA TLX is used to collect work load assessment of drivers, due to the reason it is comparatively easy to collect, inexpensive, reported directly by the test subject. In this experiment, work load is assessed by paper pencil method, where test subjects were required to
report the experienced work load instantly on a paper pencil-based form, after completion of every scenario. The paper pencil form consists of six dimensions, mental demand, physical demand, temporal demand, performance, frustration and level of effort put in, which are measured on scale of 20 points. In appendices XIII, a table of descriptive analysis of work load assessment can be found.

7.2.1 Graphical Analysis
Figure no.20, further elaborates in terms of graphical representation, amount of work load experienced in different scenarios.

![Graphical representation of work load experienced](image)

**Figure 20 Graphical representation of work load experienced**

7.2.2 Statistical Analysis
As suggested by Shakouri et al. (2014) that NASA TLX can also be used to tabulate work load measurements in transportation oriented field. Moreover apart from descriptive statistics analysis, literature by Mueller et al. (2014) suggests variance can also be analysed by ANOVA to foresee work load effect of scenarios separately. Shakouri et al. (2014) analysed the effects of merge configuration and traffic density on NASA TLX subcomponents by MANOVA. Thus in this master’s thesis experiment one way repeated measures ANOVA is analysed to foresee possible individual effects of every scenarios separately.

**Mental demand**
Scenario 5 was considered the most, mentally demanding condition, having average value of 6.156. Multivariate analysis of variance showed, no significant effects for the responses recorded by the different test subjects. Wilk’s lambda test shows no significant effects for assessed work load behaviour, V=0.789, F (5, 40) =2.145, p=0.08 ($\eta^2_p =0.211$). Further test of within subject contrast showed some significant differences among scenario 4 and scenario 5, F (1, 44) =9.635, p=0.003 ($\eta^2_p =0.180$)
**Physical demand**
Scenario 5 was considered the most, physically demanding condition, having average value of 4.111. Multivariate analysis of variance showed, no significant effects for the responses recorded by the different test subjects. Wilk’s lambda test shows no significant effects for assessed work load behaviour, $V=0.872$, $F (5, 40) =1.174$, $p=0.339$ ($\eta^2_p =0.128$).

**Temporal demand**
Scenario 6 was considered the most, temporal demanding condition, having average value of 5.378. Multivariate analysis of variance showed, no significant effects for the responses recorded by the different test subjects. Wilk’s lambda test shows no significant effects for assessed work load behaviour, $V=0.880$, $F (5, 40) =1.087$, $p=0.383$ ($\eta^2_p =0.120$).

**Performance**
Scenario 1 was considered the most, performance oriented condition, having average value of 16.28. Multivariate analysis of variance showed, no significant effects for the responses recorded by the different test subjects. Wilk’s lambda test shows no significant effects for assessed work load behaviour, $V=0.899$, $F (5, 40) =0.903$, $p=0.489$ ($\eta^2_p =0.101$).

**Level of effort**
Scenario 5 was considered the most, effort requiring condition, having average value of 5.533. Multivariate analysis of variance showed, no significant effects for the responses recorded by the different test subjects. Wilk’s lambda test shows no significant effects for assessed work load behaviour, $V=0.814$, $F (5, 40) =1.830$, $p=0.129$ ($\eta^2_p =0.186$). Further test of within subject contrast showed some significant differences among scenario 1 and scenario 2, $F (1, 44) =5.374$, $p=0.025$ ($\eta^2_p =0.109$).

**Frustration**
Scenario 3 was considered the most, frustrated oriented condition, having average value of 7. Multivariate analysis of variance showed, no significant effects for the responses recorded by the different test subjects. Wilk’s lambda test shows no significant effects for assessed work load behaviour, $V=0.908$, $F (5, 40) =0.811$, $p=0.549$ ($\eta^2_p =0.092$).

### 7.3 Analysis
This section includes the interpretation of statistical analysis. Further it focuses on the spotted significant values due to the introduction of addition/deletion of TTC measure. The assumption of sphericity is reported by mauchly’s test, the corrected degrees of freedom are reported by greenhouse-geisser and huynh-feldt test if the $p$ value is less than 0.75. If $p$ value is greater than 0.75 (invalid f-ratio), than degrees of freedom are reported by multivariate tests.

#### 7.3.1 Control zone
A section of the experiment is taken as control zone. Main reason of taking control zone is verify the simulation results with the expected results. The control zone a section consisted of 750 meters, having an overhead bridge in the middle of the control zone, showing the sign “file mogelijk”. The control zone was taken as same for all six scenarios, hence having no differences. The expected results were that it should not contain any statistical difference in driving parameters among all the six scenarios. One way repeated measures ANOVA, is carried out, to foresee the effect of different scenarios and their significant differences on the driving performance measures.
**Mean Speed**

The results show that there was no significant difference on mean speed in control zone among all test subjects, while driving through six different scenarios. Mauchly’s test indicates that assumption of sphericity had been violated, $\chi^2 (14) = 102.454, p < 0.05$. Wilk’s lambda test, show that there were no significant differences in the scenarios for test subjects while going through control zone, $V=0.822, F (5, 39) =1.693, p>0.05$. The results show that in control zone, there was no effect on mean speed by the type of scenario/condition.

**Standard deviation of mean speed**

The multivariate test (Wilk’s lambda test) reveal no differences, $V=0.330, F (5, 1) =0.405, p>0.05$ ($\eta_p^2=0.670$). There was no significant difference on standard deviation of mean speed in control zone among all test subjects, while driving through six different scenarios. Since, there was no manipulation in control zone in six different scenarios, hence no effect on standard deviation of mean speed is encountered.
Standard deviation of lane position (sdlp)

No significant differences were encountered in standard deviation of lane position in different scenarios in control zone. The assumption of sphericity had being violated, $\chi^2 (14) = 31.100$, $p=0.017$. Thus corrected degree of freedom are reported by univariate test (greenhouse-geisser), $F (1.596, 7.98) = 1.724$, $p= 0.236$. The results confirm the fact that there were no differences among scenarios, due to the reason that no manipulation in control zone existed in control zone.

Acceleration

The results show that there were no significant differences for acceleration in control zone. The greenhouse-geisser correction shows that, $F (2.035, 87.499) = 1.611$, $p=0.205$. The results confirm the fact, that there were no difference in control zone in different scenarios, hence there was no effect on acceleration.

Deceleration

The results show that there were no significant differences for deceleration in control zone. The multivariate tests (wilk’s lambda) results show that, $F (5, 39) = 0.268$, $p=0.928$. The results confirm the fact, that there were no difference in control zone in different scenarios, hence there was no effect of deceleration.

7.3.1 C43 (Speed limit of 90 km/h at 300 m)

This section is taken in account, to evaluate the effectiveness of C43 speed limit sign board 90 km/h at 300 metres. The sign board is evaluated, before 250 metres its location and after 250 metres of its location. Two way repeated measure of ANOVA (within subjects design) is used, to check the effect of the C43 sign on driving performance measures.

Mean Speed

Mauchly’s test, indicate that assumption of sphericity had being violated for conditions (six scenarios), $\chi^2 (14) = 49.230$, $p<0.05$. No significant differences were noted by multivariate test (Wilk’s lambda), for main effects of conditions (six scenarios), $V=0.877$, $F (5, 36) = 1.011$, $p=0.426$. For interaction term (time period*conditions) no significant differences were noted, $F (4.242, 169.697) =0.715$, $p=0.591$. Thus test subjects had uniform driving behaviour, sign did not had significant effect on scenarios.

There is significant main effect of time period (before and after occurrence of sign), on mean speed. $F (1, 40) = 540.932$, $p < 0.05$. Bonferroni post hoc test, shows there was significant reduction in mean speed after occurrence of speed limit sign, $M.D=8.103$, $SE=0.348$, $p<0.05$. It is further concluded that C43 speed limit of 90 km/h at 300 meters can be helpful in reducing speed by 11.208 %. The test subjects reduced their mean speed significantly due to sign presence.
Figure 23 Mean speed, the difference before and after sign C43 90 km/h at 300 m

Overall mean speed reduction of 11.2088% was seen, after the placement of the sign board. Figure 24, contains the detail description of before/after mean speed reduction.

Figure 24 Reduction in mean speed after C43 sign 90 km/h at 300 m
Figure 25 Speed profile, before and after C43 sign 90 km/h at 300 m

Standard deviation of mean speed
There was no significant main effect of time period $F(1, 5) = 3.840, p = 0.107$ and conditions $F(1, 25) = 1.565, p = 0.206$ on standard deviation of mean speed, hence all $p$ values were found to be $p > 0.05$.

There was no significant effect seen for interaction terms time-period*conditions, $F(5, 25) = 1.589, p = 0.200$. Thus test subjects did not deviate from their respective mean speed, in all scenarios.

Standard deviation of mean speed

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sc1</td>
<td>7.830</td>
<td>5.344</td>
</tr>
<tr>
<td>Sc2</td>
<td>6.677</td>
<td>5.360</td>
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<tr>
<td>Sc3</td>
<td>7.950</td>
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<td>Sc4</td>
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<tr>
<td>Sc5</td>
<td>7.210</td>
<td>6.622</td>
</tr>
<tr>
<td>Sc6</td>
<td>9.710</td>
<td>8.977</td>
</tr>
</tbody>
</table>

Figure 26 Standard deviation of mean speed, before and after C43 sign 90 km/h at 300 m

Standard deviation of lane position
There are no significant differences main effects of sign in conditions (six scenarios) $F(5, 25) = 0.653, p = 0.662 (\eta^2 = .116)$, and no significant differences for interaction effect of sign time-period*scenario $F(5, 25) = 1.557, p = 0.209, (\eta^2 = 0.237)$. Whereas a significant effect is noted for sign before and after the occurrence of sign C43, $F(1, 5) = 6.632, p = 0.05$. Further contrasts reveal that sdlp values
before sign location was significantly higher than after location of sign. The standard deviation of lane position, effect was larger before \((M=1.3563, SE=0.117)\) than after \((M=1.2878, SE=0.093)\). The test subjects had uniform lane position change driving behaviour.

**Figure 27 Standard deviation of lane position, before and after C43 sign 90 km/h at 300 m**

7.4.1 C43 Transition from 120 to 90 km/h

This section is taken in account, to evaluate the effectiveness of C43 speed limit sign board 90 km/h. The sign board is evaluated, before 250 metres its location and after 250 metres of its location. Two way repeated measure of ANOVA (within subjects design) is used, to evaluate the effect of the C43 sign on driving performance measures.

**Mean speed**

Mauchly’s test indicate that assumption of sphericity had being violated for the main effects of conditions (six scenarios), \(\chi^2 (14) = 43.388, p<0.05\), and interaction effect time*conditions, \(\chi^2 (14) = 41.242, p<0.05\).

The main effect of condition (six scenarios) is reported not to be significant, \(F (3.531, 137.701) =1.146, p= 0.336\).

There was no significant effect on interaction effect (time*conditions), \(F (3.429, 133.712) =0.986, p= 0.409\). The contrast reveal that no significant interaction effect, when comparing before and after occurrence of sign with six difference scenario conditions. Thus test subjects tended to have uniform speeding behaviour in all scenarios, despite of some changes in conditions.

Significant main effect of time period (before/after sign occurrence) was noted to be, \(F (1, 39) =79.002, p<0.000\). The test subjects drove before \((M=61.341 \text{ km/h}, SE=0.797)\) and after \((M=57.630 \text{ km/h}, SE=0.566)\). Hence the difference in mean speed, before and after sign C43 occurrence was \((M=3.711, SE=0.418, p<0.005)\).
Overall mean speed reduction of 5.548% was seen, after the placement of the sign board. Figure 29, contains the detail description of before/after mean speed reduction.
Figure 30 Speed profile, before and after sign C43 90 km/h occurrence

**Standard deviation of mean speed**

The assumption of sphericity had being violated for the main effects of conditions (six scenarios) $\chi^2 (14) = 32.736$, $p=0.011$ and interaction effect time-period*conditions, $\chi^2 (14) = 28.606$, $p=0.033$.

Significant main effect of time period (before/after sign occurrence) was noted to be, $F (1, 5) = 21.601$, $p=0.006$ ($\eta_p^2=0.05$). The standard deviation before $(M=7.122, SE=0.430)$ and after $(M=5.879, SE=0.403)$. Hence the difference in mean speed, before and after sign C43 occurrence was $(M.D=1.244, SE=0.268, p=0.006)$.

The **main effect of condition** (six scenarios) is reported **not to be significant**, $F (1.861, 9.304) = 0.767$, $p=0.483$ ($\eta_p^2=0.133$).

There was **no significant effect on interaction effect** (time*conditions), $F (1.928, 9.642) = 1.95$, $p=0.195$ ($\eta_p^2=0.281$).

No significant effect tells us that test subjects tended not to deviate from mean speeds in all scenarios, did not had any effect of any individual scenario.
Figure 31 Standard deviation of mean speed before and after sign C43 90 km/h occurrence

**Standard deviation of lane position**

No **significant difference** is seen for main effect of **conditions** (six scenarios), $F(5, 40) = 0.857, p = 0.475$. Pairwise comparison, shows sdlp values higher for before location of sign ($MD=0.272, SE=102$).

There was **no significant difference** seen in interaction effect (time*conditions), $F(5, 40) = 0.773, p = 0.521$. The contrast, did not had any significant difference for interaction term.

The test subjects tended not to change their lane position, in scenarios even before and after sign placement.

Figure 32 Standard deviation of lane position before and after C43 90 km/h
7.5.1 C43 Transition from 90 to 70 km/h

This 500 metres section evaluates the effectiveness of C43 speed limit sign board 70 km/h. In this section the sign board is evaluated, before 250 metres its location and after 250 metres of its location. Two way repeated measure of ANOVA (within subjects design) is used, to foresee the effect of the C43 sign on driving performance measures in all scenarios.

**Mean speed**

There was significant effect of sign occurrence on main effect of time period (before/after sign occurrence), $F(1, 43) = 638.813, p= 0.000$ ($\eta^2 =0.937$). The test subjects drove higher, before sign occurrence, hence the sign has a significant effect ($M.D=5.823, SE=0.23, p<0.00$).

The main effect of condition (six scenarios) is **significant**, multivariate test (Wilk’s lambda test) $V=0.760, F (5, 39) =2.459, p= 0.05$ ($\eta^2 =0.024$). Table of contrast tell that there was significant difference in mean speed between scenario 5(police with speed camera sign), scenario 6(yellow speed limit sign), $F (1, 43) =5.534, p= 0.023$ ($\eta^2 =0.114$). Showing scenario 5, having lower mean speed in comparison to scenario 6 (M.D=3.265, SE=0.35). Pairwise comparison reveal that after sign placement scenario 3(remove left hand side), had significant differences with scenario 5(M.D=2.948, SE=0.794, p=0.038).

There was **no significant interaction effect** (time*conditions), Wilk’s lambda test reveal that $V=0.763, F (5, 39) =2.428, p= 0.052$ ($\eta^2 =0.237$).

Pairwise comparison reveal effectiveness of sign, before/after its occurrence:

- Scenario 1, had significant reduction in mean speed after sign occurrence, $MD=5.313, SE=0.617, p=0.01$.
- Scenario 2, had significant reduction in mean speed after sign occurrence, $MD=4.964, SE=0.491, p=0.01$.
- Scenario 3, had significant reduction in mean speed after sign occurrence, $MD=5.656, SE=0.441, p=0.01$.
- Scenario 4, had significant reduction in mean speed after sign occurrence, $MD=6.527, SE=0.499, p=0.01$.
- Scenario 5, had significant reduction in mean speed after sign occurrence, $MD=6.776, SE=0.407, p=0.01$.
- Scenario 6, had significant reduction in mean speed after sign occurrence, $MD=5.704, SE=0.612, p=0.01$. 
Mean speed before and after sign C43 70 km/h

Overall mean speed reduction of 11.06% was seen, after the placement of the sign board. Figure 34, contains the detail description of before/after mean speed reduction.

Percentage decrease in mean speed, before and after sign C43 70 km/h
Standard deviation of mean speed

No Significant effect was seen for main term of time period (before/after sign occurrence), $F (1, 8) = 5.60, p = 0.476$ ($\eta^2 = 0.65$).

Main effect of condition (six scenarios) is reported not to be significant, $F (5, 40) = 1.054, p = 0.400$ ($\eta^2 = 0.116$).

There was no significant effect on interaction term (time*conditions), $F (5, 40) = 0.054, p = 0.998$ ($\eta^2 = 0.007$). Test of within subject contrast did not reveal any significant difference in the interaction term. Thus test subjects did not deviate from their mean speed due to sign C43 70 km/h.
Standard deviation of lane position

There was no significant effect on standard deviation of lane position for main effect of conditions and interaction effect of time period*conditions, \( p > 0.005 \). While for main effect of time period before/after location of sign resulted in, significant effect which are denoted by multivariate test of Wilk’s lambda \( V = 0.506, F (1, 8) = 7.821, p = 0.023 (\eta^p = 0.494) \).

Thus test subjects did not had any significant effect on deviation from lane position due to sign C43 70 km/h.

![Figure 37 Lowest and highest values of standard deviation of lane position, before and after sign C43 70 km/h](image)

7.6.1 Speed camera sign

This section is taken in account, to evaluate the effectiveness of speed camera sign board. The sign board is evaluated, before 250 metres its location and after 250 metres of its location. Two way repeated measure of ANOVA (within subjects design) is used in this section, to check the effect of the speed camera sign on driving performance measures.

Mean speed

Mauchly’s test indicate that assumption of sphericity had being violated for the main effects of conditions, \( \chi^2 (14) = 84.804, p = 0.000 \).

Significant effect was noted of speed camera sign on main effect of time period (before/after sign occurrence), \( F (1, 43) = 532.799, p = 0.000 (\eta^p = 0.925) \). The test subjects drove higher, before sign occurrence, hence the sign has a significant effect (M.D=5.044, SE=0.219, \( p < 0.05 \)).

The main effect of condition is significant (Wilk’s lambda test), \( V = 0.602, F (5, 39) = 5.148, p = 0.01 (\eta^p = 0.398) \). Contrast, further revealed notable differences among scenarios. There was significant difference in mean speed between scenario 5(police with speed camera sign), scenario 6(yellow speed limit sign), \( F (1, 43) = 9.159, p = 0.004 (\eta^p = 0.176) \). Showing scenario 5, having lower mean speed in comparison to scenario 6 (M.D=3.973, SE=1.313). Further analysis reveal scenario 3(remove left hand side), had significant differences with scenario 5(M.D=3.058, SE=0.676, \( p = 0.001 \)).

There was no significant effect on interaction term (time*conditions), \( F (4.378, 188.254) = 2.061, p = 0.081 (\eta^p = 0.046) \).
Pairwise comparison reveal effectiveness of sign, before/after its occurrence:

- Scenario 1, had significant reduction in mean speed after sign occurrence, MD=4.23, SE=0.551, p<0.05.
- Scenario 2, had significant reduction in mean speed after sign occurrence, MD=1.362, SE=0.529, p<0.05.
- Scenario 3, had significant reduction in mean speed after sign occurrence, MD=1.694, SE=0.459, p<0.05.
- Scenario 4, had significant reduction in mean speed after sign occurrence, MD=5.714, SE=0.490, p<0.05.
- Scenario 5, had significant reduction in mean speed after sign occurrence, MD=6.294, SE=0.511, p<0.05.
- Scenario 6, had significant reduction in mean speed after sign occurrence, MD=4.310, SE=0.703, p<0.05.

![Figure 38 Mean speed, before and after speed camera sign](image)

Overall mean speed reduction of 12.076% was seen, after the placement of the sign board. To be noted that significant differences were noted for test subjects driving with higher speeds in scenario 3 as compared to scenario 5 (Speed camera). Figure 39, contains the detail description of before/after mean speed reduction.
Figure 39 Evaluation of effectiveness of speed camera sign

Figure 40 Speed profile before and after location of speed camera sign

Standard deviation of mean speed

No Significant effect was seen for main term of time period (before/after sign occurrence), $F(1, 8) = 2.061, p = 0.189\ (\eta^2 = 0.05)$. Main effect of condition (six scenarios) is reported not to be significant, $F(5, 40) = 0.869, p = 0.460\ (\eta^2 = 0.098)$. There was no significant effect on interaction term (time*conditions), $F(2.96, 23.752) = 1.141, p = 0.353\ (\eta^2 = 0.125)$. Thus concluded that drivers tended not to have deviate from their mean speed in all scenarios.
Standard deviation of lane position

Significant effect was encountered in main effect of time-period (before/after sign placement) for sdlp, $F (1, 8) =35.142, p = 0.00 \ (\eta^2=0.815)$. Whereas sdlp values were higher for before location of sign, lower for after sign occurrence (M.D=0.097, SE=0.016).

No significant effect is seen for main effect of conditions (six scenarios), $F (5, 40) =1.327, p = 0.287 \ (\eta^2=0.142)$. There was no significant effect seen in interaction effect (time*conditions), $F (5, 40) =0.778, p = 0.510 \ (\eta^2=0.089)$. Subjects tend not to deviate their lanes due to sign occurrence.

Deceleration

The assumption of sphericity had been violated for the main effects of conditions (six scenarios) $\chi^2 (14) = 28.462, p=0.012$. For interaction effect (before & after of sign occurrence) time period*conditions the assumption of sphericity was also violated, $\chi^2 (14) = 78.235, p=0.00$. 
There was **significant effect** of sign occurrence on **main effect of time period** (before/after sign occurrence), $F (1, 43) = 25.022$, $p = 0.000$ ($\eta_p^2 = 0.368$). The test subjects had higher deceleration before sign occurrence, hence the sign has a significant effect $(M.D=0.287, SE=0.057, p<0.00)$.

The main effect of **condition** (six scenarios) is **not significant**, $F (3, 97) = 0.765$, $p = 0.549$ ($\eta_p^2=0.017$).

There was **no significant effect on interaction term** (time*conditions), $F (2.92, 125.91) = 1.910$, $p = 0.133$ ($\eta_p^2=0.043$).

Pairwise comparison reveal significant effect, on deceleration. Effectiveness of sign, before/after its occurrence is discussed below:

- Scenario 1, had no significant reduction in deceleration after sign occurrence, $MD=0.247$, $SE=0.080$, $p=0.347$.
- Scenario 2, had no significant reduction in deceleration after sign occurrence, $MD=0.121$, $SE=0.116$, $p=0.71$.
- Scenario 3, had no significant reduction in deceleration after sign occurrence, $MD=0.231$, $SE=0.069$, $p=0.137$.
- Scenario 4, had significant reduction in deceleration after sign occurrence, $MD=0.384$, $SE=0.068$, $p=0.043$.
- Scenario 5, had significant reduction in deceleration after sign occurrence, $MD=0.494$, $SE=0.078$, $p=0.008$.
- Scenario 6, had no significant reduction in deceleration after sign occurrence, $MD=0.274$, $SE=0.160$, $p=0.236$.

![Figure 43 Decrease in deceleration for before and after speed camera sign](image-url)
7.7.1 Police car enforcement

This section is taken in account, to evaluate the effectiveness of police car presence at start of work zone area on highways. In this section the sign board is evaluated, before 250 metres its location and after 250 metres of its location. Two way repeated measure of ANOVA is used, to foresee possible effects of police car presence on driving performance measures.

**Mean speed**

Sphericity assumption had being violated for both the main effects and the interaction effects. For the main effects conditions (all scenarios) results tell us, $\chi^2 (14) = 61.754$, $p=0.000$. For interaction effect (before & after of sign occurrence) time period*conditions the assumption of sphericity was also violated, $\chi^2 (14) = 46.264$, $p=0.000$. 

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**Figure 44** Deceleration profile for before and after speed camera sign occurrence

**Figure 45** Percentage and average rate for deceleration for speed camera sign

- **Figure 44 Deceleration profile for before and after speed camera sign occurrence**
- **Figure 45 Percentage and average rate for deceleration for speed camera sign**
**Significant effect** was noted for police presence on main effect of **time period** (before/after sign occurrence), $F(1, 44) = 19.982, p = 0.000$ ($\eta^2_p = 0.312$). The test subjects drove higher, before sign occurrence, hence the sign had a significant effect (M.D=1.461, SE=0.327, $p<0.05$).

The main effect of **condition** (six scenarios) is **not significant**, $F(3.129, 137.683) = 0.822, p = 0.488$ ($\eta^2_p = 0.018$). Contrast test, revealed no significant difference among the different scenario driven.

**Significant** effect is seen on **interaction term** (time*conditions), $F(3.157, 138.905) = 33.322, p=0.00$ ($\eta^2_p = 0.431$). The contrast test shows significant difference in interaction term when comparing scenario 4 with scenario 5, $F(1, 44) = 74.026, p=0.05$ and scenario 5 with scenario 6, $F(1, 44) = 43.234, p=0.00$ ($\eta^2_p = 0.496$). Whereas significant differences were also seen in interaction terms, between scenario 5 with scenario 1, $F(1, 44) = 49.401, p<0.05$ ($\eta^2_p = 0.529$). Thus it was seen that due to police presence there was significant differences noted among all scenarios, hence drivers tended to not to have a uniform speeding behaviour, whilst a TTC measure is introduced.

Pairwise comparison reveal mix results, due to the reason in some scenarios it did not had any effect (due to its absence). Thus effective results can only be seen before/after for scenario 5 (where sign is placed):

- Scenario 1, had no significant reduction in mean speed after sign occurrence, MD=0.414, SE=0.540, $p>0.05$.
- Scenario 2, had no significant reduction in mean speed after sign occurrence, MD=0.193, SE=0.504, $p>0.05$.
- Scenario 3, had no significant reduction in mean speed after sign occurrence, MD=-0.140, SE=0.459, $p>0.05$.
- Scenario 4, had no significant reduction in mean speed after sign occurrence, MD=-0.720, SE=0.477, $p>0.05$.
- Scenario 5, had significant reduction in mean speed after sign occurrence, MD=8.818, SE=0.954, $p<0.05$.
- Scenario 6, had no significant reduction in mean speed after sign occurrence, MD=0.410, SE=0.649, $p>0.05$.

**Figure 46** Mean speed for before and after police car presence
Overall mean speed reduction of 17.206% was seen, after the placement of the sign board. Figure 48, contains the detail description of before/after mean speed reduction.

**Figure 47 Speed profiles of scenarios for police car presence**

**Figure 48 Evaluation of effectiveness of Police car presence before and after**

**Standard deviation of mean speed**

The assumption of sphericity had been violated for both the main effects of conditions (six scenarios) $\chi^2 (14) = 39.712$, $p=0.001$, and interaction effect (time-period*conditions), $\chi^2 (14) = 30.219$, $p=0.011$.

No significant effect was seen in main effect of **time-period** (before/after sign placement) for standard deviation of mean speed, $F (1, 8) =0.226$, $p=0.647$ ($\eta^2=0.027$). Whereas standard deviation of mean speed values were higher for before location of sign, lower for after sign occurrence (M.D=0.096, SE=0.203).

No significant difference is seen for **main effect of conditions** (six scenarios), degrees of freedom are reported by greenhouse geisser estimates, $F (1.907, 15.256) =0.748$, $p=0.484$ ($\eta^2=0.086$).
There was no significant difference seen in interaction effect (time*conditions), $F(2.459, 19.669) = 0.810, p = 0.482 (\eta^2 = 0.092)$.

**Figure 49** Standard deviation of lane position, for scenarios, when police car is present.

**Standard deviation of lane position**

Significant effect was encountered in main effect of time-period (before/after sign placement) for sdlp, $F(1, 8) = 21.837, p = 0.002 (\eta^2 = 0.732)$. Whereas sdlp values were higher for before location of sign, lower for after sign occurrence (M.D=0.177, SE=0.038).

No significant difference is seen for main effect of conditions (six scenarios) by wilk’s lambda test, $\Lambda = 0.359, F(5, 40) = 0.359, p = 0.854 (\eta^2 = 0.310)$.

There was no significant difference seen in interaction effect (time*conditions), $\Lambda = 0.725, F(5, 40) = 0.304, p = 0.888 (\eta^2 = 0.275)$. Hence test subjects tended to have uniform behaviour in terms of deviation of lane position when they crossed the area where police car was present.

**Figure 50** Standard deviation of lane position values in presence of police car
Deceleration

For interaction effect the sphericity assumption is violated (before & after of sign occurrence) time period*conditions, $\chi^2 (14) = 30.457, p=0.007$.

There was significant effect of sign occurrence on main effect of time period (before/after sign occurrence), $F (1, 43) = 7.535, p= 0.009$ ($\eta^2 =0.149$). The test subjects had higher deceleration, before sign occurrence, hence the sign has a significant effect (M.D=0.049, SE=0.018, $p=0.009$).

The main effect of condition (six scenarios) is not significant, $F (5,215) =0.925, p= 0.459$ ($\eta^2 =0.021$). There was no significant interaction effect (time*conditions), $F (3.874, 166.595) =1.921, p= 0.111$ ($\eta^2=0.043$).

Hence drivers had significant effect on deceleration in their respective scenarios, whereas no significant effect was encountered whilst comparing them, with each other, this reaffirms the fact that drivers tend to change their driving behaviour instantly when they encounter TTC measure.

Effectiveness of sign, before/after its occurrence is discussed below:

- Scenario 1, had no significant effect in deceleration after sign occurrence, MD=0.0028, SE=0.061, $p=1$.
- Scenario 2, had no significant effect in deceleration after sign occurrence, MD=0.0142, SE=0.044, $p=1$.
- Scenario 3, had no significant effect in deceleration after sign occurrence, MD=0.0027, SE=0.047, $p=0.745$.
- Scenario 4, had significant effect in deceleration after sign occurrence, MD=0.1246, SE=0.041, $p=0.032$.
- Scenario 5, had significant effect in deceleration after sign occurrence, MD=0.1347, SE=0.031, $p=0.002$.
- Scenario 6, had no significant reduction in deceleration after sign occurrence, MD=0.0207, SE=0.044, $p=0.985$.

![Figure 51 Deceleration before and after, sign occurrence when police car is present](image-url)
7.8.1 Centre of work zone area

This section of experiment is taken into account, to foresee driver's compliance inside work zone, when only speed limits are placed. The centre of work zone comprises of 500 metres, located from 8750 to 9250 metres, having only speed limits (70 km/h) sign boards on both side. In this section one way repeated measure of ANOVA is carried out to give possible explanation of driving parameters

**Mean speed**

A one way repeated measures of anova, determined that assumption of sphericity was violated $\chi^2 (14) = 102.066$, $p <0.05$. Whereas greenhouse geisser correction for degree of freedom found no statistical difference between different scenarios, $F (2.910, 124.738) =0.970$, $p =0.47$. Thus results conclude that test subjects often drive with the same driving behaviour while passing through work zone areas, whereas increase in mean speed of 5.85 km/h, is also seen among drivers in centre of work zone area, as compared to start of work zone.

**Figure 52** Percentage and average rate for deceleration when police car is present

**Figure 53** Deceleration profile, when police car is present
Pairwise comparison did not help in revealing significant differences. Thus concluding that drivers tended to have uniform driving behaviour in centre of work zone. There are some notable differences among scenarios, which can be useful to interpret about speeding behaviour of particular scenarios:

- Scenario 5, had significant difference in mean speed as compared to scenario 3, MD=1.797, SE=0.588, p<0.05.

![Figure 54 Mean speed in centre of work zone](image)

Overall mean speed reduction of 0.944% was seen, after the placement of the sign board. Figure 55, contains the detail description of before/after mean speed reduction.

![Figure 55 Difference in mean speed, at start and centre of work zone](image)

**Standard deviation of Mean speed**

The results show that in centre of work zone, there was no significant effect on standard deviation of mean speed by driving in six different scenario. The assumption of sphericity had been violated $\chi^2 (14)$
= 43.032, \( p < 0.05 \), hence degree of freedom are corrected using Huynh-Feldt. The results show that no significant effect was found on standard deviation of mean speed, by driving in different type of scenarios, \( F(1.631, 8.156) = 0.457, p = 0.611 (\eta_p^2 = 0.084) \).

Figure 56 Standard deviation of mean speed in centre of work zone

**Standard deviation of Lane position**

A one way repeated measures anova was conducted to see effects on standard deviation of lane position (SDLP) in centre of work zone. There was no significant effect on standard deviation of lane position, compared to any other scenario. Mauchly’s test tells us that assumption of sphericity had being violated, \( \chi^2 (14) = 39.195, p = 0.002 (p<0.05) \). Hence multivariate test (Pillai’s trace) reports no significant effect on SDLP due to different scenario types, \( V=0.996, F (5, 1) =52.195, p = 0.105 \). These results reveal that in centre of work zone, no significant difference is noted among participants while driving through different scenarios. This may happen, due to the fact that in centre of work zone there was no TTC measure present which might not have influenced the decision on changing lane position.

**Acceleration**

The results show no significant difference on acceleration due to different scenario type. Wilk’s lambda test is reported \( V=0.925, F (5, 36) =0.587, p = 0.710 \).

**Deceleration**

No significant difference on deceleration is seen while driving through six different scenarios. Sphericity assumption had also being violated, \( \chi^2 (14) = 88.903, p<0.05 \). Corrected degree of freedom are reported by Greenhouse-geisser, \( F (2.294, 98.658) =0.561, p = 0.596 \).

**7.9.1 End of work zone sign**

This section is taken in account, to evaluate the effectiveness of end of work zone sign board. The sign board is evaluated, before 250 metres its location and after 250 metres of its location. Two way repeated measure of ANOVA (within subjects design) is used in this section, to check the effect of the end of work zone sign on driving performance measures.
Mean speed
The assumption of sphericity had being violated for both the main effects (conditions), $\chi^2 (14) = 36.257, p=0.001 (\eta^2 = 0.20)$.

Significant effect was noted for end of work zone sign on main effect of time period (before/after sign occurrence), $F (1, 44) = 398.287, p= 0.000 (\eta^2 =0.901)$. The test subjects drove slower, before sign occurrence, hence the sign has a significant effect ($M.D=9.937, SE=0.498, p<0.05$).

The main effect of condition (six scenarios) is not significant, $F (3.814, 167.801) =1.418, p= 0.232 (\eta^2 =0.031)$. Contrast test, revealed significant difference among the scenario.5 and scenario.6, $F (1, 44) =5.020, p= 0.030 (\eta^2 =0.102)$.

Significant effect is not seen on interaction term (time-period*conditions), $F (4.460, 196.251) =2.209, p=0.062 (\eta^2=0.48)$.

Pairwise comparison shows significant results, for before/after sign placement. Thus effective results can be seen in before/after situation for all scenarios. A generic increase in mean speed can be seen in all scenarios:

- Scenario 1, had significant increase in mean speed after sign occurrence, MD=9.867, SE=0.737, $p<0.05$.
- Scenario 2, had significant increase in mean speed after sign occurrence, MD=9.27, SE=0.846, $p<0.05$.
- Scenario 3, had significant increase in mean speed after sign occurrence, MD=8.628, SE=0.877, $p<0.05$.
- Scenario 4, had significant increase in mean speed after sign occurrence, MD=9.874, SE=0.778, $p<0.05$.
- Scenario 5, had significant increase in mean speed after sign occurrence, MD=10.471, SE=0.705, $p<0.05$.
- Scenario 6, had significant increase in mean speed after sign occurrence, MD=11.512, SE=0.768, $p<0.05$.

![Figure 57 Mean speed before and after end of work zone sign](image)
Overall mean speed increase of 16.11% was seen, after the placement of the sign board. Figure 58, contains the detail description of before/after mean speed reduction. Since there was no difference noted among all scenarios, this means test subjects behaved similarly in all scenarios, when they encountered end of work zone sign.
There was **no significant difference** seen in **interaction effect** (time*conditions), $F (5, 40) = 0.509, p = 0.768 (\eta^2 = 0.06)$. Thus meaning that drivers tended not to deviate from their mean speed, while comparing different scenarios altogether, therefore they had uniform driving behaviour.

![Figure 60 Standard deviation of mean speed, before and after end of work zone sign](image)

**Standard deviation of lane position**

Significant effect was encountered in main effect of time-period (before/after sign placement) for sdlp, $F (1, 8) = 9.842, p = 0.014 (\eta^2 = 0.552)$. Whereas sdlp values were lower for before location of sign, higher for after sign occurrence (M.D=0.195, SE=0.062).

**No significant effect** was noted for **main effect of conditions** (six scenarios), $F (5, 40) = 1.268, p = 0.297 (\eta^2 = 0.137)$. There was **no significant** effect noted in **interaction effect** (time*conditions), $F (5, 40) = 0.569, p = 0.723 (\eta^2 = 0.066)$. Thus means drivers changed their lane position after sign occurrence, but this was found in all the scenarios, thus no behavioural differences where encountered among test subjects in all scenarios.
Figure 61 Standard deviation of lane position values for end of work zone sign

Acceleration

The assumption of sphericity had being violated for the main effects of conditions (six scenarios) $\chi^2(14) = 109.728$, $p=0.00$.

There was significant effect of sign occurrence on main effect of time period (before/after sign occurrence), $F(1, 43) = 17.479$, $p=0.00$. The test subjects had lower acceleration, before sign occurrence, hence the sign has a significant effect (M.D=0.168, SE=0.04, $p=0.00$).

The main effect of condition (six scenarios) is not significant, $F(5, 215) =0.998$, $p= 0.420$.

There was no significant effect on interaction term (time*conditions), $F(5, 215) =1.070$, $p= 0.378$.

Pairwise comparison reveal significant effect, of acceleration in scenario.5. Effectiveness of sign, before/after its occurrence is discussed below:

- Scenario 1, had no significant reduction in deceleration after sign occurrence, MD=0.118, SE=0.058, $p=1$.
- Scenario 2, had no significant reduction in deceleration after sign occurrence, MD=0.118, SE=0.065, $p=1$.
- Scenario 3, had no significant reduction in deceleration after sign occurrence, MD=0.030, SE=0.086, $p=1$.
- Scenario 4, had no significant reduction in deceleration after sign occurrence, MD=0.240, SE=0.069, $p=1$.
- Scenario 5, had significant reduction in deceleration after sign occurrence, MD=0.430, SE=0.073, $p=0.044$.
- Scenario 6, had no significant reduction in deceleration after sign occurrence, MD=0.092, SE=0.088, $p=0.798$.
Figure 62 Acceleration values, before and after end of work zone sign

Overall mean speed reduction of 0.9009% was seen, after the placement of the sign board. Figure 63, contains the detail description of before/after mean speed reduction.

Figure 63 Percentage increase for end of work zone sign
8 CONCLUSIONS

This master’s thesis experiment investigated the effects of different temporary traffic control (TTC) measures in work zone areas on highways. The outcomes of this study provided positive impact in terms of traffic safety on work zone configurations on highways. The literature suggest that using different TTC measures, results in higher speed compliances, lower amount of speed violations, and lesser amount of traffic incidents. The main conclusion of this study, is that traditional speed limits sign (C43), tended to possess uniform speed distributions, whereas added TTC measures (speed camera sign, police presence) results in decrease in average speed and disruption in uniform speed distribution.

Due to time limitations, the scope of this research was limited to driving simulator study. Six different conditions were programmed in STISIM 3, in which test subjects drove through work zone configurations having traditional static sign boards and newly experimented TTC measures. This chapter focuses on answering the research questions and hypothesis formulated earlier. Later the final chapter will draw attention towards discussion, limitations, recommendations and further research.

8.1 Research questions and hypothesis

This section addresses to give possible answers to research questions and hypothesis of this Master’s thesis formulated earlier. The research questions are addressed first, lastly hypothesis is tested. The research questions and hypothesis are represented in Italic and bold form.

i. What are the effects of adaptation of different sign typology, sign boards in all different scenarios while observing driving behaviour in construction work zone highways?

Yes, effect of change in mean speed before and after 250 meters was seen. When different sign boards was used for the first time in the scenario. But later on no effect was observed when sign were repeated. Moreover, significant differences were noted among different scenarios at several place i.e. C43 sign 70 km/h, Speed camera sign, and Police presence. Whereas current signalisation scheme proves to be useful in terms speed compliance, driving
behaviour and traffic safety, since it did not had any significant differences with any scenarios except in few cases.

**ii. What are the effects in driving in removing all signs except speed limits from left hand side in comparison with all other scenarios?**

No effect was noted in before and after sign occurrence. The average speed before and after remained same. Whereas, comparing with different scenarios at various sign locations and TTC measures it was noted that, removing left hand side sign boards except speed limits tend not to influence drivers in any scenario. Only at one positions significant differences were noted. Difference in Standard deviation of mean speed was only noted in scenario 1 (Reference scenario) and scenario 2(left hand signs removed except speed limit) at location of C43 sign (90 km/h).

**iii. What are the effects in driving in no left hand sign board, in comparison with all other scenarios?**

Removing left hand side scenarios had a significant difference as compared to scenario 5 at C 43 70 km/h speed limit and speed camera sign board. An effect was noted that drivers tended to drive with higher speeds as compared to other scenarios, but the difference is not significant due to the reason the signs were still visible since there was no traffic on road. This may be reason that drivers driving on the extreme left lane did not notice the speed limit or noticed the speed limit later on. Whereas no left hand sides scenario resulted in higher speed than scenario with speed camera and police presence. Significant difference was also noted at C43 (90 km/h) in standard deviation of lane position between scenario 3 and scenario 4.

**iv. What are the effects in driving in a yellow background speed limit sign board, in comparison with all other scenarios?**

Driving in scenario which possess yellow background sign board, resulted in higher visual acuity, which help drivers to speed limit recognition. This was concluded, when there were significant differences noted for scenario 6 (yellow background speed limits) with speed camera signs, police presence and C43 70 km/h speed limit. It was noted that drivers driving in yellow background speed limits tend to drive at higher speeds.

**v. What are the effects in driving in speed camera sign board, in comparison with all other scenarios?**

Due to speed camera sign presence, drivers resulted in sudden decrease in mean speed. Reduction in mean speed was seen by 12.07 % which is quite high. Whereas this sign also helped in sudden deceleration, which was noted to be significant having average deceleration rate of 0.2963. Drivers tended to also shift there lane position due to speed camera to the slower right lane. Whereas tended to increase their speed after speed camera sign board, thus only if police was present than compliance was noted.

**vi. What are the effects in driving in speed camera sign with police enforcement car presence, in comparison with all other scenarios?**
Significant effects were noted for police presence scenario. Mean speed reduction of 5.74 % was noted. Besides there was also significant interaction effect noted between scenarios 4 and 5, 5 and 4, 1 and 5. Whereas there was significant deceleration noted when police was present, having deceleration rate of 0.48145. Comparative statistical analysis with other scenarios reveal that speed camera sign had significant effect on main conditions and interaction terms. Differences were noted for main conditions, between scenario 3 and 5, scenario 5 and scenario 6, while both speed camera sign and 70 km/h sign board were present. Interaction effect was also noted for police car presence for scenario 5 and scenario 6, scenario 5 and scenario 1, and scenario 4 with scenario 5.

vii. What is the effect of end of work zone sign on mean speed and acceleration?
End of work zone sign, resulted in sudden increase in mean speed. Resulted in mean speed increase of 16.11 % for end of work zone sign. Significant effect was also noted for standard deviation of mean speed, before and after sign occurrence. There was significant effect on standard deviation of lane position before and after sign occurrence. End of work zone sign also resulted in sudden acceleration, resulting in percentage increase in acceleration of 0.900. Whereas it was seen that test subjects behave uniformly towards this end of work zone sign, hence no significant differences were noted for comparative analysis among different scenarios.

viii. What is the effect of speed limits sign boards, before and after its occurrence?
C 43 sign boards resulted in compliance of speed when introduced for the first time in the scenario. Whereas repetition of sign boards had no main significant effect, since the drivers already had reduced their mean speed.

ix. Which sign results in higher deceleration speed camera sign or police car presence combined with speed camera sign?
Police presence results in higher deceleration as compared to speed camera sign. Police presence resulted in deceleration rate of 0.5382. Whereas speed camera sign resulted in lower deceleration rate of 0.2963.

x. Is there any effect of sign on standard deviation of mean speed and standard deviation of lane position?
Yes, there was significant effect noted for standard deviation of mean speed and standard deviation of lane position.

Sign C43 (90 km/h) effected standard deviation of mean speed when sign was introduced for the first time in a scenario, values were higher before sign board occurrence. End of work zone sign also resulted in significant effect on standard deviation of mean speed, after sign occurrence. Values were lower before sign occurrence.

Significant effect was noted for standard deviation of lane position when different TTC measures were introduced for the first time. Sign C43 (90 km/h; 70km/h) and end of work zone sign resulted in significant effect on standard deviation of lane position.
8.1.1 Hypothesis

“Would the implementation of different signs typology, using signs boards, removing sign boards, providing extra sign boards i.e. speed camera sign, yellow speed limit signs and police presence strategies have a positive impact on general safety in work zone areas. Which sign board will give appropriate information to increase drivers understanding of the situation at site, without further confusing them in work zone highways. Which signs would result in compliance of drivers?”

After analysis of the results, the above hypothesis has been approved. Due to the fact that C43 speed limit sign boards resulted in compliance with speed. Whereas lane closures also helped to change the lane, increasing them to understand situation at site. Speed camera sign and active police presence resulted in higher speed compliance. Whereas removing sign boards from left hand side resulted in higher mean speed, thus are not recommended to use, since they may have negative effect when traffic density is high.

9 DISCUSSION

The aim of this experiment was to investigate effect of different TTC measures on driving performance variables. Additional self-assessment of subjective work load was conducted to foresee possible differences in subjective work load in different conditions (scenarios).

According to the conclusions formulated in previous chapter, effect of using different TTC measures seem to have a positive impact on driving behaviour, traffic flows performance and traffic safety levels.

It was noted that test subjects tended to drive more socially acceptable way, thus there average speeds were influenced. For instance test subjects drove in the work zone area with a mean speed of 46 km/h, where speed limit was 70 km/h, which in reality is not does not happen. This finding is in contrast with study done by Bella (2005), which concludes results in real life and driving simulator while driving through work zones are not statistically different. This can be explained that most test subjects were not familiar with the driving simulator environment, were participating for the first time or higher perception of risk in work zones, which agrees with the study done by McAvoy et al. (2007) that mean speed are different from real world in work zones, due to motorist perceived risk of work zones. But on the other hand drivers seem to have a realistic driving behaviour towards speed camera sign, police car presence and end of work zone sign. Where sudden increase/decrease of speed was noticed, with higher acceleration/deceleration rate. Thus it can be concluded that results in this experiment were relative valid but not absolute valid, this finding correlates with study by Meuleners and Fraser (2015), which concludes that some parameters of the simulation are valid(mirror checking, forward observation, braking) and some are not (speed behaviours, gap selection and lane changing).

In this experiment it was also noted that test subjects recorded zero number of crashes inside the different scenarios, to be noted that work zone areas are considered as hazardous conditions. This finding also correlate with study of Underwood et al. (2011), that drivers tended to be alert and have earlier fixations in hazardous areas.

This study also finds that presence of active police enforcement, results in reduction in mean speed. In this experiment police was present in advance warning zone which resulted in reduction of speed by 2.5 km/h, whereas previous studies done by Minnesota (1999), reveals that police presence in upstream area of work zone results in speed reduction of 11 km/h. This can be explained by the reason that drivers were already driving with lower speeds (50 km/h) than posted speed limits (70 km/h), which is already explained that drivers were new to simulation environment, and had increased hazard
perception. Yet even with lower average speed (43.5) drivers reduced their speeds by 2.5 km/h. Thus it proves the results to be relative valid.

This experiment also finds the use of speed camera signs to be relative valid, help reducing the average speed by 12.07 %, even with lower entering speeds. This finding is in correlation with findings done in real life field study by Retting and Farmer (2003), which reveals that speed camera signs and presence of speed cameras, help reduce the by 14%.

Literature by (Howell et al., 2015; Matthews & Mertins, 1987; C.-M. Yang et al., 2005) suggested that use of amber sign board gives good visual recognition. In this experiment, combined effects were foreseen for yellow speed limit background sign boards. The drivers tended to decelerate and accelerate more as compared to reference scenario. Yellow background sign boards resulted in higher speeds in comparison with other scenarios, when introduced with C43 sign (90 km/h), and higher average speeds at end of work zone area when comparing with other scenario. This distinct behaviour towards speed adoption, in different scenarios, helps us to agree with literature that amber/yellow background sign, results in higher visual recognition.

However, still some limitations might have influenced the results in this driving simulator study. This chapter further elaborates and gives attention to the possible limitations in the methodology of the study, implications, recommendations, and proposal for further research.

### 9.1 Driving simulator research

The driving simulator, as described earlier is used as method to conduct the experiment. Therefore results acquired from this study are meant to represent the driving behaviour of test subjects in real life, but still the results obtained from this study need to be compared with the field observations to appropriate validation. Further, while comparing the results obtained from this study, with results from studies previously done (literature), similarities are being observed. Similarities help make the conclusion of the reactions obtained by test subjects on different TTC measures and their driving behaviour are relative valid with real life. However, it is still necessary to assess the validity of impact size and driving performance measure of a particular TTC measure.

While driving the different test subjects might be inclined to adopt more sociably driving behaviour. Thus biased could have being introduced to results.

Especially test subjects tend to have a (i) Lower speeds than specified speed limit i.e. inside work zone speed limit was 70 km/h, whereas subjects drove with 50 km/h which in reality is not the case (ii) uniform speed distributions while being introduced to C43 (70 km/h) till the end of work zone, which in reality drivers tend not to do.

It is not possible to detect to what level the results could be biased, however the biased results could have affected the driving behaviour to smaller or larger extent. Thus to encounter this phenomenon, the test subjects were left alone in the simulator, without having any communication with a third party during the process of the experiment.

The urge for validation of the results arises, due to the fact that driving simulator has a limitation of realism in terms of simulated environment. Still there are issues such as speed perception, visual acuity and movement of the car. Most of the test subjects, were first time participating in the experiment, hence commented that the simulator lacked on realism issues. Thus urge of need for validation of results with field observation is needed.
9.2 Implications

The results of this study indicate that traffic flows and traffic safety levels can be influenced in a positive manner by introducing different temporary traffic calming measures, without violating the traffic rules and regulations of that particular country. With the help of this observations, one could decide to imply the different TTC measures (changeable message sign, speed enforcement, portable devices and information measures) depending upon the nature (congested, long term, lengthy) of the work zone. In work zone highways, combined TTC measures, will effect positively when traffic flows are uninterrupted (not congested), but for non-compliant drivers, will result in sudden deceleration when TTC measure is present, but later after sign occurrence they will increase their respective speed again. Thus combined application of different TTC measure will only result positively, when they are implied at multiple times in work zone area i.e. start, middle, end or averagely at 150 metres, hence not reminding drivers again for the compliance. However by doing so, there are chances of traffic disruptions, bottle neck, tail gating and rear end crashes in rush hours/traffic volume is high.

9.3 Limitations

The study was conducted in driving simulator which has certain limitations as compared to real life driving. This study is mainly associated in finding evidence in driving behavioural responses, whereas lacks the fundamental tools to assess socio-physiological responses of drivers. If socio-physiological responses i.e. heart beat rate, respiration rate and galvanic responses are added, they would help provide more objective evaluation of behavioural and emotional responses for their driving style as done by Donkor, Burnett, and Sharples (2014). The test subjects often commented on physical dimensions of the simulator, that it real life driving is a distinct as driving in a simulator. It was also commented by test subjects absence of traffic, was not realistic, which was done to lower work load. Whereas study by Shakouri et al. (2014) reveal that traffic density influences the speeding behaviour of drivers. Hence traffic presence in the study would have also produced different results.

Visual acuity is also seen as important limitation. To be noted that in the driving simulated environment, test subjects often confronted with the problem of visual acuity, referring to sharpness of the object visible on screen. Whereas in reality, driving in day conditions, a driver does not confront with these issues. Still other visibility issues also appeared in the experiment. It was insured in the experiment that drivers have visibility of a sign at distance of 500 meters, whereas in reality the sign board are readable at distance of 50 to 200 meters. So two questions arise due to that effect which are (i) would it have affected the driving behaviour (ii) this may also have introduced bias when validating with field study.

9.4 Reccomendations

Based on the results of the experiment, the recommendations for better compliance, lesser drivers errors and improving traffic safety. In work zone areas, when traditional signs are placed, drivers tend to have uniform speed distribution, until and unless added TTC measures is used, thus resulting in reduction in average speed. Therefore use of different TTC measures shall be adopted in work zone configurations in Belgium for improving the traffic safety. The current work zone signalisation in Belgium, seems to serve the traffic safety issues in a good manner, nevertheless one can always give advice to improve the situation. The recommendations are following

1. This study with its comparative statistical analysis concludes that, removing left hand sides sign board’s results to show significant differences, and higher speeding averages with other scenarios. Therefore using this sign is not recommended, since it may prove to be vulnerable in dense traffic conditions, when driver work load is high.
2. Yellow background speed limits shall be used inside work zone areas, since they prove to provide better speed compliance, higher visual recognition taken as compared to other scenarios.

3. Speed camera sign boards shall be used for increasing driver compliance at both start and middle of work zone, so that drivers tend not to speed down at start and speed up after passing the sign.

4. Active police enforcement shall be used so that drivers do not violate the speed limits, since police presence results in higher speed compliance, due to fear of punishment.

5. Inside work zone and before work zone (1 km prior) all sign boards shall have yellow background so, drivers have higher visual recognition.

6. Apart from yellow background sign boards, all work zones shall also have yellow lane markings, which will also result in higher visual recognition and alertness due to its distinct colour background from traditional sign boards.

7. The fines for speed violation inside the work zone shall also be raised, and communicated properly to the general public, since accidents in work zone result in injuries both to the workers and drivers. If the public is properly informed about the fine raise than, there will be a better compliance with traffic rules even in late hours (night time), when there is low traffic density.

8. Use of digital information systems with innovative message sign, at start and middle of work zone can also prove to useful in addressing driving behaviour psychologically, since they alert drivers about their current speed and give socially approve messages, which discourage over speeding.

9.5 Further research

The focus of this study, was to examine driving behaviour while implementing different TTC measures, and evaluation of effectiveness of current signalisation scheme in Belgium. Many studies have already being done for the topic work zone compliance both field study and driving simulator study. But still there is a gap to experiment, the effect of different intelligent transportation system (I.T.S) inside the work zone. I.T.S will help drivers to be better inform with current changing conditions inside work zone, which it can help in real world, due to its co-ordinated system. Apart from investigating effect of I.T.S technologies in work zone areas, combine effect of portable rumble strips, optical speed bars, variable speed limit, and digital information system inside work zone areas can be assessed, since they have being proved useful in giving positive outcome in terms of traffic safety in general. Whereas studies have not yet being done to assess the combine effect of the aforementioned topic. To be noted that special care shall be taken, while designing the experiment, and low density traffic (provide lower workload) shall also be present in the scenarios, since they cover the aspect of realism. Use of visual distraction parameters in the study will also help explore the driving behaviour in a better manner since in real life distractions are often present.

Furthermore for future research, for better driving assessment. Driving behaviour shall be assessed with socio-physiological responses along with subjective performance measurement. Since most experienced drivers in complex situations often tend to overrate their driving performance. Thus additional assessment measures will give better subjective and objective evaluation of driving behaviour.
10. REFERENCES:


Fudala, N., & Fontaine, M. (2010). Interaction between system design and operations of variable speed limit systems in work zones. Transportation Research Record: Journal of the Transportation Research Board(2169), 1-10.


11. APPENDICES
APPENDICE I: Scenario 2 description in detail
APPENDICE II: Scenario 3 description in detail
APPENDICE III: Scenario 4 description in detail

11000 M
End of post work zone area

POST WORK ZONE AREA
10 K TO 11 KM

10150 M

10050 M

10000 M

WORK ZONE AREA FROM 8000 M TO 10000 M

9750 M

9250 M

8750 M

8250 M
APPENDICE IV: Scenario 5 description in detail
APPENDICE V: Scenario 6 description in detail
APPENDICE VI: Description of sign boards to be used in the signalisation scheme (Flanders.Govt, 2015)

<table>
<thead>
<tr>
<th>SIGN NUMBER</th>
<th>SIGNS</th>
<th>NAME OF SIGN</th>
<th>DESCRIPTION</th>
<th>LOCATION</th>
</tr>
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<td>1</td>
<td></td>
<td>Type B4-1</td>
<td>Overhead Bridge CMS</td>
<td>Location at 3000 m</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Type B3-2</td>
<td>Portable CMS</td>
<td>Location at 3000 m</td>
</tr>
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<td></td>
<td>F79</td>
<td>Lane closure after 3000 m</td>
<td>Location at 5000 m</td>
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<td>4</td>
<td></td>
<td>A51</td>
<td>Attention possible congestion ahead</td>
<td>Location at 5500 m</td>
</tr>
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<td></td>
<td></td>
<td>Sign post announcing reduction in number of lanes</td>
<td>Location at 6000 m</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>F79</td>
<td>Lane Closure after 1500M</td>
<td>Location at 6500 m</td>
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<td>C43</td>
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<td>Location at 7500 m, 7850, 8250, 8750, 9250, and 9750 m</td>
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## APPENDICE VII: Description of signs to be used in the manipulated scenarios

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## APPENDICE VIII: Details of randomization set *(Urbaniak & Plous, 2015)*
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APPENDICE IX: Pre-Questionnaire
Beste proefpersoon

ID-nr: ...
Gelieve dit document in te vullen in afwachting dat u wordt opgehaald door de onderzoeker. Indien er een vraag onduidelijk is, kunt u deze open laten en de onderzoeker zal alle vragen met u overlopen.

Bedankt voor de medewerking

***************

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| 1. Geslacht?         | O Man
                          O Vrouw |
| 3. Woonplaats?       | .......................................... (postcode + gemeente) |
| 4. Wat is uw hoogst voltooide opleiding (met diploma)? |
|                      | O Lager onderwijs
                          O Lager middelbaar onderwijs
                          O Hoger middelbaar onderwijs
                          O Hoger onderwijs, niet universitair
                          O Hoger onderwijs, universitair onderwijs
                          O Ander:................................. |
| 5. Wat is uw beroep? |
|                      | O Bediende
                          O Arbeider
                          O Zelfstandige
                          O Student
                          O Niet beroepsmatig actief
                          O Ander:................................. |
**Rij-informatie**

6. Welk type rijbewijs bezit u en sinds wanneer?
   
   O B, sinds .......... *(jaartal)*
   O C, sinds .......... *(jaartal)*
   O D, sinds .......... *(jaartal)*

7. Hoeveel kilometer rijdt u gemiddeld per jaar als bestuurder?
   
   O 0 tot 4.999km
   O 5.000 tot 9.999km
   O 10.000 tot 14.999km
   O 15.000 tot 19.999km
   O 20.000 tot 25.000km
   O Meer dan 25.000km

8. Hoe vaak per week rijdt u op snelwegen?
   
   O Dagelijks
   O Wekelijks
   O Maandelijks
   O Jaarlijks
   O Nooit

9. Waarvoor gebruikt u het vaakst de wagen?
   
   O Woon-werkverkeer
   O Professioneel
   O Ontspanning
   O Winkelen
   O Ander: __________________________

10. Wanneer verplaatst u zich het vaakst?

    *[Spitsuren: van 07:00 tot 09:00 en van 16:30 tot 18:30]*
    
   O Buiten spitsuren
   O Binnen spitsuren

11. Draagt u een bril of contactlenzen tijden het besturen van een wagen?
   
   O Ja
   O Nee

12. Rijdt u meestal handgeschakeld of via automatische versnelling?
   
   O Handgeschakeld
Verkeersveiligheid

13. Hoe vaak bent u als bestuurder betrokken geweest bij een ongeval?

- O Nog nooit
- ............. keer met enkel materiële schade
- ............. keer met lichtgewonden
- ............. keer met zwaargewonden
- ............. keer met doden

14. Hoe vaak per week gebruikt u de gsm handenvrij achter het stuur?

- O Nooit of 0 keer per week
- O 1-3 keer per week
- O 4-6 keer per week
- O 7 of meer keer per week

15. Hoe vaak per week gebruikt u de gsm niet handenvrij achter het stuur?

- O Nooit of 0 keer per week
- O 1-3 keer per week
- O 4-6 keer per week
- O 7 of meer keer per week
How hurried or rushed was the pace of the task?

[Rating scale]

Very Low  |  Very High

How successful were you in accomplishing what you were asked to do?

[Rating scale]

Very Low  |  Very High

How hard did you have to work to accomplish your level of performance?

[Rating scale]

Very Low  |  Very High

How insecure, discouraged, irritated, stressed, and annoyed were you?

[Rating scale]

Very Low  |  Very High

APPENDICE XI: Post Questionnaire

Post-bevraging

ID-nr: .......

1. Wat is volgens u het doel van dit onderzoek?

……………………………………………………………………..…………………………………………………………

……………………………………………………………………..…………………………………………………………

……………………………………………………………………..…………………………………………………………

2. Vond u dat uw rijgedrag in de simulator als volgt overeenkwam met uw rijgedrag in de werkelijkheid

O Min of meer overeenkwam
O Enigszins afweek
O Sterk afweek
Indien uw gedrag afweek, op welke punten week uw gedrag af?

…………………………………………………………………
………………………………………………………………………………

3. Weet u wat dit bord betekent? Heeft u dit bord opgemerkt? (snelheidscontrole)

O Correct  O Ja
O Niet correct  O Nee

4. Heeft u de volgende zaken opgemerkt?

Oranje snelheidsbord  O Ja  O Nee
Geel snelheidsbord  O Ja  O Nee
Blauw snelheidsbord  O Ja  O Nee
Politieauto  O Ja  O Nee

4. Heeft u nog opmerkingen?

……………………………………………………………………..…………………………………………………………
……………………………………………………………………..…………………………………………………………
……………………………………………………………………..…………………………………………………………

5. Heeft u suggesties voor het aanbrengen van wegsignalisatie bij wegenwerken?

……………………………………………………………………..…………………………………………………………
……………………………………………………………………..…………………………………………………………
……………………………………………………………………..…………………………………………………………

Appendices XII: Box plot for outliers
### DESCRIPTIVE ANALYSIS OF NASA TLX

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Richting: **Master of Transportation Sciences-Traffic Safety**  
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Datum: **11/01/2016**