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2014•2015
SCHOOL FOR TRANSPORTATION SCIENCES
Master of Transportation Sciences

Master's thesis

The effect of countdowntimers on traffic flow and safety

Supervisor :
Prof.dr.ir Tom BELLEMANS

Co-supervisor :
Prof. dr. Tom BRIJS

Wouter van Haperen

Thesis presented in fulfillment of the requirements for the degree of Master of Transportation Sciences

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PREFACE

The final part of the Transportation Sciences Master Program is the master thesis, in which students propose a topic, perform a literature review and conduct a research study in order to answer the composed research questions. During the last three semesters, I was able to put a lot of time, effort and joy in performing my research. With pride, I present this dissertation, which describes and concludes on my graduation project.

Many thanks go out to prof. dr. T. Brijs, my co-promotor, who pointed out which aspects of driving simulator studies I needed to take into account. Without his help and advice, the simulation experiment would have been too complex to analyze. Other thanks go out to prof. dr. ir. T. Bellemans, my promotor, who provided important feedback during the defense of the first part of this thesis.

I also would like to thank mr. D. Roox, for providing me with an introduction towards the driving simulator software STISIM DRIVE 3 and the countdown timer files I needed during my research, and mrs C. Ariën and mr J. Cornu for helping me with the statistical analyses.

Most thanks go out to dr ir. A. Pirdavani, for supervising and supporting my progress during the entire process and offering aid whenever I needed it. The discussions regarding the different aspects of the method selection and composition of the scenarios have increased the quality of this research.

Last of all, I want to thank all of my friends and family, who supported me, showed interest in my project and helped me by participating in my experiment. They helped me to find the motivation to put as much effort in the thesis as I could. Without their help, I would not have been able to present this report with a satisfied feeling.

Wouter van Haperen,

Master student of Transportation Sciences at Hasselt University, January 2015

SUMMARY

This thesis describes a study that was performed to assess the effects of numerical countdown timers at traffic lights on Belgian driving behavior. The purpose of such devices is to warn drivers that the oncoming phase change is about to happen, which could help drivers to start earlier at the onset of the green phase and offer aid in their decision to stop or go at the onset of the amber phase. The scientific literature regarding numerical countdown timers is limited and mainly focused on cities in Asia. Some of these studies report contradicting results. Because of differences in driving culture, it was not possible to transfer results from these studies into the Belgian context. Therefore, a new study needed to be conducted. Since countdown timers are not yet implemented in Belgium and therefore before-and-after or with-or-without studies could not be performed, the driving simulator was selected to provide first results. People that were accustomed to the Belgian driving culture and possessed a valid driving license were selected as test subjects. Both traffic flow efficiency and traffic safety aspects were taken into account.

With regard to traffic flow efficiency, the literature suggested that the saturation flow decreases if countdown timers are installed. Due to the fact that drivers will become more confident that they will pass the green signal in time, they tend to leave more space between them and the vehicle in front and can even decrease their speed slightly. In order to avoid these effects, a new approach is proposed, in which only the final stage of the green phase is counted down. A duration of three seconds was selected, since this value includes the perception-reaction time towards a phase change (on average 1.30 seconds) up until the 99th percentile range (2.80 seconds). The main idea behind this approach is to provide some information to approaching drivers, but not too much.

The final-stage countdown timers could also be beneficial for the end of the red phase. Although several studies reported that drivers appreciate the timers because they know how long they have to wait, it is also mentioned that these people use the waiting time for other activities like reading a paper or checking their mobile phone. Especially during the final seconds of the red phase, there is the risk that drivers overestimate the time they have left, thereby creating the adverse effect that they will react later to the phase change.

Final-stage countdown timing has an additional advantage. The practical application of the 'standard' countdown timers in Belgium is losing ground, since more traffic lights are equipped with traffic actuated signal programs. These programs adapt the signal phasing to the current traffic demand. One could introduce adaptable countdown timers, but this could result in mistrust in the timers when people experience several adaptations that are disadvantageous to them.

In this driving simulator study, a within-subject design was used to compare six unique conditions, in which test subjects were faced with intersections with either no countdown timer, or countdown timers for the entire phase or the final three seconds. Each countdown timer type was encountered twice: all test subjects were caught in a dilemma zone and encountered a situation in which the traffic light turned to red during their approach. In order to apply to the standards of driving simulator study regulations, full randomization was applied, so each test subject encountered a unique sequence of scenarios. The set-up of the study was to assess how the first vehicle in line reacts towards the countdown timers, so no interaction with vehicles driving in the same direction was programmed.

For the dilemma zone scenarios, it was found that the amount of vehicle stops increased significantly when countdown timers were applied. This indicated a negative effect on traffic flow efficiency, but the results also suggested improvements for traffic safety. The maximum average deceleration force decreased from almost 10 m/s^2 to less than 5 m/s^2 for the final-stage and less than 4 m/s^2 for the entire phase timer. Another important observation made was that drivers who decided to stop for the entire countdown timer, started to decrease their speed already 175 meters in advance of the intersection.

No positive or negative effects were observed regarding traffic safety aspects in case of red-on-approach scenarios. However, the results suggested that traffic flow efficiency could be improved if either one of the timers would be installed. A significant reduction of around 1,1 second was found for the reaction times and start-up lost times. However, no statistical significant difference between the two countdown timers was found.

The only difference between the final-stage and entire phase timers that was found in this study, was the amount of vehicle stops during the dilemma zone

scenarios. Although the traffic flow efficiency decreases, safety levels seem to improve if countdown timers are installed for the green phase. For the red phase, countdown timers seem successful in improving the traffic flow efficiency by reducing the start-up lost time. The fact that no significant differences were found between the two types of countdown timers, increases the potential for final-stage countdown timing of the red phase.

This study also included a short survey, in which the test participants were asked whether they believed if countdown timing of the green and red phase could improve the traffic flow efficiency and traffic safety levels. It was found that the majority of the test subjects were convinced that green phase countdown timing is beneficial for both aspects. Furthermore, over 93% of the participants appreciated the timers and stated it would help them in making the decision to stop or go at the intersections. For the red phase timers, half of the test subjects did not perceive any safety benefits at all. Traffic flow efficiency however was perceived to be improved.

Key words *Countdown timers, dilemma zone, final-stage timers, reaction time, start-up lost time, traffic flow efficiency, traffic safety, vehicle stops*

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1. INTRODUCTION

Traffic demand has increased rapidly during the last decades. Major cities face congestion problems on a daily basis, since roads and intersections are operating above their capacity level. Besides negative impacts on traffic flow efficiency, the increasing traffic demand also decreases safety levels. Especially when time constraints are present, drivers could make improper decisions at the onset of the amber and red phase, resulting in severe side-impact or rear-end crashes.

In order to improve traffic flow efficiency and safety levels, several mechanisms have been developed to inform drivers about an oncoming phase change. One of these systems is the numerical countdown timer, which is used for both the green and the red phase (figure 1). These devices show the exact amount of time left until the start of the next phase. This additional information should enable drivers to react faster at the beginning of the green phase and could provide help in their decision to stop at the onset of the amber phase.

Figure 1 Examples of numerical countdown timers installed at traffic lights. They are used for both counting down the green and red phase.

The numerical countdown devices were already introduced in the 1970s in Florida and Texas, but were abandoned since there didn't seem to be any significant improvement in safety levels. During the early 2000s, the devices were re-introduced, mainly in heavy congested cities in Asia. Since then, limited research has been performed to assess the effects on the traffic flow and safety aspects. The researches that have been performed, report contradicting results.

Although countdown timers seem to reduce red-light violations and potentially reduce the start-up lost times, reported disadvantages include decreased saturation flows and an increase of the indecision zone. This study proposes to implement countdown timers for only the final stages of the green and red phase. Providing just enough information, rather than too much, could maintain the positive effects of the regular timers, but possibly avoid the negative ones.

2. PROBLEM DEFINITION

During the last ten years, the amount of registered vehicles in Belgium increased with almost 17% ("Voertuigenpark - Statistieken & Analyses," 2014), from just over 6 million to just over 7 million vehicles, while the average occupation rate decreased from 2.14 to 2.01 persons per car (figure 2). According to TomTom International BV, the index for the congestion level, which is based on a comparison between peak and off-peak hours, reached 34% for Brussels (2014). It was also pointed out that congestion levels for non-highway roads are slightly higher (36% compared to 31% for highways), a trend that is observed for almost all of the 60 cities that were included in their report.

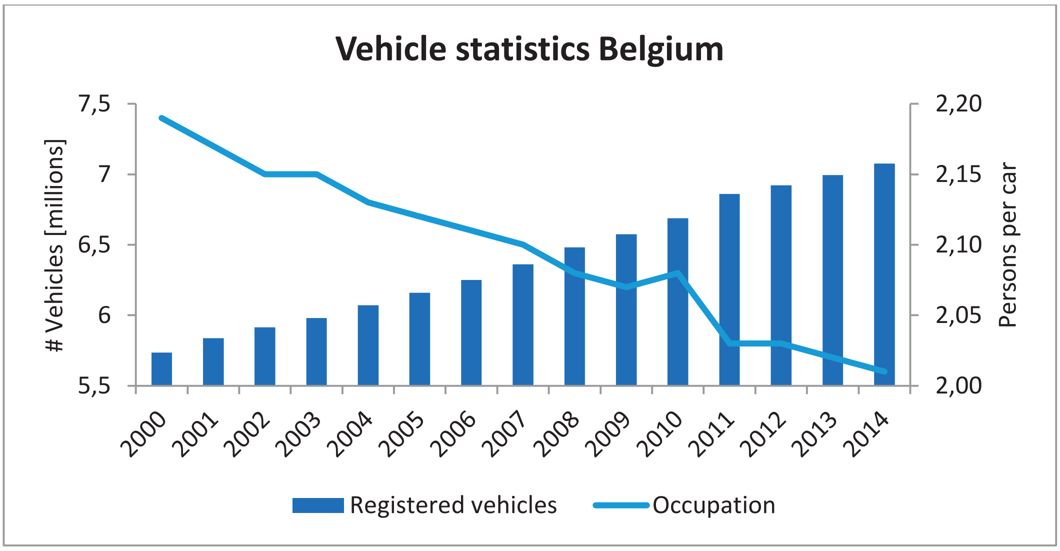

Figure 2 The increase of registered vehicles and the decrease of the average amount of persons per car for Belgium are possible reasons for the increase of congestions levels (figures retrieved from www.statbel.fgov.be, 2014).

Initiatives for reducing congestion in or near city centers are focused on influencing or convincing drivers to change their mode use. Examples are congestion pricing, the free bus service in the city of Hasselt (which was cancelled at the beginning of January 2014, due to budgetary constraints) or the introduction of park-and-ride facilities. Little effort is put into optimizing the current infrastructure. With regard to signalized intersections, the most known approach currently adopted in order to improve the traffic flow, is the installment of traffic actuated signal controllers. These controllers use detectors to assess the current traffic demand and if necessary, they can extent the duration of the green signal phase for a particular direction or skip phases and provide a green signal for the direction for which it is needed.

Another approach towards optimizing signalized intersections is the use of phase change warning systems, which aim at letting drivers react faster. Today, several systems are in use to warn drivers that the oncoming phase change is about to happen. In some countries in Europe, the beginning of the green phase is announced with a combination of a solid red and solid amber light. However, such a system is only being used for warning drivers for the onset of the green phase and does not provide an exact value of time left until the actual phase change. In Asia, heavy congested cities make use of numerical countdown timers, which are also applied for indicating the end of the green phase. Results from studies regarding this numerical devices show that their effect is not clear. Even more, in some cases, contradicting observations are reported. The main goal of this study is to assess if it is possible to improve traffic flow efficiency at signalized intersections in Belgium, using numerical final-stage countdown timers. Since the assessment of such devices should not be limited to the traffic management perspective only, this study also includes some conclusions regarding their effects on traffic safety levels and concerns.

2.1 Research development

The initial research question described the assessment of the effects of numerical countdown timers on the traffic flow. Prior to the start of this study, it was determined that the research would focus on Belgian roadway conditions. After the literature was reviewed, it became clear that the research question needed to be refined and include more details, since the use of countdown timers is much more complicated than one could expect at first sight. The main problem was posed by the absence of numerical countdown timers for motorized traffic in Belgium. The literature implied that the driving culture can have a huge impact on the effects and driver's attitudes regarding these devices. Therefore, it was necessary to first assess the effects of these entire-phase countdown timers on Belgian driving behavior, before a comparison with final-stage countdown devices could be made. One could argue that the research therefore should be limited to check if the effects of the countdown timers in Asia are transferable to Belgium. However, in light of the practical application for Belgium, the increasing use of traffic actuated signal programs needed to be taken into account, thereby already discouraging the use of countdown timing of the entire phase.

2.2 Research questions and hypotheses

As mentioned before, this study is concerned with comparing two different types of phase change warning systems using numerical countdown devices. A distinction is made between entire-phase and final-stage countdown timing for both the red and green phase. In order to make a proper comparison, these two types are compared with the reference scenario that has no countdown timers, which is the current situation in Belgium. The main research question is formulated as follows:

What are the effects of countdown timers on traffic flow and safety?

Since it is the aim of this study to compare the effects of final-stage countdown timers with the regular countdown timers and conditions without such devices, some additional questions and hypothesis were composed. The hypotheses describe on which aspects the research will focus. The additional questions and hypothesis are formulated as follows:

1. Is there a difference in effects of the final-stage countdown timers compared to conditions without countdown timers?

H1: Final-stage countdown timers reduce the start-up lost time.

H2: The number of vehicle stops during the onset of the amber phase is higher for conditions with final-stage countdown timers.

2. Is there a difference in effects of the entire-phase countdown timers compared to conditions without countdown timers?

H3: Entire-phase countdown timers reduce the start-up lost time.

H4: The number of vehicle stops during the onset of the amber phase is higher for conditions with entire-phase countdown timers.

3. Is there a difference in effects of the final-stage countdown timers compared to the entire-phase countdown timers?

H5: There is no difference in the reduction of the start-up lost time.

H6: There is no difference in the amount of vehicle stops during the onset of the amber phase.

As stated in the hypotheses, the main comparison between the different signal light types will be based on the amount of vehicle stops at the onset of the amber phase and the reduction of the start-up lost times. Some additional measures, that might influence these main aspects, are also taken into account. Attention will be given to the approaching speeds, the location of the stop-or-go decision and the force of acceleration or deceleration used during the onset of the amber phase and reaction times at the onset of the green signal phase are measured. Although it is not expected to happen, red light running violations for both phase changes will also be monitored.

3. LITERATURE REVIEW

In order to provide additional information about the oncoming phase change of a traffic light, several countries implemented some form of a warning system. The United Kingdom and Germany, for example, use a combination of red/amber to inform drivers about the start of the green phase. In Austria, a flashing green phase is added between the continuous green and continuous amber phase and in many heavily congested cities in Asia, numerical countdown devices are installed. Although the use of these numerical countdown timers is becoming more popular, their effects on both safety and traffic flow efficiency are lacking scientific evidence. Literature is rather scarce and the researches that have been performed, seem to contradict each other at various points. Therefore, their effectiveness remains uncertain.

This section of the paper provides an overview of the available literature with regard to phase change warning systems. First, the perception-reaction time and the amber phase will be discussed, of which the latter one includes rules and regulations and the dilemma zone. Different systems for aiding the driver to make the right decisions during a phase change are also introduced. Afterwards, this chapter will focus on numerical countdown timers and discuss the results that have been found so far.

3.1 Perception-Reaction Time

When a change in behavior or actions is required, the most important aspect is the reaction time. The human brain needs some time to translate the perception of an event into a (proper) reaction. Figure 3 illustrates that the distance covered during this 'translation' time, which is referred to as 'thinking' distance, depends on the speed.

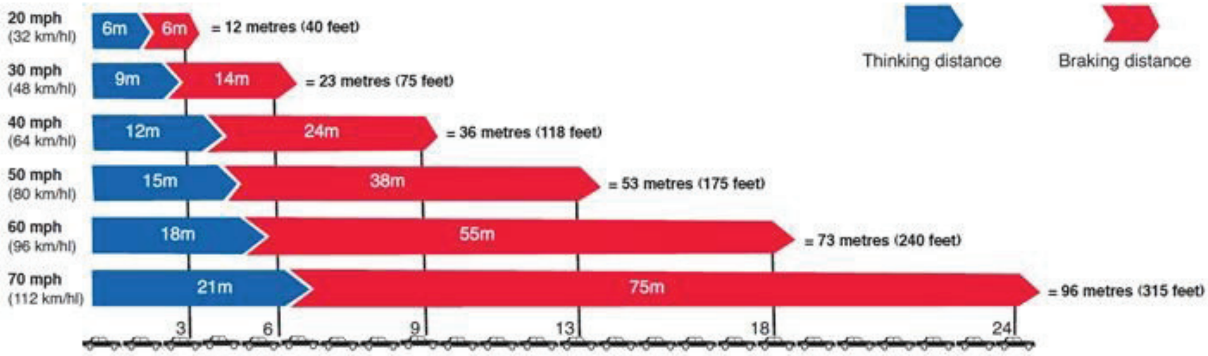

Figure 3 The effect of the perception-reaction time and speed on stopping distances.

With regard to traffic flows and driving behavior, empirical research provided an average value of 1.50 seconds for this so called perception-reaction time (Gartner, Messer, & Rathi, n.d.). Chang et al (1985) and Wortman and Matthias (1983) focused on traffic signal phase changes and found an average value of 1.30 seconds for this perception-reaction time (with a 99th percentile of 2.80 seconds). The slight decrease of this perception-reaction time can be due to the fact that one is expecting a phase change to happen, therefore noticing and processing this event quicker.

3.2 The Amber Phase

Informing approaching drivers that the red signal phase is about to start, can be achieved in various ways. The most important warning is provided by the amber phase, which is mandatory in Belgium (AWV, 2011). Dependent on the speed limit, a minimum duration of amber time is specified in order to improve safety levels (table 1).

Table 1 The minimum duration of the amber phase (AWV, 2011).

Speed limit [km/hr]	Minimum amber time [s]
50	3
70	4
90	5

Rules and regulations regarding the amber phase are not exact. Belgian law describes the behavior that is expected when confronted with the onset of this phase, but doesn't explicitly state when a driver is allowed to pass or not. The following rule applies (translation from: "Artikel 61. Driekleurige verkeerslichten," n.d.):

"A solid amber light means that it is prohibited to pass the stop line or, in case of absence of a stop line, the traffic light, unless the driver at the onset of the light has approached at such distance that it is not possible for him to stop safely; if the light is placed at an intersection, the driver is, if adhered to previous described circumstances, only allowed to cross the intersection if he does not endanger the other road users."

It is described that one is allowed to drive through the amber light if he assesses that he is not able to stop safely any more. Therefore, the decision to pass the light is entirely dependent on the driver himself. It is to be expected that different drivers make different decisions (either speed up or brake), based on personal factors, for example attitude, driving style and mood, and environmental factors, like weather and traffic conditions. When two consecutive drivers make different decisions, in which the first driver decides to stop and the second one to increase its speed in order to pass the light, severe rear-end crashes could occur. The area in which these opposite decisions are made, is referred to as the dilemma zone in traffic engineering (figure 4). In scientific research, the boundaries of this area are determined by the distances where more than 10 percent, but less than 90 percent of the drivers decide to stop (Chiou & Chang, 2010; Lum & Halim, 2006).

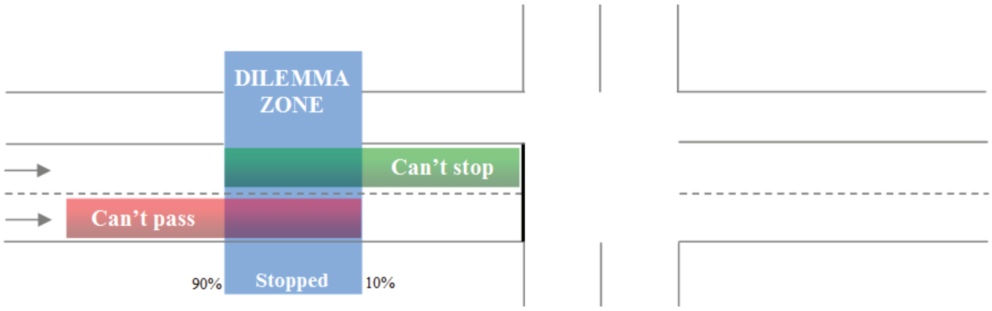

Figure 4 The dilemma zone, determined by the percentage of vehicles stopping, based on their distance to the stop line.

In order to improve traffic safety and reduce the number of rear-end collisions, several systems have been developed to inform drivers about the oncoming onset of the amber phase. It is believed that additional information should aid drivers in their decision to stop or pass the intersection, therefore reducing the length of the dilemma zone.

3.3 Phase Warning Systems

Different approaches towards warning drivers about an oncoming phase change have been applied in the past. In most of the experiments and research, only traffic safety aspects are taken into account and conclusions are based on the behavior drivers express during the onset of the amber phase. When comparing these different approaches, a distinction into three categories can be made:

- Signal light sequence
- Advanced Warning Flashers
- Countdown Timers

Some of these approaches indicate a positive effect on the safety aspects, while others show a serious reduction in safety levels. In the following sections, the different types of phase warning systems will be discussed briefly.

3.3.1 Signal light sequence

As pointed out earlier, various signal light sequences are used around the world. The main differences can be found with regard to the onset of the amber phase, since it is believed that a longer decision period should result in more proper stopping decisions, thereby reducing the number of accidents (Limanond, Chookerd, & Roubtonglang, 2009). Research that has been performed to assess the performance of flashing amber in conjunction with solid green before the solid amber phase showed that this is not the case (Mussa, Newton, Matthias, Sadalla, & Burns, 1996; Newton, Mussa, Sadalla, Burns, & Matthias, 1997). It seemed that the indecision zone actually increased, resulting in more rear-end collisions. Newton et al. suggested that this was the result of the drivers attitude regarding the flashing amber, which was considered as an extension rather than a pre-warning. However, it was indicated that flashing amber can potentially reduce severe decelerations, compared to flashing green. Other studies that examined a flashing green phase found an increase in the amount of improper stopping decisions (Koll, Bader, & Axhausen, 2004; Mahalel, Zaidel, & Klein, 1985). Koll et al suggested that the increase of early stops was caused by the driver's underestimation of the time until the onset of the amber and red phase.

Limanond et al. point out that pedestrian countdown signals should also be taken into consideration (2010). Also according to Huey and Ragland, approaching drivers tend to use this extra information at the end of the amber phase to decide to drive through or to stop (2006). Furthermore, when signal programs include pedestrian phases in the same through movement, in which the pedestrian phases start and end slightly earlier than the phases for motorized traffic, drivers can predict when a phase change is likely to happen (Rijavec, Zakovsek, & Maher, 2013). At the onset of the green phase, this can result in a reduction of the start-up lost time, but at the end of the green phase, it can result in 'racing against the clock' behavior.

3.3.2 Advanced warning flashers

The Texas' Department of Transport conducted research in which advanced warning flashers were analyzed (Messer, Sunkari, Charara, & Parker, 2003). These systems, that are placed some distance in advance of the intersection (figure 5), recommend approaching drivers to stop when the amber phase is about to commence. With the use of a sign, which reads 'prepare to stop when flashing', and flashing lights, the decision to stop is provided by the system, rather than by the interpretation of the driver himself. These warning systems are mostly applied on high speed intersections (v > 70 km/h) or intersections where there is insufficient sight. The study concluded that these advanced warning flashers are efficient in improving intersection safety.

Figure 5 An advanced warning flasher.

3.3.3 Countdown Timers

Several countdown timers have been developed to give an accurate estimation of the time left until the next phase change. There are two different types of these timers: the numerical countdown and the image countdown timers. The difference between them is that the numerical timers show the exact amount of time left, while the image timers should be interpreted.

Countdown timers can be used for both the red and the green phase (figure 6). It seems that there is no standardization regarding the use of green phase countdown timers. Some timers include the amber phase (Chiou and Chang, 2010), while other countdown timers show the remaining time until the onset of amber.

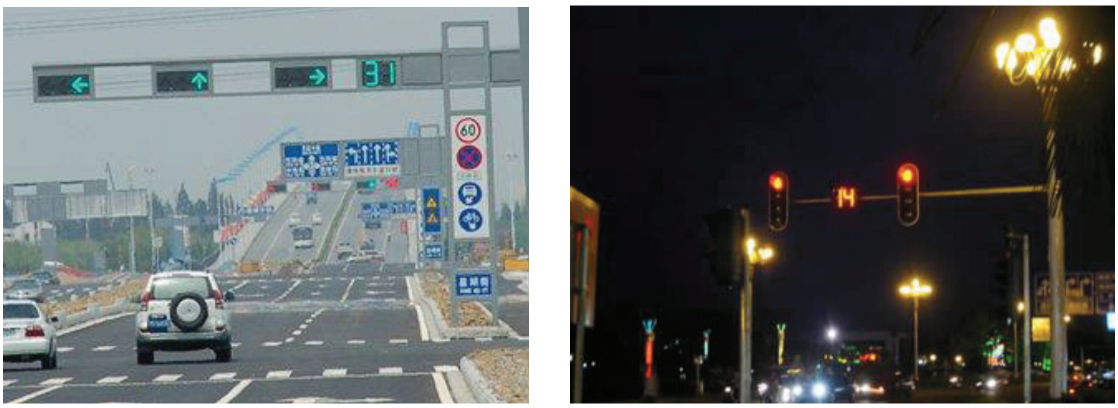

Figure 6 Countdown timers for the green and red phase.

According to Newton et al., cities in Florida and Texas experimented with numerical countdown timers during the 1970s (1997). Because experiments didn't find any significant improvements in safety, the use of these timers was abandoned. However, numerical timers were re-introduced during the early 2000s in Asia (Limanond, Prabjabok, & Tippayawong, 2010). Although scientific research on this topic is limited, several studies report contradicting effects.

3.4 Research on numerical countdown timers

The most used research techniques for identifying the benefits and drawbacks of numerical countdown devices are before-and-after studies (Kidwai, Karim, & Ibrahim, 2005; Lum & Halim, 2006; Rijavec et al., 2013; Sharma, Vanajakshi, Girish, & Harshitha, 2012; Wenbo, Zhaocheng, Xi, & Feifei, 2013) or with-or-without studies (Chiou & Chang, 2010; Limanond et al., 2009, 2010; Long, Liu, & Han, 2013). Other approaches include the use of a comparison between intersections with and without countdown timers (Liu, Yu, Wang, Ma, & Wang, 2012; Long et al., 2013; Sharma, Vanajakshi, & Rao, 2009) or the use of a driving simulator (Newton et al., 1997). With exception of the last one, all studies assessed the performance of a numeric countdown device. In the case of Newton et al. (1997), the simulator was used to test the introduction of a flashing green combined with solid amber phase, between the solid green and solid amber phase. Since it is already mentioned that such an approach does not seem to improve safety, the remainder of this section will focus on numeric countdown devices. However, it should be noted that due to differences in driving culture and time, such an approach isn't necessarily disadvantageous for Belgian traffic lights now-a-days.

As outlined above, studies regarding the effects of numerical countdown timers are scarce. Furthermore, the conclusions drawn from this studies seem to contradict one another at various points. It should be pointed out that comparison of the different studies is difficult, since the context of the examined intersections differ (business district versus non business district) and differences in driving culture could influence driver's attitude regarding the timers.

This section aims at providing an overview of the research that has been performed so far and focuses on measurements of performance that have been used. In order to provide a clear overview, a distinction has been made between green phase and red phase countdown timing.

3.4.1 End of green

Several studies have been performed to investigate the effects of green signal countdown timers. Table 2 gives an overview of the results that were found in these studies. The table shows that not all the studies used the same measurements of performance. It is surprising to see that only the research of Chiou and Chang (2010) included measurements of the dilemma zone, since it seems at first sight that countdown timers could potentially shorten this area. However, the researchers found that the dilemma zone doubled in length when the timers were installed. It would have been interesting to observe if similar results were found in other cities or countries as well.

The most used measurement is the presence and level of red-light-running violations. All studies that included this parameter, concluded that this number decreased when countdown timers were in place. With regard to safety aspects, this is an important observation, since it could indicate a decrease in the chance of a severe side-impact crash to happen.

Table 2 An overview of the results of previous studies. One should be careful to compare different studies, since the context and driving culture can differ.

	Location	Red-light-Running	Saturation Flow	Decision to stop	Dilemma Zone
Kidwai et al, 2005	Malaysia	Decrease from 66,2% to 37,1%	Decrease		
Lum and Halim 2006	Singapore	65% reduction*		Amount 6.2 times higher	
Sharma et al, 2009	Chennai		Increase discharge rate		
Limanond et al, 2009	Bangkok		Increase during evening/night		
Limanond et al, 2010	Bangkok	50% reduction	Slight decrease during day		
Chiou and Chang 2010	Taipei	Potential reduction		Increase	Increase of 28 meters
Rijavec et al, 2013	Ljubljana	Potential reduction			
Long et al, 2013	Changsha			Probability 0.7 times lower	

* This is the reported short-term effect.

3.4.1.1 Traffic flow

Some studies examined the effect of countdown timers on the saturation flow (Kidwai et al., 2005; Limanond et al., 2009, 2010; Sharma et al., 2009). Limanond et al. (2009; 2010) performed studies at the same intersection, of which the later study was an extension to observe the effects during evening and night time conditions. It was found that during the day the saturation flow slightly decreased after installation of the countdown timers. It was suggested that because of the high traffic demand during the day and the presence of time pressures, drivers already tend to leave the smallest gaps possible to the vehicles in front of them in order to increase the chance of passing the light. A countdown timer could potentially have a negative effect, since it can make drivers confident that they will pass the light, thereby increasing the gap with the vehicle in front to a more comfortable length. This phenomenon was also reported in the study of Wenbo et al. (2013). During evening and night-time conditions, the countdown timer did seem to have a positive effect in terms of saturation flow rate. The absence of time constraints and a lower traffic demand were suggested to be the main contributors to this effect. In another study, Kidwai et al also found a reduction of the saturation flow (2005). The throughput was measured before and after the countdown timers were installed. Slight reductions of around two percent were measured and attributed to high differences in car lengths and driver behavior. Sharma et al on the other hand found an increase of saturation flow (2009), especially during the second half of the green phase. This is also indicated by Liu et al., who found that compression of the headways start when 14 seconds of green time remain (Liu et al., 2012).

3.4.1.2 Traffic safety

Safety aspects of the countdown timers are mainly assessed using the red light violation figures. Most studies argue that if this number reduces, the chances of side-impact crashes decreases as well. However, it is hinted that the reduction in these type of crashes is traded off with an increased risk of being involved in rear-end crashes, since the dilemma zone increases. As of yet, only one study assessed the traffic safety using actual accident data (Chen, Chang, Chang, & Lai, 2007), up to one year after the installation of the devices. They found an alarming increase of 100% of fatal and injury accidents, which was probably caused by the aggressive accelerations of approaching drivers.

3.4.1.3 Long term effects

Almost all of the studies limited their research to the short-term effects only. Lum and Halim (2006) are an exception, since they observed driver's behavior up to 7,5 months after the installation of the timers. With regard to the red light violations, it was found that the reduction of 65% measured 1,5 months after the installation wasn't sustainable. During the last measurement, 7,5 months after installation, numbers increased to almost prior-countdown levels again. However, the timers seemed to have a lasting effect on drivers decision to stop during the onset of the amber light. The initial increase of 6,2 times slightly decreased over the long term, but remained significantly different at the 95% confidence level.

3.4.2 End of red

A few studies have researched the effects of red phase countdown timers. All of these studies included the start-up lost time as one of the most important measurements. In contrast to the studies assessing the green signal countdown timers, the research is mainly focused on traffic flow efficiency rather than traffic safety aspects. Table 3 contains an overview of the results that have been found so far.

Table 3 An overview of the results of previous studies. One should be careful to compare different studies, since the context and driving culture can differ.

	Location	Early start Ratio	Start-Up Lost Time	Frustration level
Sharma et al, 2009	Chennai		Substantial reduction	
Limanond et al, 2009	Bangkok		Reduction between 1-1,92s	
Limanond et al, 2010	Bangkok		Decrease of 22% (1,79 s)	Decrease
Chiou and Chang, 2010	Taipei	Decrease*	Increase*	
Liu et al, 2012	China		Reduction of 2,25 s	
Rijavec et al, 2013	Ljubljana		Slight increase	
Wenbo et al, 2013	GuangZhou		Reduction	

* This is the reported short-term effect.

3.4.2.1 Traffic flow

Not all studies conclude the same with regard to the start-up lost times. Although the majority points out that countdown timers have a reducing effect on this aspect, two studies have measured a slight increase. Chiou and Chang suggest that the increase is caused by the intention of the drivers to start accelerating after the light has changed to green (2010), instead of starting accelerating before the actual phase change. Rijavec et al suggest that an increase of start-up lost time could be due to decreased attention levels. They argue that in case of the absence of countdown timers, drivers observe traffic flows in cross directions and prepare to start when they note that those flows prepare to stop. In case traffic lights are equipped with countdown timers, drivers might only focus on the countdown timers, thereby removing their focus from the rest of the driving environment.

Most studies report a decrease of average start-up lost times. One study calculated the effects on the traffic flow (Limanond et al., 2010). Assuming a cycle length of 230 seconds, a green phase of 102 seconds and a start-up lost time reduction of 1,79 seconds, an additional 15 vehicles per lane per hour could be accommodated. If it seems that this reduction in start-up lost time is transferable for Belgium, the increase in capacity could be higher. Cycle lengths are usually much shorter and the start-up lost time reduction only seems to affect the first five or six vehicles in the queue (figure 7), since they are mainly focusing their decision to start moving based on the traffic light, rather than the vehicles moving in front of them.

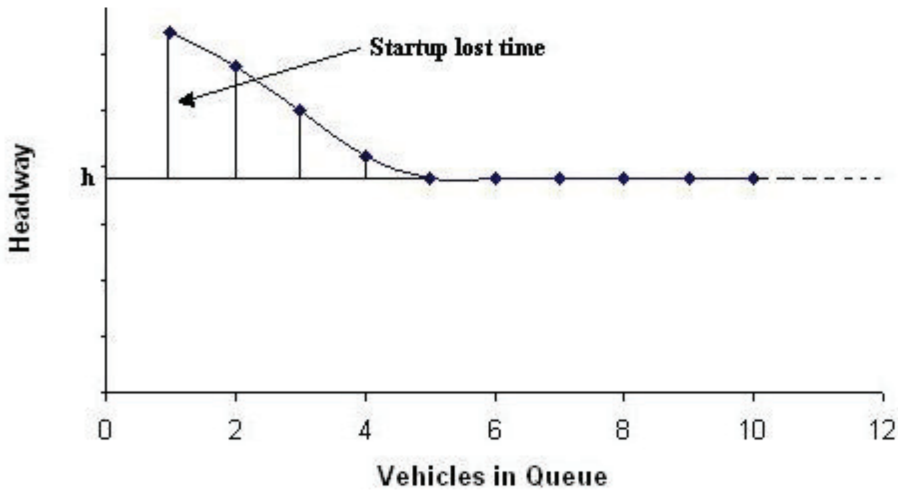

Figure 7 The start-up lost time is different for the first five vehicles, since they need to react to the signal phase change. Other vehicles merely react towards the movement of the vehicle in front of them.

3.4.2.2 Traffic safety

When considering red phase countdown timers, mainly traffic flow aspects are considered. It is surprising that only the research of Chiou and Chang included early-start ratios (2010). It is not unthinkable that, especially when time constraints are present, drivers will misuse the countdown timers. Based on their knowledge that there is a margin of safety between the green signals of two opposing traffic flows and their assessment of the traffic conditions, they might decide to start earlier to minimize their delay. Again, only the study of Chen et al. (2007) provide some results based on actual accident data. They reported that a decrease of 50% of fatal and injury accidents was measured after installation of the timers. This could indicate that red phase countdown timers have a beneficial safety effect, if early-start ratios at the onset of the red phase are problematic. Again, one should consider that driving culture differences might be involved. The study also examined if the number of fatal or injury accidents would increase if both red and green phase countdown timers were installed. They found a value of 19% compared to conditions without countdown timers, which could indicate that in the driving culture examined, the safety benefits of the red phase are smaller than the safety concerns regarding the green phase. Based on these results, the researchers recommended that only the red phase countdown timers should be installed.

3.4.2.3 Long term effects

Only one study examined the long term effects of the red phase countdown timers (Chiou & Chang, 2010). Four observation periods were selected, ranging from before the installment, until 4,5 months afterwards. When taking into account this long term effects, it showed that the initial slight increase of start-up lost time changed in an actual decrease in the longer term. It is suggested by the authors that familiarity towards the new countdown timers enabled drivers to take advantage of it. Instead of waiting until the phase change, vehicles started slightly earlier, but without crossing the stopping line before the actual phase change happened. However, the results also showed that the early-start ratios increased or even exceeded the level prior to installation of the countdown timer. This could indicate that not all the drivers are able to take proper advantage of the timer, since they cross the stopping line too early.

3.4.3 Driver's acceptability

A few studies investigated to which level numerical countdown timers are appreciated by drivers. Limanond et al. found that over 95% of the respondents recognized that the countdown timers could be beneficial to them (2010). When asked whether the respondent would agree or disagree with certain statements, the majority agreed that countdown timers could reduce frustration levels (64%), aid them in starting at the beginning of the green phase (63%) and provide help in the stopping decision at the onset of the amber phase (54%). Slightly less percentages were recorded in the survey of Rijavec et al. (2013). Of the respondents, 55% agreed that the timer would help to respond quicker to a phase change and around 15% believed countdown timers would be able to improve traffic safety. Around 10% of the respondents considered the countdown timers a negative complement. Of them, about a third stated that these timers would distract drivers, another third believed that red-light-running violations would increase and 16% claimed that traffic safety levels would decrease.

3.5 Summary

In order to aid drivers in their decision to start at the onset of the green phase and to stop at the onset of the amber and red phase, numerical countdown timers could be applied. Although their use in the last decade seems to become more popular, scientific research about the actual effects of these timers is scarce. Furthermore, different researchers have reached different conclusions.

With regard to the end of the green phase, countdown timers seems successful in reducing the amount of red-light running violations. Most studies only observed the short term effects, but the research of Lum and Halim seems to indicate that this effect will decrease in the long term, possibly due to familiarity and getting used to the new system (2006). Green signal countdown timers seem to have a negative effect on the traffic flow. Since drivers acquire more information about the onset of the amber phase, they tend to leave more space between them and the vehicle in front, thereby reducing the saturation flow. Although the timers can reduce the amount of side-impact crashes, they seem to increase the dilemma zone (Chiou and Chang, 2010), thereby increasing the risk of a rear-end crash occurring. Chen et al. analyzed accident data before and after the installment of green phase countdown timers and found that the amount of fatal and injury accidents doubled, possibly due to the aggressive accelerations drivers used during the end of the countdown (2007).

Red phase countdown timers seem more beneficial. Studies indicate that the start-up lost time could be reduced. Reductions between 1 and 2,25 seconds are measured. Although Chiou and Chang measured an increase of the start-up lost time 1,5 month after the timers were installed, a decrease was measured in the long term (2010). The countdown timers seem beneficial with regard to safety aspects. Chen et al found that fatal and injury accidents decreased with 50%, after installation of these devices (2007).

Based on public opinion surveys, Limanond et al. (2010) and Rijavec et al. (2013) observed that the majority of drivers appreciate the countdown timers. They offer help in the decision to pass or stop at the onset of the amber phase and enable to react faster to the onset of the green phase.

It is very important to note that comparing the studies that have been performed so far is very difficult. Differences in driving culture can influence the attitude towards countdown timers substantially. Another important aspect that can be of influence is the cycle length. Most of the included studies used cycle lengths of around or above 200 seconds, which is much higher than the maximum of 120 seconds for built-up areas in Belgium (AWV, 2011). Final aspects that could limit the transferability of the results are the context of the intersections (central business district or not) and the speed limits.

4. OBJECTIVE

The use of numerical countdown timers at traffic lights is becoming more popular, especially in congested cities in Asia. Scientific research regarding their effects is scarce and in some cases even contradictive. Green phase countdown devices seem to have a negative effect on saturation flow, since drivers are made more confident that they have plenty of time to pass the intersection before the onset of the red phase and as a result leave a more comfortable gap with the vehicle in front of them. Although countdown timers can reduce the number of severe side-impact crashes, it seems to increase the risk of being involved in a rear-end crash, due to an increased indecision zone.

As of yet, countdown timers are only applied at intersections that make use of a fixed signal phasing cycle. When considering traffic actuated signal programs, some sort of mechanism should be applied that adjusts the countdown. Introducing adaptable countdown timers could impose new problems as not registering the change in time left because the driver has focused his attention on something else momentarily, or not trusting the timers during the approach, since they depict only the maximum amount of time rather than the exact amount of time left. Especially for the green phase this could become problematic, since drivers might be made confident to pass, but in the end they will be forced to stop. These concerns are assumptions and adjustable countdown timers need to be tested in order to verify these possible problems.

4.1 Partial countdown timers

This study proposes a new approach for applying numerical countdown devices. In order to overcome the negative effects of the current numerical countdown devices and ease the process of integrating them with traffic actuated signal programs, it is proposed to only count down the final stages of the red and green phase. The idea behind this approach is that one should offer not too much information about the oncoming phase change, but at the same time provide the approaching driver with enough time to register and react properly to the warning for the oncoming phase change that is given. In this study, a duration of three seconds is selected, since the average perception-reaction time regarding phase changes is 1,30 seconds, with a 99th percentile of 2,80 seconds (Gartner et al., n.d.). It is important to note that this approach differs from the warning systems that use a flashing green or flashing amber light, which seemed to decrease traffic safety levels (Mussa et al., 1996; Newton et al., 1997). In this new approach, the exact time until the phase change is given, rather than a warning that the phase change could happen any second.

4.2 Method selection

The literature review showed that the most used research technique regarding countdown timers is the use of before-and-after and with-or-without studies. In ideal circumstances, a similar approach would be adopted. However, since no countdown timers in Belgium existed and the research had to deal with budget and time restraints, the driving simulator was selected to perform the research. As a result, one should be aware that the outcomes of this study should be regarded as an indication, since there is a substantial gap between the virtual driving environment and reality. For this research, the driving simulator at the Transportation Research Institute (IMOB) of Hasselt University was used. This simulator made use of STISIM DRIVE 3 ("STISIM Drive," n.d.) and the scenarios were programmed by the author himself.

4.3 Simulation parameters

Because this study is a first attempt to examine Belgian driving behavior towards numerical countdown devices, some limitations were used in order to avoid the simulation to become too complex. This research is concerned with behavior of drivers who are first in line at the onset of the green phase and their decision to stop or pass when caught in the dilemma zone. Therefore, interaction with traffic moving in the same direction was avoided. It would be interesting to include this interaction for conflict observation purposes, but in order to do so, one needs to base assumptions regarding this programmed interaction on data that is not yet available (how would these programmed vehicles react to the countdown timers?).

The visualization of the simulation was aimed at resembling the ring-road structure, which is used at many towns in Belgium. A two lane road with a speed limit of 70 km/h and a wide median was programmed. It should be noted again that this study aims at providing preliminary results. The fact that the driving simulator is used, stresses verification of possible positive results in real life conditions.

5. METHODOLOGY

As described in the previous chapter, this study uses the driving simulator to examine Belgian driving behavior towards numerical countdown devices. A different approach is proposed, in which only the final stages of the red and green phase are counted down. Because no research regarding entire-phase countdown timing and Belgian driving behavior exists, this aspect had to be included as well. This resulted in a simulation with several conditions and scenarios.

5.1 Conditions

The simulation consisted of six different conditions, which were encountered two times by each test subject. The conditions were developed from the two different types of countdown timers for the traffic lights and their use for the green and the red phase. Conditions without countdown timers, the current situation in Belgium, were added as reference scenarios.

In order to make sure that the data of interest could be gathered, two scenarios for each traffic light type were created. With regard to the green phase, the simulation was programmed to capture the participants in the dilemma zone. Because in these cases it is not certain if a participant will stop, a second set of scenarios needed to be created in order to avoid data losses of red phase encounters. During these scenarios, the traffic light turned to red during the approach. In short, the following scenarios were developed:

- Green phase > Dilemma zone
    - Reference scenario
    - Entire-phase countdown
    - Three-second countdown
- Red phase > Red-on-approach
    - Reference scenario
    - Entire-phase countdown
    - Three-second countdown

For each programmed condition, which resembled an intersection, only one type of traffic light was used for both the green and red phase. It was decided to avoid combinations of the different types, in order to avoid confusion for the participants. The following sections describe the different conditions and the data that was gathered.

5.1.1 Countdown Timers

The traffic lights in the countdown timer conditions contained a digital timer right next to the traffic light. The size of the timer was programmed to be readable at a distance of at least 200 meters in advance of the intersection. Figure 8 shows the sequence of the timer that was used in the three second timer condition. The green phase was counted down with green numbers and the timing of the red phase was shown in red. During the four second amber phase, two orange stripes were shown. In case no information was given, the timer remained black.

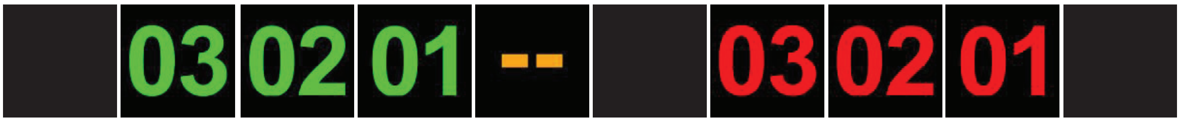

Figure 8 The sequence of the three second countdown timer.

5.1.2 Green phase; Dilemma zone

The selection of the driving simulator as research technique limited the possibilities to include the assessment of the dilemma zone. Since the software needed to be programmed in such a way that the traffic light changes its phase when the driver is at a specified distance, it was not possible to measure if the dilemma zone would increase during the countdown timer scenarios. The only measurement that could be performed was to program the distance at which the phase change should happen for all dilemma-zone scenarios at exactly the same distance and to observe if the number of vehicle stops would differ between the scenarios. During the programming, no assumptions were made regarding the actual decision to pass or not. The scenarios were based on the literature and tested to see if different test subjects would make different decisions.

During the experiment, data was gathered regarding the driver's decision to stop or not and the applied force of acceleration or deceleration used. If there are high differences between the reference and countdown scenarios, it could indicate a change in the dilemma zone. Further testing is then required to determine the extent of this change. In addition, the distance at which the stop or go decisions are taken, were also recorded. In line with the studies described in the literature review, this study also took into account the amount of red-light-running violations.

A final aspect that was assessed during the dilemma zone scenarios, were the approaching speeds of the different traffic light types. It is possible that the timers encourage racing-against-the-clock behavior, in which drivers tend to ensure their passage of the light and avoid being trapped in the dilemma zone. On the other hand, as already pointed out in the literature review regarding studies of flashing green and amber, some drivers might consider the three-second countdown timer as an extension of the solid amber phase, thereby reducing their speed in advance and reacting too soon at the oncoming phase change.

5.1.3 Red Phase; Red-on-approach

The second set of conditions focused on gathering data with regard to driver's behavior at the end of the red phase. Therefore, the scenarios were programmed that during the approach the traffic lights would turn red, without capturing test subjects in the dilemma zone. Furthermore, the duration of the red phase was sufficiently enough to guarantee that a test subject would have to stop completely, before the phase change to green occurred. This requirement was important, since only then differences in start-up lost times could be properly compared.

Between the different traffic light types, the start-up lost times of the test subjects were measured. This value is described as the time that passes between the phase change and the moment the vehicle crosses the stop line. However, the start-up lost time can be influenced by the distances drivers keep from the stopping line. Therefore, stopping distances were recorded as well to assess if these differ for the different traffic light types.

Another important measure that was recorded, were the reaction times. In this study, reaction times are described as the time that passes between the phase change and the first movement of the vehicle. Due to the nature of the research, in which the effects on traffic flow were examined, the first movement of the vehicle rather than the first reaction of the driver itself was selected. Recording this variable allowed to examine if drivers would take advantage of the countdown timer by starting before the actual phase change, without crossing the stop line.

This study also proposed a new sort of measurement, in which the time was recorded it took participants to travel the first five meters, starting at the moment the traffic light turned green. This variable was created in order to see if stopping distances would influence the start-up lost times. For the outcome of the analysis, similar results for these two parameters were expected. A final measurement included the speed of the vehicles during the actual phase change.

5.2 Set-up of the simulation

The final simulation contained twelve intersections, in which the conditions were encountered twice. During the programming of the simulation, requirements for driving simulator studies were adhered. Full randomization of the scenarios for the test subjects was applied and test subjects were able to get somewhat familiar with the software by means of a test drive. The following sections describe how these aspects were taken into account.

5.2.1 Randomization

An important concern of this driving simulator study is the effect of learning by sequence. In general, people can adapt their behavior for the next intersection based on their experience with the previous one. If for example one passes the traffic light during the final stages of amber at the first intersection, he or she is more likely to stop at the second intersection, when caught in the dilemma zone again. If one fixed sequence is used for all participants, this learning by sequence could negatively influence the results or even falsely point out that one of the tested traffic light types is not efficient in improving safety and/or traffic flow. In order to mitigate these concerns, full randomization is encouraged. When applied, every test subject receives a unique sequence of events.

The driving simulator software of STISIM DRIVE 3 has no built in function for randomization. The only way to ensure that each participant receives a different sequence, is to create as many programming codes as participants one is expecting. Because of time constraints and the ease of data analyzing, it was not possible to create over 40 different programming codes. Therefore, a different approach was used. Eight blocks, containing the six conditions in different order, were programmed. Each test subject drove through a unique combination of two blocks, to ensure a full randomization. However, as a side effect, test subjects received a short break when the switch between the two blocks was made.

5.2.2 Test drive

In order to get familiar with the driving simulator, test subjects were offered to participate in a short test drive. This was necessary, since many driving simulator programs are not able at mimicking the speed perception correctly. Furthermore, participants needed time to get used to the gas and brake pedal and the distance estimation. During the test drive, several intersections were encountered. The driving environment resembled the setting of the actual experiment, with the exception that dilemma zones were avoided. Only once a countdown timer was displayed, to show the participant what he could expect. During the test drive, some additional instructions were given to help the test subject to become more familiar with the simulator.

5.2.3 Simulation design

As stated before, the simulation is set up to resemble the ring road structure, which is found around many urban city centers in Belgium. Assuming a speed limit of 70 km/hr, curves that were easy to drive through were added. Furthermore, some buildings, trees and opposing and crossing traffic were added to the simulation, to make it feel more real. Figure 9 includes a snapshot of the simulation.

Figure 9 An impression of the programmed simulation.

One of the main issues with driving simulator software is the inefficient mimicking of speed and distance perception. Because of this issue, traffic signals in STISIM DRIVE 3 are larger compared to the size they would have in real life. The countdown timer faced comparable issues, since it needed to be visible at a certain distance. In this research, it was chosen that the timers should be clearly readable at least 200 meters in advance. As a result, the timers were quite large in the simulation, also when compared to the already enlarged traffic lights.

Because it might influence the perception-reaction times, a manual gearbox instead of an automatic one was preferred and programmed. Furthermore, the sound of the engine was added to the simulation, since it was one of the few feedback mechanisms to improve the speed perception.

5.2.4 Within-subjects design

When using the driving simulator to collect data, one could choose between a between-subject or within-subject design. The advantage of within-subject design is that all participants encounter all conditions and that one compares the different behaviors between the different conditions for each participant. When applying a between-subjects design, the sample population is divided into different groups, which do not encounter all conditions. Since humans are different and not easy to compare, a bias could be introduced. For example, it is well known that males and youngsters take more risks than elders or females. If one group is overrepresented by male youngsters, comparing them with other groups need some caution. However, the advantage of between-subject design is that one is able to increase the sample size relatively easy. Since the simulations in this experiment are relative short and a sample size between 40 and 50 participants was sufficient, the approach of a within-subjects design could be adopted.

5.3 The experiment

After registration for a certain time slot, test subjects were invited to visit the driving simulator. The experiment was divided in four stages, in which information was gathered and an introduction was given:

1. Short questionnaire + introduction and instruction
2. Test drive

3. Driving simulation
4. Short questionnaire

During the first questionnaire, an introduction towards the topic of the experiment was given. Numerical countdown timers were briefly introduced and the participants were only told that during the experiment, they would encounter traffic lights with and without timers. Information regarding the entire-phase and final-stage countdown timing was not provided, nor that they would experience dilemma zones or red-on-approach scenarios. The questionnaire focused on basic statistical data as age, gender, nationality and how long they were in possession of a driving license. With regard to countdown timing, the participants were asked if they had encountered them before and if so, in which countries. In appendix 1, the questionnaire is included.

The second and third stage of the experiment covered the driving simulation. The process of the test drive and the set-up of the simulation are already discussed in the previous section. The participants were instructed to drive the trajectory and apply the driving style they use in real life. It was asked to respect the speed limit of 70 km/h and to drive straight on at each intersection.

During the final questionnaire, the attitude and the level of appreciation of the test subjects regarding the countdown timers was tested. Immediately after the simulation was finished, the test subjects were confronted with several agree/disagree statements on a scale of 1 to 6. These statements asked the participants if they thought that countdown timers would increase safety levels and the capacity of intersection equipped with these devices and if the timers could help them to make a proper stopping decision at the onset of the amber phase or relieve frustration levels during the red phase. Four additional open ended questions asked about what they perceived to be the most important advantage and disadvantage of the green phase and red phase countdown timers. The two final open ended questions asked about what the participants thought the aim of the research was and if they had some additional remarks. A copy of this final questionnaire can be found in appendix 2.

5.4 Test subjects

Because of the nature of the experiment and the time constraints, the only requirement for test subjects to participate included the possession of a valid driving license. The main target group of the experiment were Belgian drivers, or people that were accustomed to the Belgian driving culture. No further specification of age, gender or driving experience was made, but could be interesting for further research, if countdown timers seem to have a positive effect.

In order to recruit as much test subjects as soon as possible, an e-mail was sent to all the students of Hasselt University and the researchers at the Transportation Research Institute IMOB. As a result, test subjects were mainly students in the age category of 18 until 25 years.

5.5 Summary

This study examined the effects of entire-phase and final-stage countdown timers on Belgian driving behavior. Since countdown timers for motorized traffic do not exist in Belgium, the driving simulator was selected to perform the research.

In total, six different conditions were created. The three types of traffic lights, no countdown, entire-phase countdown and final-stage countdown, were combined with the green and the red phase. In the first case, test subjects were caught in the dilemma zone and their decision to stop or go was monitored. Additional data collected included acceleration and deceleration forces, approaching speed and the location of the stop-or-go decision. In case of red phase scenarios, the traffic light turned red on approach, forcing the test subject to stop. Start-up lost times, reaction times and the amount of red-light violations were collected. In order to avoid the learning-by-sequence effect, scenarios were fully randomized for all test subjects. A within-subjects design was applied.

A small survey was set up to assess if Belgian drivers are positive about numerical countdown timers. Based on a few agree-disagree statements and open ended questions that asked what the participants perceived to be the most important advantage and disadvantage, an indication of the public acceptance of countdown timers was acquired. Table 4 gives an overview of all the data that was collected during the experiments.

Due to time constraints, participant were recruited by means of an e-mail that was send to all the students of Hasselt University. Therefore, most test subjects consist of students in the age category of 18 till 25 years old.

Table 4 The data that is collected during the experiment.

	Green Phase	Red phase
Driving Simulator		
Dilemma Zone	Approaching speed Stop-or-go decision Location of stop-or-go decision Acceleration/deceleration force Red-light violations	
Red-on-approach		Start-up lost times Reaction time Stop distance Time to travel 5 meters Red-light violations Speed during phase change
Questionnaire		
Perception Agree/disagree Scale 1 to 6	Safety levels Capacity Help in stop-or-go decision	Safety levels Capacity Relieving frustration levels

6. RESULTS

This chapter includes the results of the descriptive and statistical analyses. The program ‘R’ was used to order, sort and visualize the raw output data of STISIM Drive 3. Based on the graphical representations, a descriptive analysis was performed. In order to determine if the observed differences were statistically significant, a MANOVA and multiple ANOVA analyses were carried out in SPSS.

First, a description of the test subjects is provided. Characteristics of the sample population are described, exclusions of data is justified and the process of the outlier analysis is provided. Afterwards, the performance measures of the Dilemma Zone scenarios and the Red-on-Approach scenarios are discussed. Each time, the descriptive analysis is supported with the statistical tests to assess if observed differences were significant at the 95% confidence level.

6.1 Participants

In total, 52 test subjects participated in the experiment. From these 52 observations, six test subjects were excluded. Two of them experienced signs of simulation sickness, three subjects did not meet the criteria to be familiar with the Belgian driving culture and one participant was classified as a statistical outlier. The remaining 46 participants consisted of 36 males and 10 females and ranged in age between 18 and 71 years old. Besides 35 Belgian participants, eight Dutch drivers, one Iraqi, one Iranian and one German driver participated. Test subjects were asked when they had passed their driving examination and according to the Dutch law, in which someone is classified as a novice driver if he has obtained his driver’s license within the last five years (www.rijksoverheid.nl, 2014), 31 out of 46 drivers were inexperienced drivers. Based on their own estimations, the majority of the participants drives less than 10.000 km/year (20 observations) or between 10.000 and 20.000 km/year (13 observations). In total, seven participants had encountered countdown timers before. Appendix 3 includes a visualized description of the sample population.

6.1.1 Outlier analysis

Different techniques exist to analyze and exclude outliers from a dataset. SPSS distinguishes two types of outliers, in which additional emphasis is placed on the ‘far’ outliers. With the use of the outlier labeling rule, SPSS calculates the inter quartile ranges to determine if observations should be labeled as outliers. The most problematic cases are marked with an asterix, the outliers that are more close to the average values of the dataset are depicted with circles. During this research, it was decided to only exclude systematic outliers. For the data acquired during the experiment, it meant that only the 'far' outliers were removed if these values were represented by the same test subject in more than 25% of the conditions. As a results, one test subject was removed from the dataset.

6.2 Data selection

As described in the section regarding the full randomization procedure of the experiment, every test subject encountered two blocks with a unique order of conditions. Because almost all participants had not encountered countdown timers before or were unfamiliar with the driving simulator, concerns regarding the novelty and learning effect needed to be addressed. It can be argued, for example, that during the first encounter with the countdown timers, the participants were more likely to wait to check if the countdown timer worked correctly, rather than assuming the timer was programmed accurately and therefore not reacting in the same manner compared to situations in which the timer is already trusted. In order to check for this novelty and learning effect, the amount of vehicle stops during the two encounters were compared (table 5). It can be seen that the number of stops for the reference condition was the same. For the countdown timer scenarios however, the number of vehicle stops decreased for the second run. It could indicate that during the second encounter, some participants already learned and adapted their behavior.

Table 5 A comparison of the vehicle stops during the first and second encounter.

Condition	Vehicle Stops 1st Run (#)	Vehicle stops 2nd run (#)
No Timer	13	13
3s Timer	40	32
Long Timer	30	25

A paired T-test was performed in order to asses if there were significant differences between the two encounters for the Red-on-Approach scenarios. Tests were performed for each type of traffic light and performance measure. The results can be found in table 6. Note that the measurement of the speed during the phase change is not included, since this data is not normally distributed.

According to the analysis, no significant differences were found for the measurements of the no timer condition, with exception of the start-up lost time. The presence of the learning effect for the countdown timer conditions seemed to have influenced the results for all included variables except the stopping distances. The mean differences proved to be significantly different.

Table 6 The outcomes of the statistical t-tests to test for differences between the two encounters. Figures in bold were significant at the 95% level.

		95% Confidence interval			
	Mean difference	Lower	Upper	t-value	Sig. (2-tailed)
Reaction Time					
No timer	0,100	-0,178	0,378	0,727	0,471
3s timer	0,636	0,292	0,976	3,729	**0,001**
Long timer	0,624	0,182	1,066	2,842	**0,007**
Start-Up Lost Time					
No timer	0,375	0,049	0,702	2,315	**0,025**
3s timer	1,008	0,489	1,526	3,915	**0,000**
Long timer	0,522	0,095	0,949	2,461	**0,018**
Stop Distance					
No timer	0,576	-0,066	1,219	1,807	0,077
3s timer	0,974	-0,363	2,311	1,468	0,149
Long timer	-0,578	-1,992	0,836	-0,823	0,415
Time to travel 5m					
No timer	0,260	-0,031	0,551	1,801	0,078
3s timer	0,853	0,353	1,352	3,436	**0,001**
Long timer	0,546	0,175	0,917	2,967	**0,005**

The analysis already showed that there were significant differences between the two encounters of the countdown timing conditions, but an additional check needed to be made in order to assess if these differences could relate to the novelty and learning effect. If so, one would expect that during the second encounter the reaction time, start-up lost time and the time needed to travel the first five meters would decrease. As the boxplot figures in appendix 4 show, this reduction was indeed observed. The appendix also includes a figure for the speed during the phase change, which shows higher values for the second encounter. Based on these results, it could be concluded that the novelty and learning effect were present during the experiment. Therefore, it was decided to only use the data from the second encounter, rather than to average the values of these variables of both encounters. By doing so, it is believed that the included data is more representative for the actual behavior when one is confronted with a countdown timer.

6.2 Dilemma Zone Scenarios

As outlined before, the analysis of the dilemma zone scenarios will focus on several performance measures. Based on the differences in amount of vehicle stops, the approaching speeds and the acceleration rates during the final stages of the green phase, conclusions about the different timing mechanisms might be drawn. With regard to the two final measurements, a split between the drivers that decided to stop and the drivers that decided to pass the intersection was made. In this chapter, these results will therefore be discussed separately. Due to the complex nature and requirements for performing certain statistical analyses, only a descriptive analysis is provided for the acceleration rates and speed measurements. One of the main problems encountered during the statistical analysis were the unequal sample sizes of drivers that stopped or passed the different traffic light types. Applying the method of equaling the sample sizes by only including those observations that either stopped or passed for all traffic light types, resulted in a sample size that was very small. This made it impossible to conduct a proper statistical analysis.

6.2.1 Vehicle stops

One of the main indicators to assess the countdown timers from a traffic flow efficiency perspective, is the amount of drivers that decide to stop for the amber light. Since more information is available, the number of vehicle stops is expected to increase in case countdown timers are present, because drivers have more time to decide whether or not to take action, rather than react in an impulsive way. As outlined before in the section about the scenario development, the distance at which the traffic light turned to amber was identical for all conditions and based on the situation in which no countdown timer was present. Figure 10 contains the number of observed vehicle stops for the different conditions.

When comparing the three conditions, huge differences are observed. In case no countdown timer is present, only 13 out of 46 drivers decided to stop (28,3 percent), while this number increased to 32 drivers (70,0 percent) in the case of a short timer. Around half of the drivers (54 percent) decided to stop when faced with a long timer, which raises the question if for the short timer the three seconds were considered as an extension of the amber phase rather than a pre-warning for the oncoming phase change.

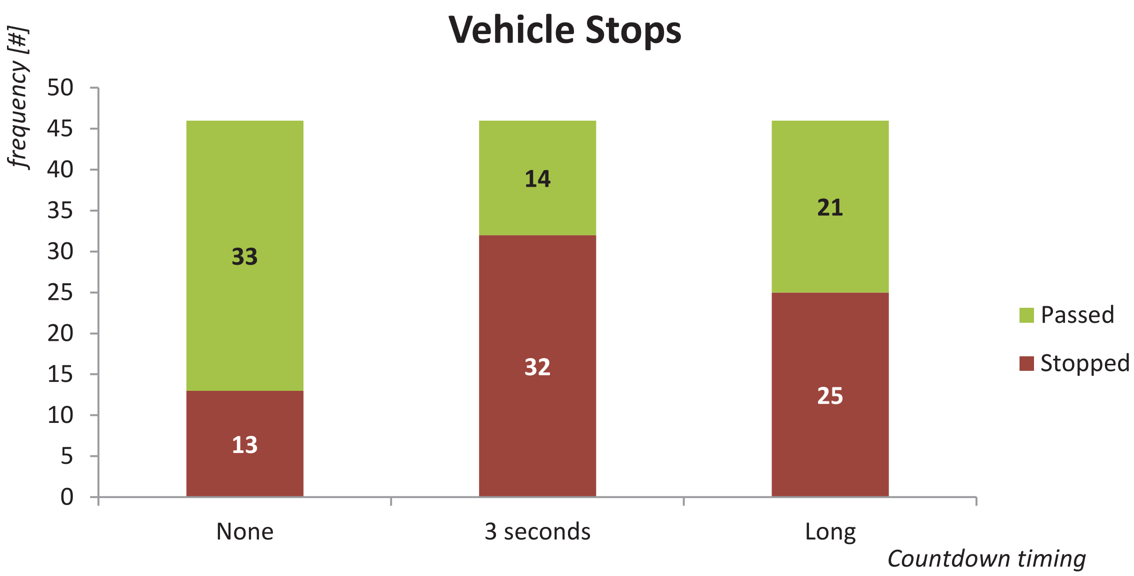

Figure 10 The amount of vehicle stops of the different countdown timing conditions.

A Chi square analysis was carried out in order to determine if the increase in amount of vehicle stops for the countdown timing conditions was significant or only due to the chance effect. The results of this analysis are included in table 7. It shows that the criterion of less than 20% of the cells containing less than 5 expected counts was met. Based on the analysis, it can be concluded that the amount of vehicle stops and the type of mechanism were dependent on each other, since the significance value of the Pearson Chi-Square test was less than 0,0005.

Table 7 The chi square statistic for the amount of vehicle stops during the dilemma zone scenarios. Table retrieved from SPSS.

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	16,061[a]	2	,000
Likelihood Ratio	16,547	2	,000
Linear-by-Linear Association	15,585	1	,000
N of Valid Cases	138		

a. 0 cells (0,0%) have expected count less than 5. The minimum expected count is 22,67.

6.2.2 Acceleration rates

A very important indicator for traffic safety levels when being caught in the dilemma zone, is the acceleration or deceleration force used during the amber phase. As already pointed out in the literature review, the phenomenon of racing-against-the-clock could be observed when traffic lights are equipped with countdown timers. In case of the three second countdown timer, some drivers might react the opposite way and apply an aggressive braking force, because they perceive the countdown as an extension of the amber phase. These contradictive behaviors could lead to an increase of rear-end collisions, thereby decreasing safety levels. In order to investigate if both these behaviors were present, the acceleration rates from a distance of 400 meters in advance of the intersection were collected. As discussed before, a distinction is made between the drivers that decided to stop and the drivers that passed the traffic light. Average values were used to compose the speed and acceleration profiles.

6.2.2.1 Stopped drivers

According to Koppa et al., a comfortable deceleration rate equals around 3,0 m/s^2 (1996). During the experiment, test subjects could apply a maximum braking force of 10,79 m/s^2. Table 8 contains an overview in which the amount of drivers that applied this maximum braking force is given. As can be seen, huge differences exist between the countdown timing and no countdown timing conditions.

Table 8 The number of drivers that used the maximal deceleration force of 10.79 m/s^2.

	# maximum deceleration	*# stopped*	*% stopped*
No Countdown Timing	12	13	92,3
3 Seconds Countdown Timing	12	32	37,5
Long Countdown Timing	1	25	4,0

When no countdown timer was present, almost all participants applied the maximum braking force. However, this number decreased rapidly when more information about the oncoming phase change was provided. The initial 92,3 percent more than halved for the three second timer (37,5 percent) and reached a value of less than 5 percent in case the entire green phase was counted down. It is indicated that if more information is given, a more comfortable braking force is used. This phenomenon is supported by the average values of the braking forces that were used during the final 200 meters of the approach towards the intersection. Figure 11 shows that all deceleration for the no timer scenario happened during the final 35 meters, while this distance more than tripled for the long countdown timer. Already 150 meters in advance, drivers prepared to stop for the traffic light. The braking force, on average, didn't exceed 4 m/s^2, which is less than halve of the average maximum force used in the no timer condition (almost 10 m/s^2). Even the three second countdown timer succeeded in halving the maximum applied braking force. Appendix 5 contains the individual acceleration profiles of all drivers that decided to stop.

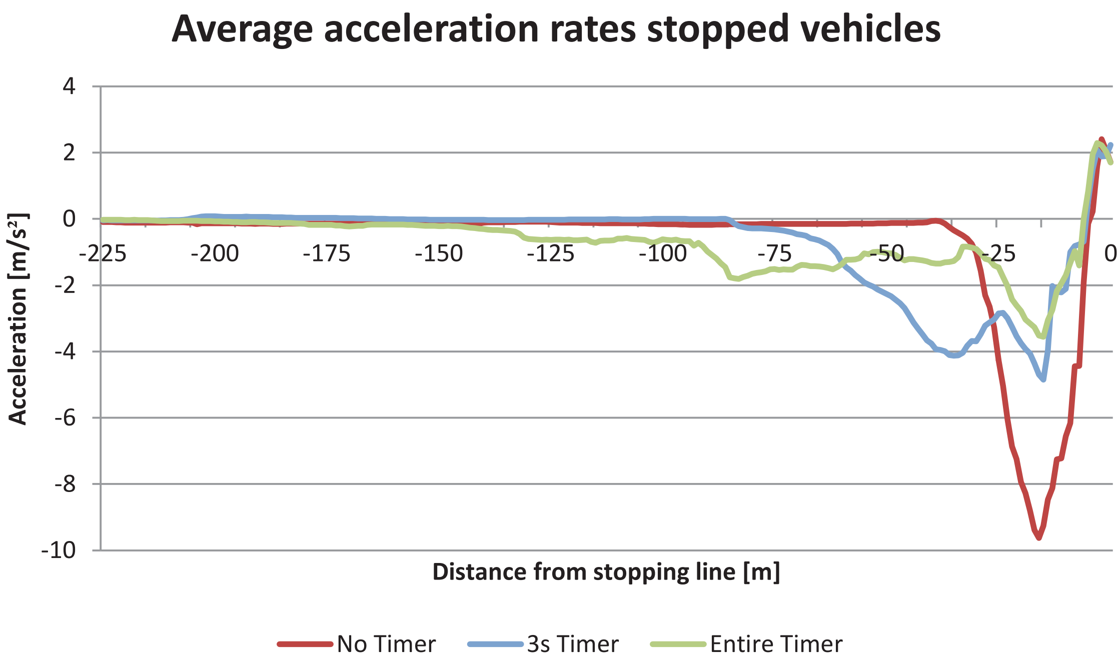

Figure 11 The average acceleration profile of the drivers that decided to stop.

6.2.2.1 Passed drivers

The results for the acceleration forces in case drivers passed the traffic light are less ambiguous. Although the literature review pointed out that one should be careful with countdown timers because of 'racing-against-the-clock' behavior, this phenomenon was not observed in the experiment. Figure 12 shows the average acceleration values for the different conditions and it can be seen that these values fluctuate between -0,25 m/s^2 and 0,25 m/s^2. The results indicate that the countdown timers did not have a positive effect on driving behavior, compared to the reference condition, but also no negative effects. Appendix 5 contains the individual acceleration rates of all drivers that passed the different traffic light types.

6.2.2.3 Dilemma Zone

Based on the acceleration and deceleration rates, one might derive the dilemma zone proportions of the different traffic light conditions. However, as pointed out before, the phase change to amber was programmed at a fixed point. Therefore, hard conclusions about the change of the dilemma zone can't be made. However, the results indicate that the length of the dilemma zones have increased for both countdown timing conditions, up to 150 meters for the long countdown timer. This is a positive effect, which also shows itself in the deceleration forces that were applied when drivers decide to stop. The forces are on average halved for the entire countdown timing (compared to no timing at all), which also indicates lower speed differences and a decreasing chance of rear-end collisions to happen.

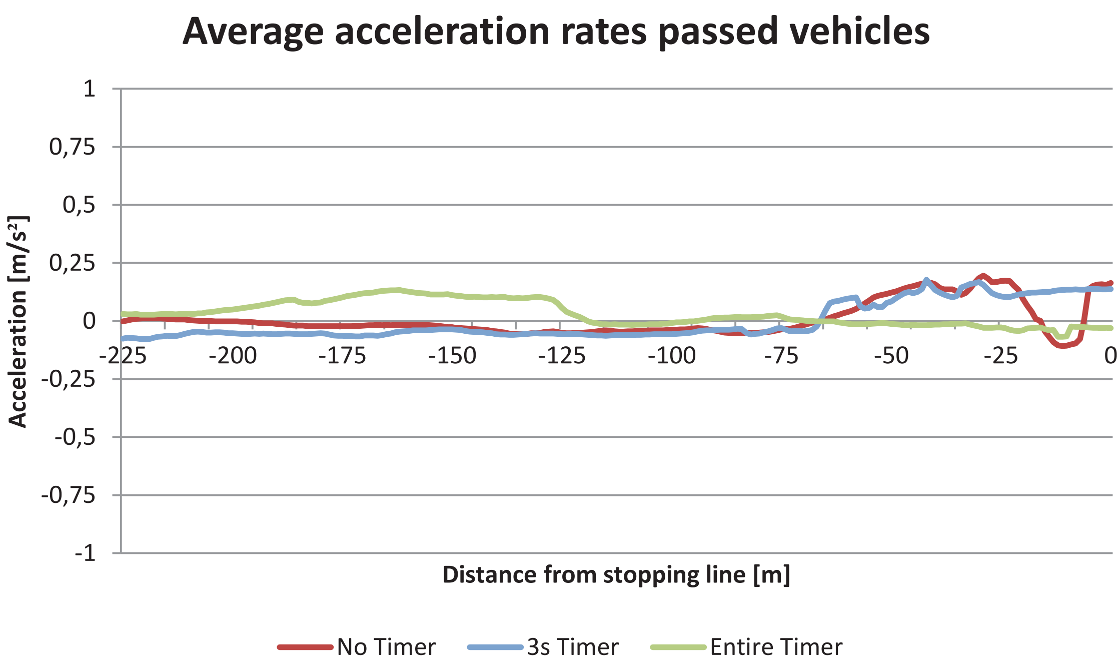

Figure 12 The average acceleration profile of the drivers that decided to pass.

6.2.3 Approaching Speed

According to Limanond et al. (2009, 2010) and Kidwai et al. (2005), countdown timers can decrease the traffic flow rate. It is argued that in case of timers, drivers leave a more comfortable gap with the vehicle in front of them. Another reason might be that drivers are made confident to pass the light in time and therefore drop their speed slightly during the approach. In this study, the speed during the final 400 meters of the approach of the intersection was examined.

Again, a distinction is made between the drivers that decided to stop and drivers that passed the traffic lights.

6.2.3.1 Stopped drivers

During the entire approach, the average value of the speed for the different conditions never exceeded 70 km/hr. Differences between the conditions were first observed around 200 meters in advance of the intersection. It seemed that the drivers who decided to stop for the traffic light in case a long countdown timer was installed, already decided to do so around 175 meters in advance. According to figure 13, which depicts the average speed values for the different conditions, this distance is seven times as high compared to the reference condition. Even for the three second countdown timer, the distance at which the decision is made is more than doubled. As can be seen in the figure, this results in less steep speed reductions, which was already pointed out in the previous section regarding the acceleration forces. Appendix 6 contains the individual speed profiles of all drivers that stopped for the traffic light.

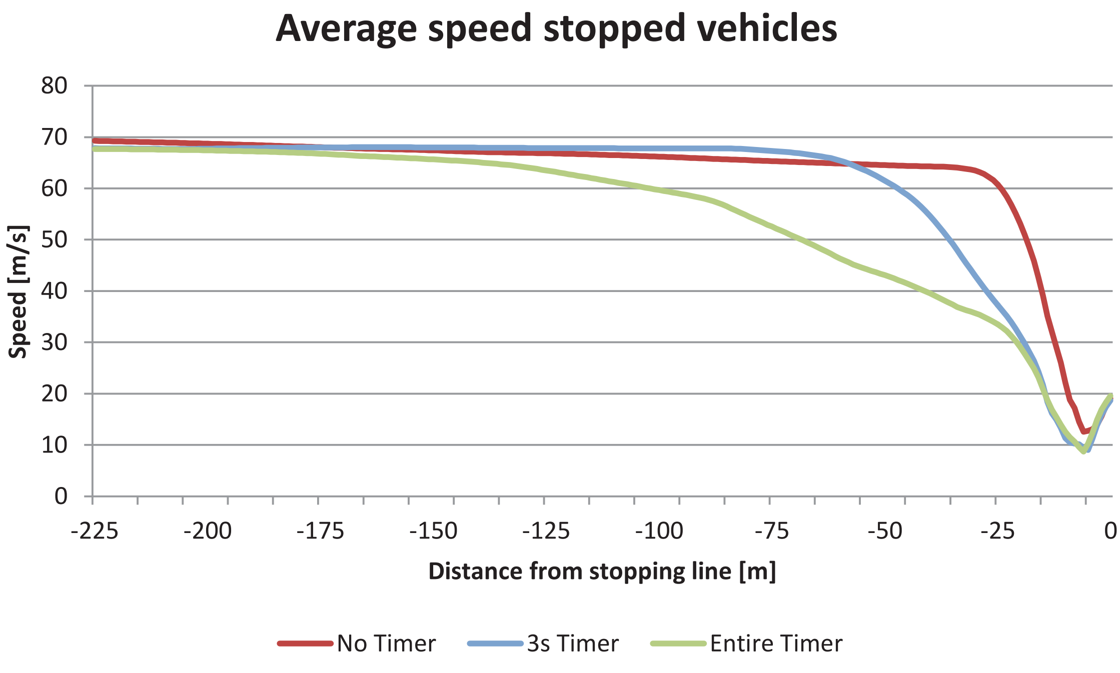

Figure 13 The average speed profile of the drivers that decided to stop at the intersection. Note that the average value doesn't reach 0, due to differences in stopping distances.

6.2.3.2 Passed drivers

Considering the cases in which drivers passed the intersection, it was observed that in the long countdown timing condition drivers tend to increase their speed slightly 175 meters in advance of the intersection (figure 14). Furthermore, during the entire approach, speeds are above the speed limit of 70 km/hr. It can also be observed that the average speed values for the condition without timers is always the lowest and remains under the speed limit. For all conditions, an increase in speed is measured prior or during the amber phase. However, these speed increases are limited to around 2 km/hr maximum and therefore cannot be classified as aggressive. In line with the section about acceleration rates, no racing-against-the-clock behavior was indicated. Appendix 6 contains the individual speed profiles of all drivers that passed the traffic light.

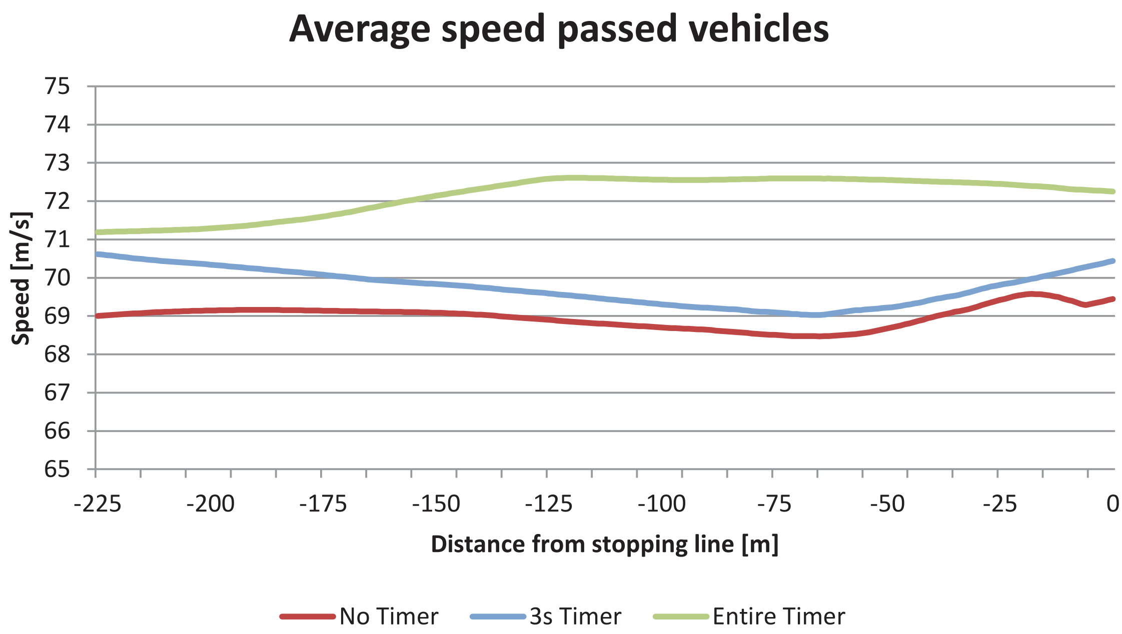

Figure 14 The average speed profile of the drivers that passed the traffic light.

6.3 Red on Approach Scenarios

For the analysis of the data gathered for the Red-on-Approach scenarios, a MANOVA analysis was performed to determine if there was correlation between different performance measurements and if the included measurements were statistically significant when compared between the different mechanisms. Because the number of observations limited the amount of variables that could be included, only the reaction times, the start-up lost times and the stopping distances were included in the MANOVA analysis. It was not possible to include the measurement of the speed during the phase change, since this variable was not normally distributed. The time to travel the first five meters was left out of the MANOVA, since it was introduced as a checking mechanism for the influence of the stopping distance and the start-up lost times, as described in chapter 4. High interaction with the start-up lost time was expected. This section will first provide a descriptive analysis of the included variables in the MANOVA analysis. Afterwards, the results of the MANOVA analysis are discussed. This chapter ends with a section describing the variables 'time to travel five meters' and the speed during the phase change from red to green.

6.3.1 Reaction Times

An important measure for comparing driving behavior at the start of the green phase is the reaction time. As already described in section 5.1.3, the reaction time in this study is defined as the time that passes between the phase change and the first movement of the vehicle. Figure 15 provides the results of this measurement. A negative value indicates that the vehicle started to move prior to the phase change.

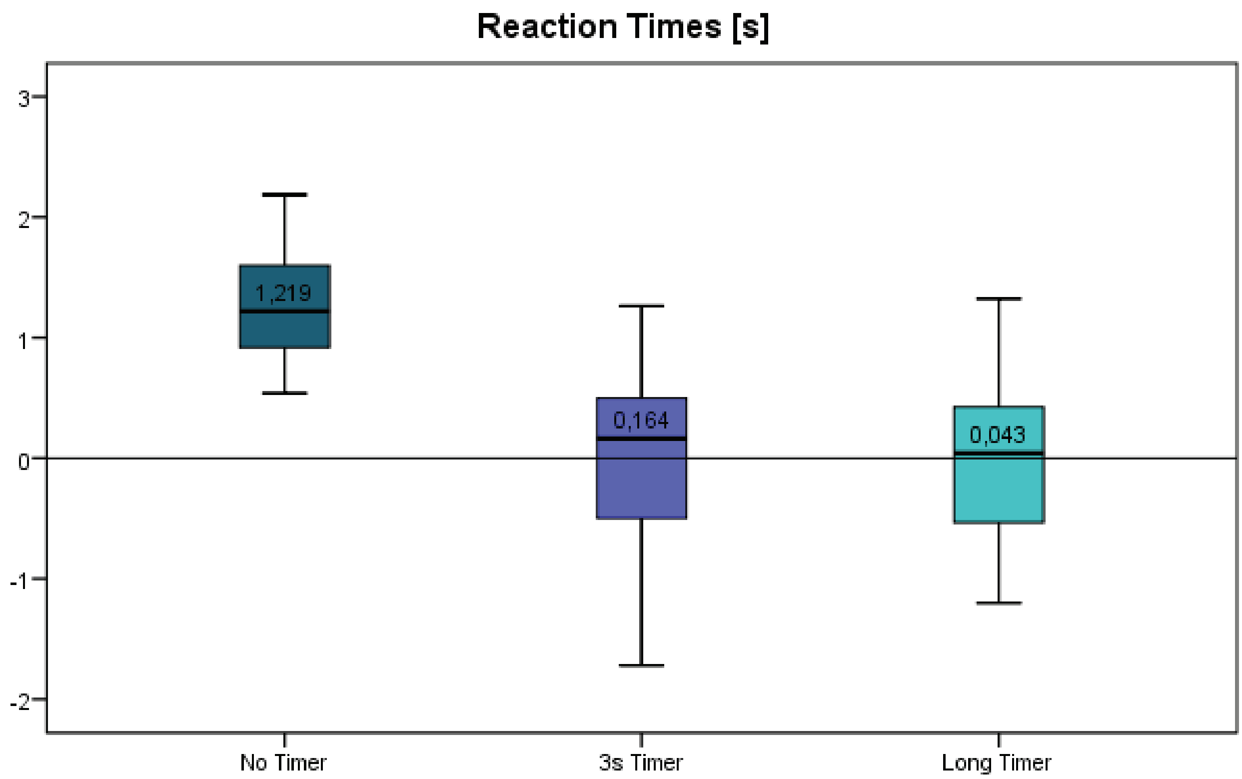

Figure 15 The boxplot diagrams of the reaction time measurements.

The graph clearly shows that the countdown timers reduced the reaction times of waiting drivers. In almost half of the cases of the countdown timer conditions, drivers started before the actual phase change. It was checked whether these drivers crossed the stopping line before the actual phase change, but no observations of red-light running were found. Another important observation is that there does not seem to be a substantial difference between the two countdown timing mechanisms. The median for both timers is around 0,1 seconds, almost over 1,1 seconds lower than for no timing conditions. A final observation regards the measured variations in reaction times. Although the reaction times are lower, the variations are higher for the countdown timing conditions.

6.3.2 Start-Up Lost Times

In almost all scientific research regarding countdown timers, the start-up lost time served as comparing measure. As described in the literature review, the start-up lost time is described as the time that passes between the phase change and the moment a vehicle crosses the stop line. Approaches in which only the first vehicle in line or all vehicles in line were used to calculate the start-up lost times, are used. In this study, where the participant is treated as the only driver faced with the countdown timer conditions, the first approach was adopted. The results are shown in figure 16.

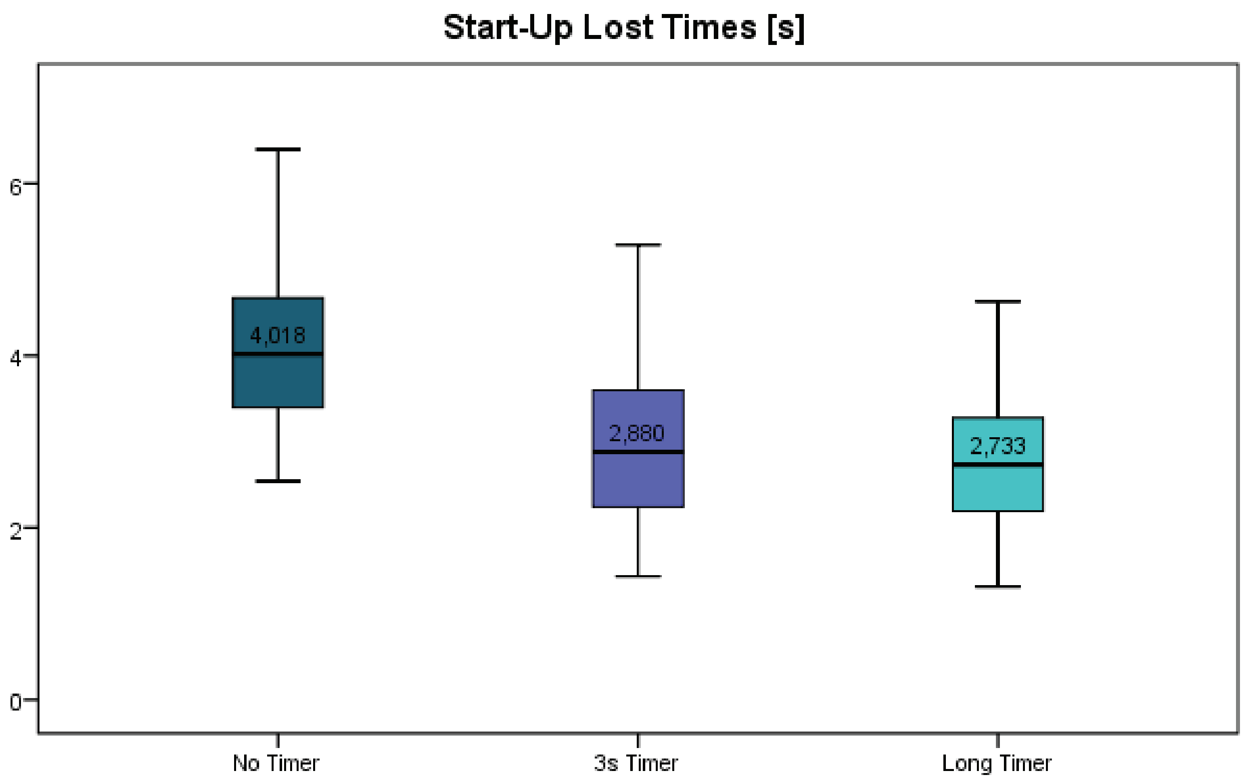

Figure 16 The boxplot diagrams of the start-up lost time measurements.

The reduction of the start-up lost times in the countdown timer conditions is comparable with the reduction of the reaction times. A value of around 1,1 second can be found for both timers. Again, there are only clear differences when the conditions with and without a timer are compared, but the start-up lost times for the two timer conditions are almost the same. In contradiction with the reaction times, the variation in the start-up lost times seems to be the same for all three conditions.

6.3.3 Stopping Distance

Almost all variables were included because differences between the conditions with and without timer were expected. However, it is also important to check whether variables that are assumed to be independent from the countdown timer condition, do not differ. The distance drivers keep to the stopping line is one example of such variable. Although one could argue that larger distances are expected for the timer conditions, since drivers will start earlier and already carry speed during the phase change and compensate this with keeping more distance, it is expected that these differences will be very small and statistically not significant. Furthermore, real life observations at traffic lights already show variations in stopping distances. In order to assess if there was indeed no (huge) difference in stopping distance between the different conditions, this variable was included in the analysis. Figure 17 shows the results. It can be seen that the median values are similar for all conditions, but that stopping distances for the long timer are slightly lower.

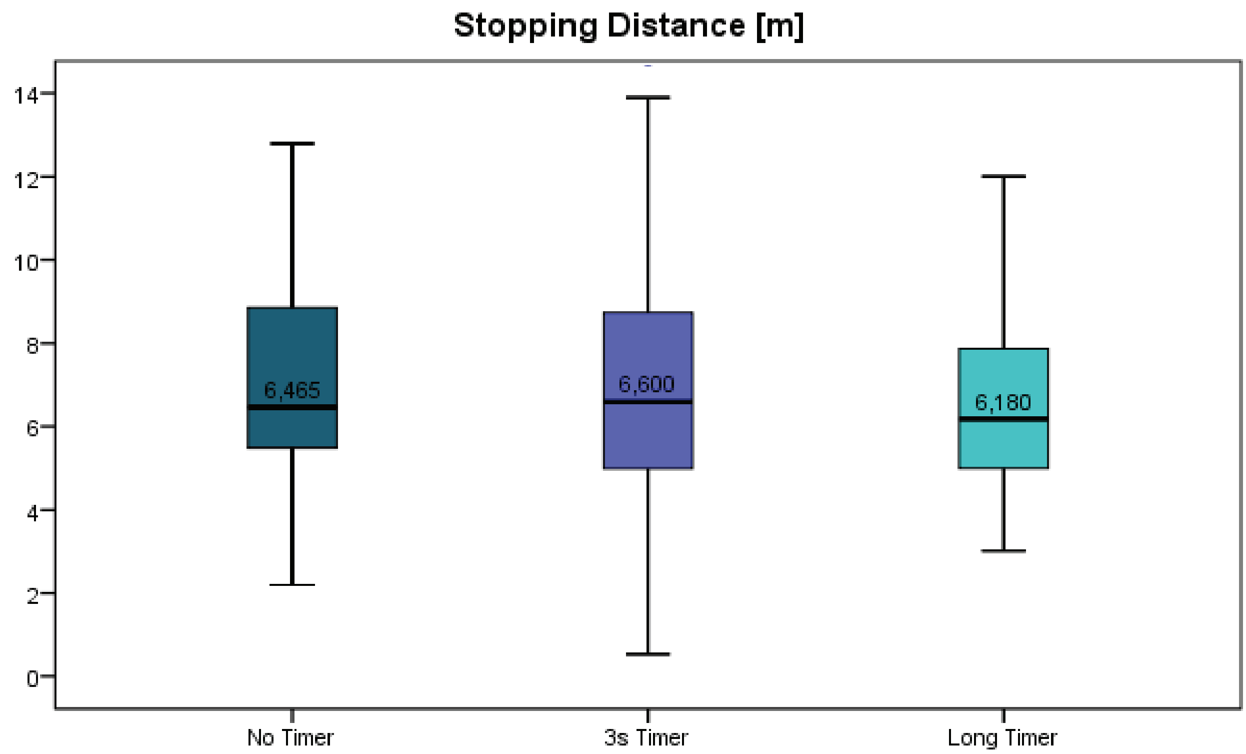

Figure 17 The boxplot diagrams of the stopping distance measurements.

6.3.4 MANOVA analysis

The previous sections provided the descriptive analysis of the reaction times, the start-up lost times and the stopping distances. Differences between the conditions with and without timer were observed. A MANOVA analysis was performed in order to determine if these differences were statistical significant and if there were interaction effects between the different variables. Because the p-value of Pilai's Trace test was less than 0,05, there was no reason to assume multivariance. Therefore, the MANOVA analysis could be used to interpret the pairwise comparisons, which are included in table 9.

Table 9 The results of the MANOVA analysis. Tests have been performed at the 95% level and figures in bold were statically significant.

Pairwise comparisons					
				95% Confidence Interval	
		Mean difference	**Sig.**	**Lower bound**	**Upper bound**
Reaction Time					
No timer	3s timer	1,486	**0,000**	1,038	1,716
No timer	Long timer	1,377	**0,000**	0,921	2,051
3s timer	Long timer	0,109	1,000	-0,394	0,613
Start-up Lost Time					
No timer	3s timer	1,265	**0,000**	0,918	1,612
No timer	Long timer	1,251	**0,000**	0,828	1,674
3s timer	Long timer	-0,014	1,000	-0,409	0,381
Stopping distance					
No timer	3s timer	-0,420	1,000	-1,129	0,743
No timer	Long timer	-0,139	1,000	-1,721	0,881
3s timer	Long timer	-0,228	1,000	1,573	1,117

When the no timer condition is compared with either one of the timer conditions, it can be seen that the results of the reaction times and start-up lost times are significantly different. The significance level is even very high, with a value of less than 0,0005. When comparing the two countdown timer mechanisms for these variables, no significant differences were found. The only variable that doesn't show any significant difference at all, was the stopping distance.

It seems that the results of the descriptive analysis are supported by the statistical analysis. The countdown timer conditions were successful in reducing the reaction times and start-up lost times, but differences between the two mechanisms were not significant. Furthermore, stopping distances were not influenced by the presence of a countdown timer and were similar for all conditions.

6.3.5 Time to travel 5 meters

The start-up lost times are influenced by many factors. Examples are the reaction times, the distances kept to the stopping line and the accelerating forces used when the first vehicle in line starts moving again. In order to perform an additional check on the start-up lost time, a new variable was introduced. The time it took drivers to travel the first five meters since the phase change was recorded. It was expected that the outcomes, or rather the differences, between the different conditions were comparable to the observations regarding the start-up lost times. The results are included in figure 18.

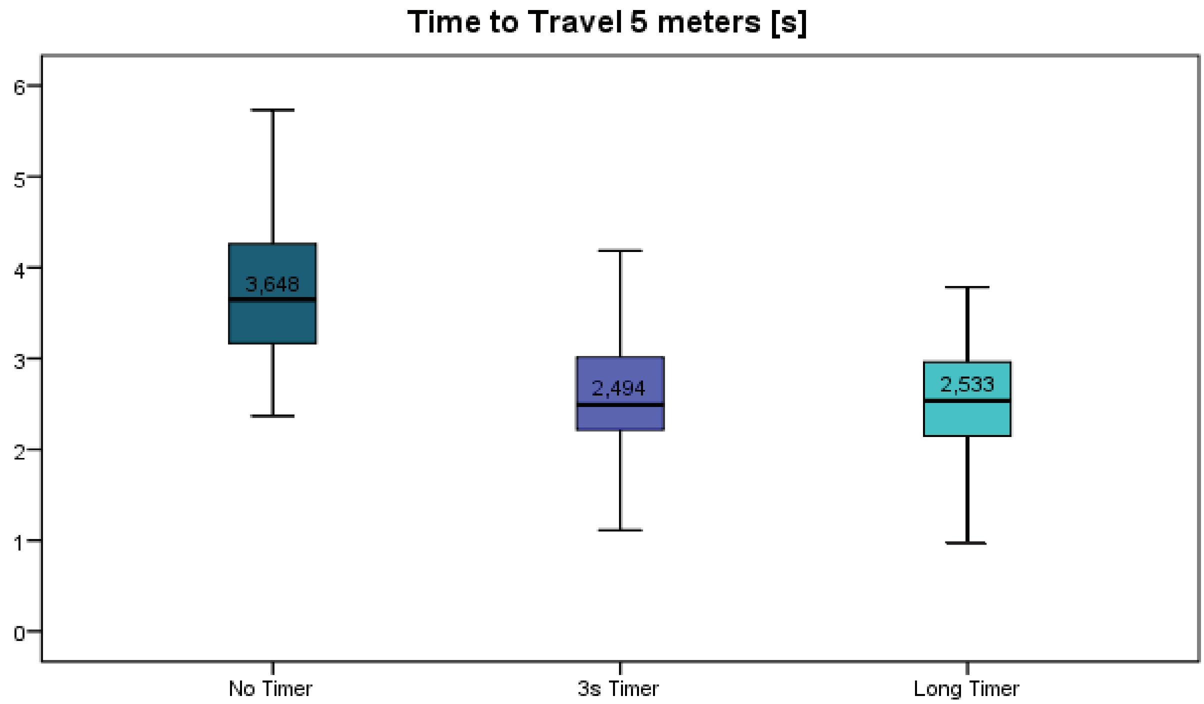

Figure 18 The boxplot diagrams of the time it took drivers to drive the first five meters, starting at the moment of the phase change.

In line with the analysis of the reaction times and the start-up lost times, differences of around 1,1 seconds for the median can be observed between the timer and no timer conditions. Again, there seemed to be no difference between the two timer conditions.

Table 10 The significance of the reaction times for the different scenarios

Pairwise comparisons					
				95% Confidence Interval	
		Mean difference	**Sig.**	**Lower bound**	**Upper bound**
Time to travel 5 meters					
No timer	3s timer	0,925	**0,000**	0,591	1,260
No timer	Long timer	1,091	**0,000**	0,795	1,387
3s timer	Long timer	0,166	0,841	-0,211	0,542

An ANOVA analysis was performed in order to assess if these differences were significant or not. The results, included in table 10, show that there are indeed differences between the timer and no timer conditions, but no statistical significant difference between the two countdown timing types.

6.3.6 Speed during phase change

A final parameter that was included into the analysis was the speed during the phase change. It was expected that this value would be '0' in case there was no countdown timing, since no information regarding the start of the green phase was provided. The highest values were expected to be observed for the long timer. The results are included in figure 19.

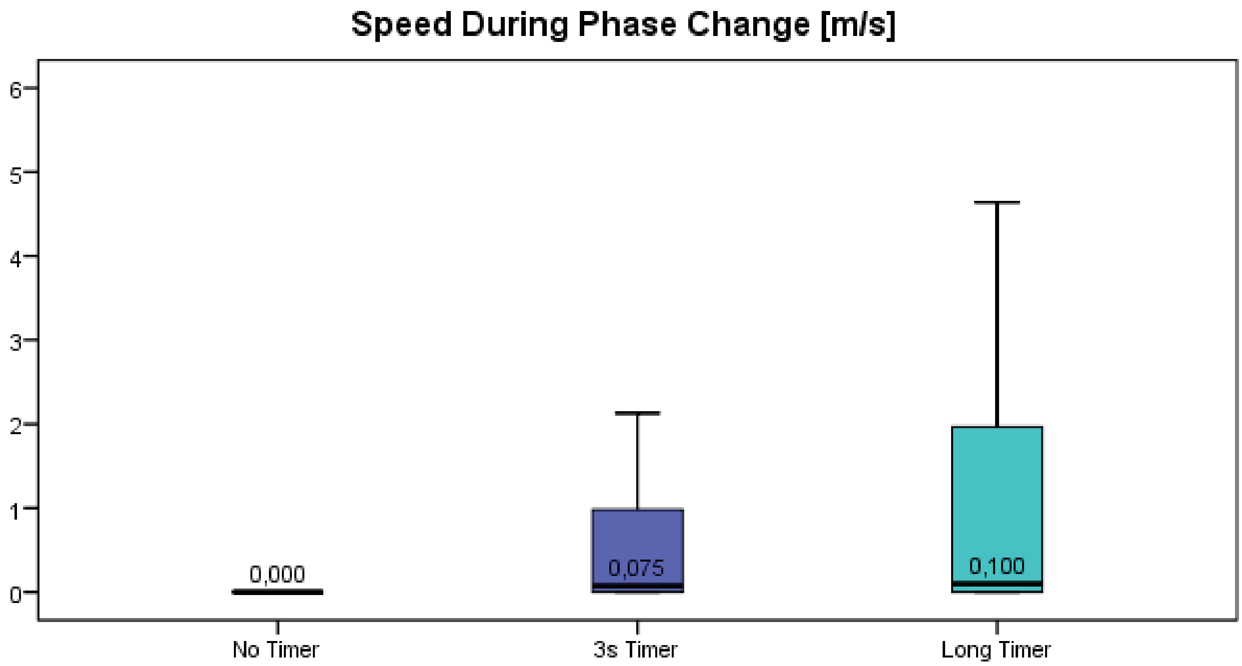

Figure 19 The boxplot diagram of the speed during the phase change.

As can be seen, the speed during the phase change increased when more information about the oncoming phase change was provided. The same trend was observed for the variations of the speeds. Due to the complicated nature of analysis techniques to compare and determine if the differences in the speed during the phase change were significantly different, this parameter was only analyzed in a descriptive manner.

6.4 Public Perception

The final part of the experiment covered the public perception towards the countdown timing mechanisms. A copy of the questionnaire that was used can be found in appendix 2. The participants were asked to rate six statements - three for the green phase countdown timing and three for the red phase countdown timing - on a scale from totally disagree to totally agree. In all cases, the statements were written down regarding an improvement of the different aspects compared to no countdown timing conditions. In order to force the participant to show at least a positive or a negative feeling towards the statements, the option of neutrality was left out. Two out of three statements were identical for both the green and the red phase countdown timing and asked whether countdown timing of the specified phase would improve safety levels and traffic flow efficiency. Two additional open-ended question were asked, in which the participants could write down the greatest advantage and disadvantage of the countdown timers. This chapter briefly discusses the results that were found in a descriptive manner. No statistical analyses were performed.

6.4.1 Safety impact

The first statement asked the participants if they perceived safety benefits from the countdown timers. The question was asked for the countdown timing of both the green and the red phase. The results are shown in figure 20.

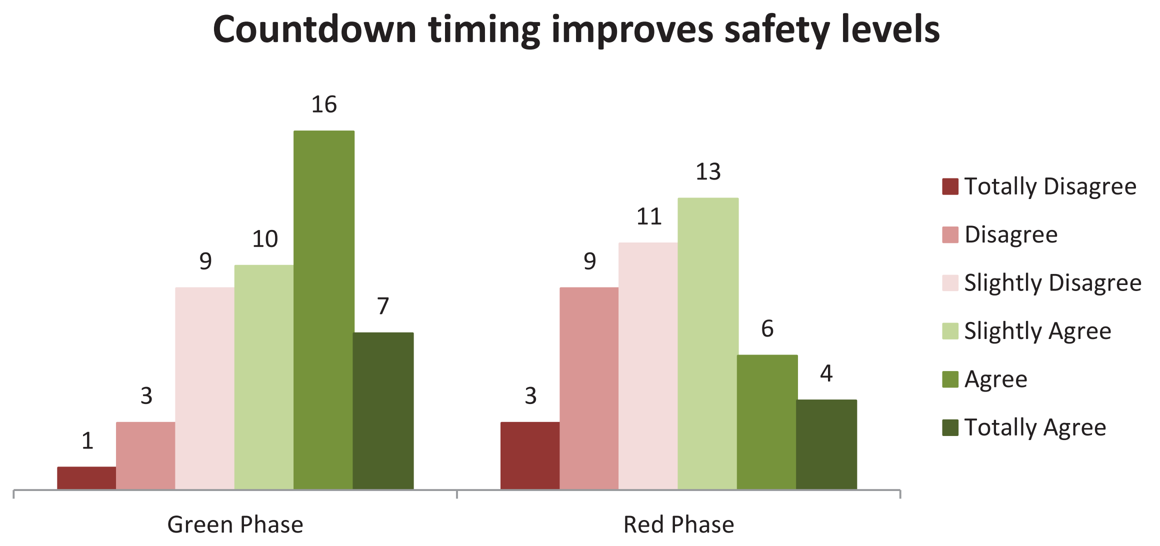

Figure 20 The frequencies of the chosen options for the statement that countdown timers improve safety levels.

According to the majority of the test subjects, equipping traffic lights with countdown timers for the green phase would improve traffic safety levels. Over 70 percent of the test subjects selected an agree statement. However, more than 65 percent of the participants wrote down in the open-ended questions that they were concerned about racing-against-the-clock behavior. This seems contradictive and might indicate that the risk of speeding at intersections is underestimated.

The perception of increased safety levels for the red phase countdown timers is less beneficial than for the green phase. Exactly 50% of the participants selected a disagree statement, of which 13 percent totally disagreed with the statement. It is not clear however if the participants that disagreed with the statement perceived negative effects of the timers on the safety levels. They may perceive no effects on traffic safety levels at all. However, some participants expressed their concern for red-light running and aggressive accelerations at the start of the green phase. One test driver mentioned that clearing times for the intersection might need adjustments.

6.4.2 Traffic flow impact

The second statement asked the participants if they perceived benefits from the countdown timers with regard to the traffic flow efficiency. The question was asked for the countdown timing of both the green and the red phase. The results are included in figure 21.

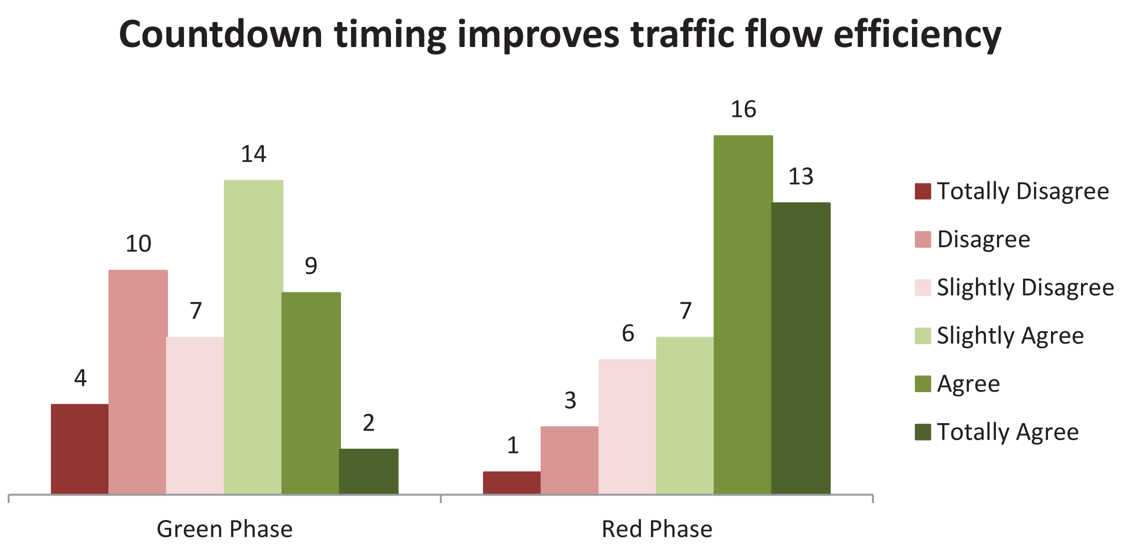

Figure 21 The frequencies of the chosen options for the statement that countdown timers improve the traffic flow efficiency.

More than half of the test subjects (54 percent) agreed that countdown timers for the green phase could improve traffic flow. Concerns regarding early stop ratios were mentioned sporadically and, as mentioned before, the majority expect signs of racing-against-the-clock behavior. Although this racing behavior has a negative effect on traffic safety, it would actually increase the traffic flow.

With regard to the red phase countdown timing, over 78 percent agreed that traffic flow could be improved by using the timers. Of the participants that agreed towards this statement, half of them selected the 'totally agree' option. Shorter reaction times or early start-ratios are mentioned as the main advantage, but two participants pointed out that in case of a long timer, drivers might get distracted to check their mobile phone and overestimate the amount of time they have left. The other eight test subjects that disagreed with the statement, did not elaborate why.

6.4.3 Aid and frustration

For the green phase countdown timer, participants were asked if they were helped by the timers in their decision to stop or pass the intersection. The results are included in figure 22.

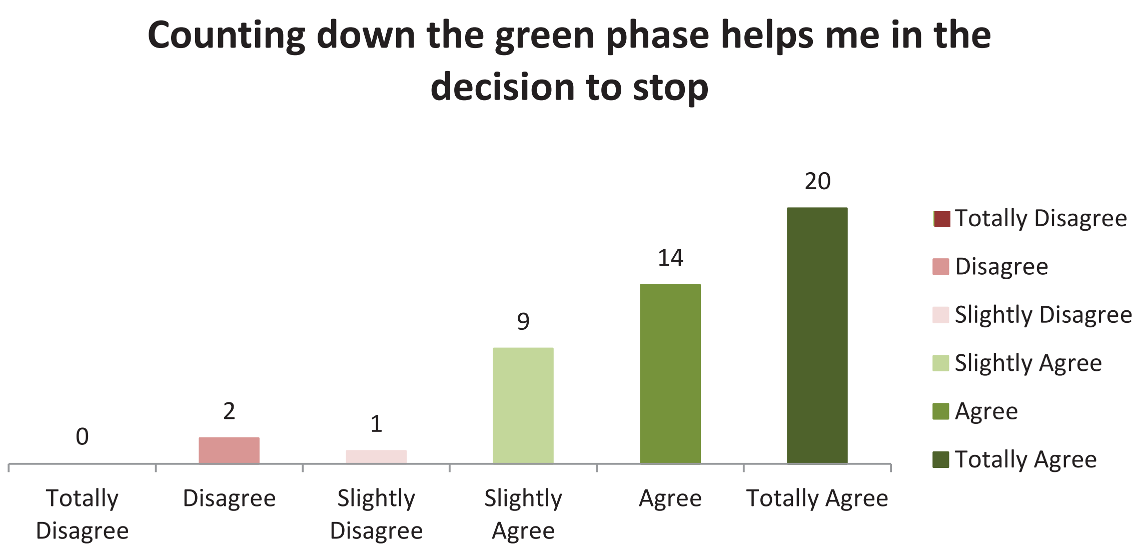

Figure 22 The frequencies of the chosen options for the statement that countdown timers aid drivers in the decision to stop for or pass the traffic light.

Only three out of 46 participants disagreed with the statement, of which no one selected the worst option. Furthermore, almost 50 percent of the test subjects chose the 'totally agree' option, indicating that countdown timers are perceived to be a huge aid in assessing if it is possible to pass an intersection in time or not. Many subjects wrote down that one of the main advantages of the timer is that one can decide in advance which actions to take, thereby using a more comfortable driving style, without abrupt braking or accelerating.

The final statement for the red phase countdown timing regarded frustration levels of waiting drivers. The results are included in figure 23. Only four participants slightly disagreed, stating that timers with a large amount of time left could have an adverse effect. The frustration levels might even increase if one encounters several red phase countdown timers in a short amount of time, because he is made aware of the amount of time that is 'lost' to him. The remaining 42 participants were positive regarding the statement.

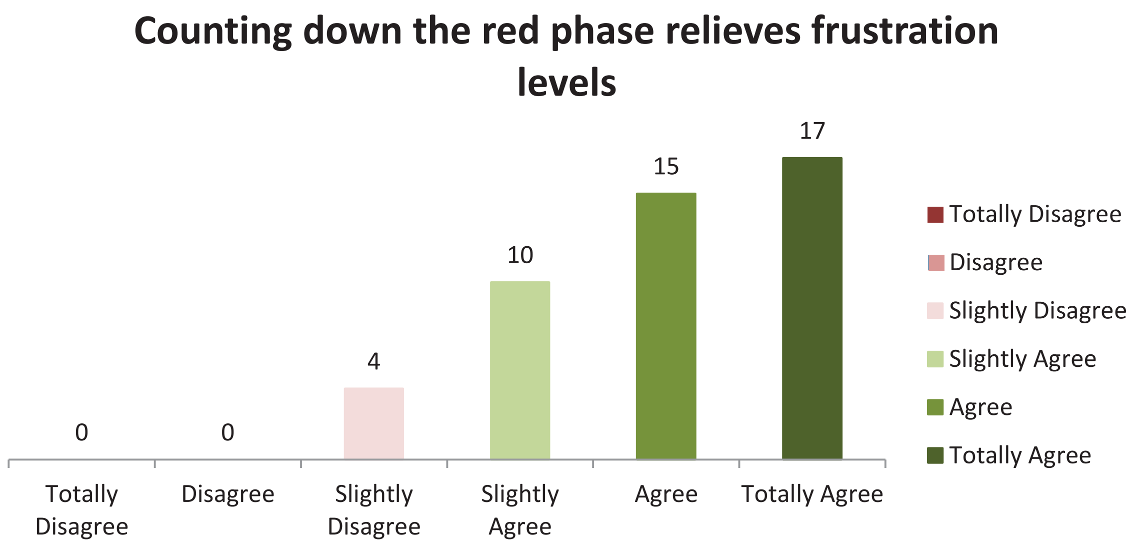

Figure 23 The frequencies of the chosen options for the statement that countdown timers relieve frustration levels during the red phase.

7. CONCLUSIONS

This study investigated the effects of different types of numerical countdown timers on Belgian driving behavior. The outcomes of the study provided a first indication of the potential of these phase change warning systems. The literature review pointed out that the effects of countdown timers can be contradictive, both for traffic safety aspects and traffic flow efficiency. Possibly, driving culture has a high influence on the perception and attitude towards the countdown timers, which makes it questionable to transfer the results gathered from different studies, mainly in Asia, into the Belgian context. As of yet, studies investigating the effects of countdown timers in Belgium are not present, but could be relevant for increasing traffic flow efficiency and intersection capacity, given the daily congestion problems.

Due to budget and time constraints, the focus of this research was limited to a driving simulator study. Six unique conditions were programmed in STISIM Drive 3 (www.stisimdrive.com, n.d.), in which test subjects encountered intersections equipped with no timer, a three second timer or an entire phase timer for both a dilemma zone and red-on-approach scenario. This chapter discusses the findings of the analyses that were performed in order to determine if the countdown timers could increase traffic flow efficiency and improve safety levels. Attention is also given to the public perception of the timers. The final section of this chapter will answer and accept or reject the research questions and hypotheses introduced in chapter 2.

7.1 Dilemma Zone scenarios

From the six unique conditions, three were programmed to capture the approaching test subjects in the dilemma zone. In order to provide a proper comparison, the distance at which the traffic light turned to amber was set to be identical for all conditions and based on the determination of the dilemma zone for the reference scenario, in which no countdown timer was present. For all conditions, participants were able to pass the intersection without violating the red light. Several performance measures were selected to assess how the presence of a timer could influence the traffic flow and the safety levels at the final stages of the green phase.

7.1.2 Traffic Flow

The most important indicator to assess if countdown timers influence the traffic flow efficiency is the number of observed vehicle stops. Although drivers are required to stop when faced with an amber signal, unless they cannot stop in a safe manner, the decision to stop or not is fully dependent on the driver's interpretation of the confronted situation. The literature showed that warning drivers about the oncoming phase change during the final stages of the green phase, with for example a countdown timer, could lead to two different behaviors: drivers either race to the clock or already slow down in advance of the intersection because they underestimate the amount of the time left.

In this study, it was observed that the number of vehicle stops during the dilemma zone scenarios increased when countdown timers were present. Only 28 percent of the drivers stopped in the reference scenario, while this number increased to 54 percent for the entire phase timer and 70 percent for the final-stage countdown timer. The statistical analysis proved that the difference in the amount of vehicle stops was statistically significant between the different conditions. The highest amount of vehicle stops was observed for the short countdown timer, which could possibly be explained by the misperception of approaching drivers, who treated the three second countdown as an extension of rather than a warning for the amber phase.

Even though passage without violating the red light was guaranteed, the number of drivers that decided to stop for the traffic light increased in case countdown timers were present. The analysis of the speed profiles during the approach showed that drivers who intended to stop, already decreased their speed up to 175 meters in advance of the intersection. Based on these results and observations, one could conclude that counting down the green phase has a negative effect on the traffic flow efficiency.

7.1.3 Traffic Safety

Acceleration and deceleration rates during the final stages of the green phase were observed in order to determine if countdown timers would positively influence traffic safety aspects. The analysis showed that when timers were present, drivers used less aggressive deceleration forces when decided to stop for the traffic light. In case of the long timer, deceleration rates were three times lower as compared with the reference scenario. Furthermore, decelerations already started up to 175 meters in advance of the intersection. Even deceleration rates for the three second timer were less aggressive and around halve of the rates used in the reference condition.

The analyses indicated that the dilemma zone changed when countdown timers were applied. However, due to the set-up of this study, it was not possible to examine if the dilemma zone increased or decreased, or moved further to the front or the back of the intersection-approach. It can be concluded, however, that countdown timers have a positive effect on the safety levels, since braking forces are lower and the moments of braking are more spread out. According to the results, the long timer achieves the most improvement in traffic safety levels.

7.1.4 Public perception

Countdown timers for the green phase are appreciated by the majority of the participants. Especially with regard to safety, 70 percent of the test subjects perceived safety benefits from the timers, explaining that the additional information allows them to think about their decision to stop rather than take this decision in an impulse. However, concerns about racing-against-the-clock behavior were expressed by over 65 percent of the test subjects, which might indicate that the risks of speeding are underestimated. With regard to traffic flow efficiency, half of the test drivers believed that countdown timers for the green phase could enable more vehicles to pass the traffic light during its green phase. However, the results of the experiment indicated the opposite.

7.2 Red-on-Approach scenarios

The second set of conditions was programmed in such a way that the traffic light changed to amber and red before drivers entered the dilemma zone. In order to force participants to come to a full stop, sufficient time for the red phase was programmed. Several performance measures were selected in order to assess how countdown timers could influence the behavior of drivers during the final stages of the red phase. Reaction times, start-up lost times and stopping distances were tested on significance using a MANOVA analysis.

7.2.2 Traffic Flow

According to the literature review, the most common measurement used in traffic flow studies aiming at examining traffic flow efficiency at the start of the green phase, is the start-up lost time. This variable is described as the time that passes between the actual phase change and the moment the first (few) vehicles pas the stopping line. This study found that there was a significant difference in start-up lost times between the with and without timer conditions. A reduction of around 1,1 second was achieved. Furthermore, it was found that the difference between the two countdown timing mechanisms was not statistically significantly different, indicating that both timers have the same effect. Similar results were found for the reaction time, which in this study was described as the time that passed between the phase change and the first movement of the vehicle. Again, the reduction of around 1,1 second between with and without timer conditions was statistically significant, but the difference between the two timer mechanisms was not. A final measurement that was included in the statistical analysis were the stopping distances. The distance drivers kept between themselves and the stopping line did not seem to differ significantly between the three conditions.

This study introduced a new variable to assess how factors like stopping distances and acceleration rates could influence the start-up lost times. The time drivers needed to travel the first five meters, starting at the moment of the phase change, was examined. In line with the previous discussed results, a significant decrease of around 1,1 second was found for the timer conditions, but again no significant difference was measured between the different timer conditions. A final variable included the speed during the phase change. The descriptive analysis backed up the assumption that this value would be zero for the reference scenario. For the countdown timing conditions, however, the speeds were between 0,075 and 0,100 m/s with variations up to 2 m/s for the three second timer and 5 m/s for the long timer. It indicates that people indeed tend to take advantage of the timers, however, their speed remains relatively low.

7.2.3 Traffic Safety

Red phase countdown timers do not seem to have safety effects. The only measure used in scientific research to address safety issues, were red-light violations. Although the data was checked for them, no red-light violation was observed in this study.

7.2.4 Public perception

With regard to traffic flow efficiency, over 78 percent of the participants agreed that countdown timers are successful in improving the traffic flow efficiency. Regarding traffic safety concerns, only half of the participants agreed that the timer might have a beneficial effect. The main concerns expressed are early start ratios and red-light violations. However, one should be careful to interpret the disagreements with the statements for improved traffic flow efficiency and safety levels as a decrease of these aspects. It is possible that the test drivers did not perceive any positive or negative effect at all.

7.3 Research questions and hypotheses

In chapter 2, the research questions and hypotheses were introduced in order to provide guidance for answering the main question of what the effect of countdown timers on traffic flow and traffic safety levels are. Since this study proposed final-stage countdown timers, in which only the last three seconds of the green and red phase are counted down, comparisons with both no countdown timing and entire phase countdown timing conditions were made. It was hypothesized that there would be differences between conditions with and without countdown timers, but that the two different types of countdown timing would not yield different results. Table 11 gives an overview of the hypothesis and states which ones were accepted and rejected, based on the analyses of the results.

Table 11 An overview of which hypothesis were accepted and rejected.

	No countdown timing compared to final-stage countdown timing	
H1	Final-stage countdown timers reduce the start-up lost time.	**Accepted**
H2	The number of vehicle stops during the onset of the amber phase is higher for conditions with final-stage countdown timers.	**Accepted**
	No timing countdown compared to entire phase countdown timing	
H3	Entire-phase countdown timers reduce the start-up lost time.	**Accepted**
H4	The number of vehicle stops during the onset of the amber phase is higher for conditions with entire-phase countdown timers.	**Accepted**
	Final-stage countdown timing compared to entire phase countdown timing	
H5	There is no difference in the reduction of the start-up lost time.	**Accepted**
H6	There is no difference in the amount of vehicle stops during the onset of the amber phase.	**Rejected**

Based on the results, some recommendations could be made for equipping traffic lights with countdown timers. First of all, countdown timing for the red phase didn't seem to have any effects, either positive or negative, on traffic safety levels. However, for improving the traffic flow efficiency, it was found that reaction times and start-up lost times are reduced with around 1,1 second on average. In congested situations, this extra second of usable green time could result in the passage of one additional vehicle per lane per cycle. No difference was found between the different timing conditions, so either one could be installed at traffic lights. However, taking into account traffic actuated signal phasing, the three second timer seems to have more potential, since it could be easily integrated with the adaptable cycle lengths.

Recommendations for implementing countdown timers for the end of the green phase are more ambiguous. Contradicting rankings can be made for the different conditions, based on traffic flow efficiency and traffic safety aspects (table 12). There seems to be a trade-off between the two aspects and based on the interpretation and context of the intersection in question, one should assess if countdown timers could be a beneficial asset. Although countdown timers seem to improve the safety by changing the dilemma zone and decreasing deceleration rates, it is dependent on the interpretation if current situations without countdown timers are unsafe or unsafe enough to invest in countdown timers.

Table 12 The rankings of the different countdown timing conditions.

Ranking	Green phase		Red phase
	Traffic Flow	**Traffic Safety**	**Traffic Flow**
1	No timer	Entire phase timer	Entire phase timer Final-stage timer
2	Entire phase timer	Final-stage timer	No timer
3	Final-stage timer	No timer	

8. DISCUSSION

According to the conclusions formulated in the previous chapter, countdown timers seem successful in increasing traffic flow performance during the start of the green phase and improve traffic safety levels during the final stage of the green phase. However, one should take into account that some limiting factors might have influenced the results of the driving simulator study. This chapter discusses the most important limitations posed by the adopted methodology and the analysis techniques that were used. Recommendations regarding future research are also discussed.

8.1 Driving simulator research

As described earlier, the driving simulator was selected as the method of data collection, due to the absence of countdown timers in Belgium. Therefore, results acquired from this experiment are a mere indication and need to be compared with measurements taken in the field. When comparing the results with the studies discussed in the literature review, similarities can be observed. It could suggest that the outcomes of the experiment are relative valid, which means that the direction and relative size of the effect of the countdown timers is similar to observations from reality (Kaptein, Theeuwes, & Horst, 1996). However, due to differences in driving culture, real observed data from experiments in Belgium is still necessary in order to assess the validity of the results regarding the actual size of the impact of the countdown timers.

When participating in driving simulator experiments, test subjects might be more inclined to adopt a more sociably accepted driving style. Especially with regard to the dilemma zone scenarios, results might be biased due to the increased motivation of participants to stop when they detect the phase change from green to amber to red. It is impossible to determine to what extent results might be biased because of this behavior, however, it is expected that the bias would have affected all the conditions. In order to mitigate the influence of this possible adapted driving style, test subjects were left alone in the driving simulator room when the experiment was carried out.

An important limitation of the driving simulator is the ability to mimic the real life environment as good as possible. Issues regarding the perception of speed and distance are difficult to control. Some test drivers commented on this aspect after they finished the experiment. Therefore, the need for validation with results gathered from field research is needed.

8.2 Data collection

In total, 52 test subjects participated in the driving simulator experiment. After exclusion of participants, 46 observations remained in the dataset. When looking in more detail, it could be observed that the age and gender where not equally or normally distributed. Because of the nature of the experiment and the limited time available, the results gathered from the test drivers were sufficient enough to provide the first results for this preliminary study.

Data collection in STISIM Drive 3 could be either selected on a time-based or a distance-based scale. In this research, the time-based approach was selected in order to acquire the results. This method was selected because it would provide a means of continuous data collection, which was needed for measurements of reaction times and start-up lost times. Furthermore, using distance-based data collection would not make it possible to determine at which moment in time the phase changes took place. Although distance-based logging would be perfect for composing the speed and acceleration profiles of the approaching vehicles, the time-based logging was set to add a record every 0,001 simulation second. It provided data that was detailed enough to gather at least one value for all included parameters during one meter of travel.

8.3 Analysis

A MANOVA analysis was performed to examine the effects of red phase countdown timers. Because the dilemma zone scenarios provided additional red phase data in case test drivers stopped, the requirement of equal sample sizes for a MANOVA analysis was not met. Therefore, data needed to be left out of the analysis. It was decided that only the data from the red-on-approach scenario would be used. Although not assumed, it is uncertain if there would be differences between the starting behavior at the beginning of the green phase between situations in which drivers were required to stop or stopped when they were caught in the dilemma zone. One could argue that due to frustration, the latter one will be more motivated to react quicker to the phase change.

The experiment and analyses partly addressed the novelty and learning effect by only taking into account the data that was acquired during the second encounter. It is not clear what the effect of a third or fourth encounter would have been. Possibly, reaction times and start-up lost times might have decreased even further for the countdown timer conditions and perhaps red-light violations at the beginning of the green phase would have been recorded. However, it can be reasonably assumed that the differences between the first and second encounter would be higher than differences for the second and third, third and fourth, and so on, encounter.

8.4 Implementation

The results in this study indicate that especially the red phase countdown timers could improve the traffic flow efficiency without compromising on safety levels. Based on this observation, one could decide to implement the timers. However, one should take into account that these timers can invoke 'flying starts' in cases where an approaching driver, rather than a stopped one, is the first in line. Because of the countdown timing, the speed carried during this flying start could be higher, which means that safety margins at the traffic lights need to be adjusted. For example, the all-red time might be extended. However, by doing so, the advantage of the timer, reducing the start-up lost time, is traded off with this additional 'red' time for ensuring traffic safety. Therefore, one could consider to use the final-stage timers, which only work if a stopped vehicle is detected.

8.5 Further research

The focus of this study was to examine driving behavior regarding different types of countdown timing, in case one would be the first in line. An interesting topic for further research would be to include interaction effects with vehicles driving in front or behind the test subjects. Prior to this research, it was not possible to do so, because programming these interaction effects could not be based on any data.

Because the results indicate that the dilemma zone changes when countdown timers are applied, further research towards the extend of this change should be performed. However, it would not be feasible to research this using a driving simulator study, since simulators are limited to program the phase change at one fixed point, based on a certain distance or time between the driver and the traffic light. It is recommended to use field observations, so the entire dilemma zone could be included in the research.

In this study, the countdown timers were tested at a fictive road with a speed limit of 70 km/hr. The results showed that for the final stage of the green phase, safety levels could be improved if traffic lights are equipped with countdown timers. It would be interesting to examine if the same safety benefit is present for intersections with lower or higher speed limits.

A final topic of further research could be how the countdown timer is programmed. In literature, two different approaches were found: in some cases, the countdown timer showed the amount of time left until the start of the red phase, while in other studies only the time until the start of the amber phase was shown. The final approach was adopted in this study, and as discussed in the discussion, some drivers may have experienced the short countdown timer as an extension of the amber phase. The question is if the amount of 'improper' stopping decisions could be reduced if the timer shows the time left till the start of the red phase.

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9.2 Figures

Figure 1 Examples of numerical countdown timers.

http://i49.tinypic.com/nvbqx4.jpg

https://c2.staticflickr.com/6/5177/5523761677_c3fe271da1_z.jpg

http://1.bp.blogspot.com/_JzUx44lr8WA/SN8iv81wbDI/AAAAAAAAFPc/_5LHJLYYZis/s400/Traffic+Light+Counter.jpg

http://www.adtdisplay.com/product-trafficCount/traffic%20light.gif

Figure 3 The perception-reaction time.

http://www.norfolkfireservice.gov.uk/nfrs/images/prevention/stoppingdistances.jpg

Figure 5 An advanced warning flasher.

http://www.gillettewy.gov/Modules/ShowImage.aspx?imageid=3383

Figure 6 Countdown timers for the green and red phase.

http://www.tqleds.com/media/catalog/category/traffic_light_with_timer.jpg

http://nudges.org/wp-content/uploads/2010/02/China-traffic-light.png

Figure 7 The start-up lost time distribution.

http://www.webpages.uidaho.edu/niattproject/images/Background/startup%20losttime.jpg

APPENDIX 1 QUESTIONNAIRE BEFORE EXPERIMENT

Answer sheet Nr

1. Gender

□ Female

□ Male

2. Date of birth

____

3. Nationality

□ Belgian

□ Different, namely:____________________

4. When did you obtain your driver's license?

____

5. How many kilometers do you drive on a yearly basis (estimation)

□ Less than 10.000 km

□ Between 10.000 and 20.000 km

□ Between 20.000 and 30.000 km

□ Between de 30.000 and 40.000 km

□ Between 40.000 and 50.000 km

□ More than 50.000 km

6. Do you have experiences with numerical countdown timers on traffic lights?

□ No

□ Yes, in the following countries:

____

APPENDIX 2 QUESTIONNAIRE AFTER EXPERIMENT

Green phase

7. To what extent do you agree or disagree to the following statements?

Numerical countdown timing of the **green** phase increases safety levels.

Disagree 1 2 3 4 5 6 Agree

Numerical countdown timing of the **green** phase allows more vehicles to pass during each cycle.

Disagree 1 2 3 4 5 6 Agree

Numerical countdown timing of the **green** phase helps me in the decision to stop at the onset of the amber phase.

Disagree 1 2 3 4 5 6 Agree

*8. According to you, what is the most beneficial advantage of numerical countdown timing of the **green** phase?*

____

____

____

*9. According to you, what is the most important disadvantage of numerical countdown timing of the **green** phase?*

____

____

____

Red phase

10. To what extent do you agree or disagree to the following statements?

Numerical countdown timing of the **red** phase increases safety levels.

Disagree 1 2 3 4 5 6 Agree

Numerical countdown timing of the **red** phase allows more vehicles to pass during each cycle.

Disagree 1 2 3 4 5 6 Agree

Numerical countdown timing of the **red** phase decreases frustration levels of dirvers waiting in the queue.

Disagree 1 2 3 4 5 6 Agree

11. According to you, what is the most beneficial advantage of numerical countdown timing of the ***red*** *phase?*

____

____

____

12. According to you, what is the most important disadvantage of numerical countdown timing of the ***red*** *phase?*

____

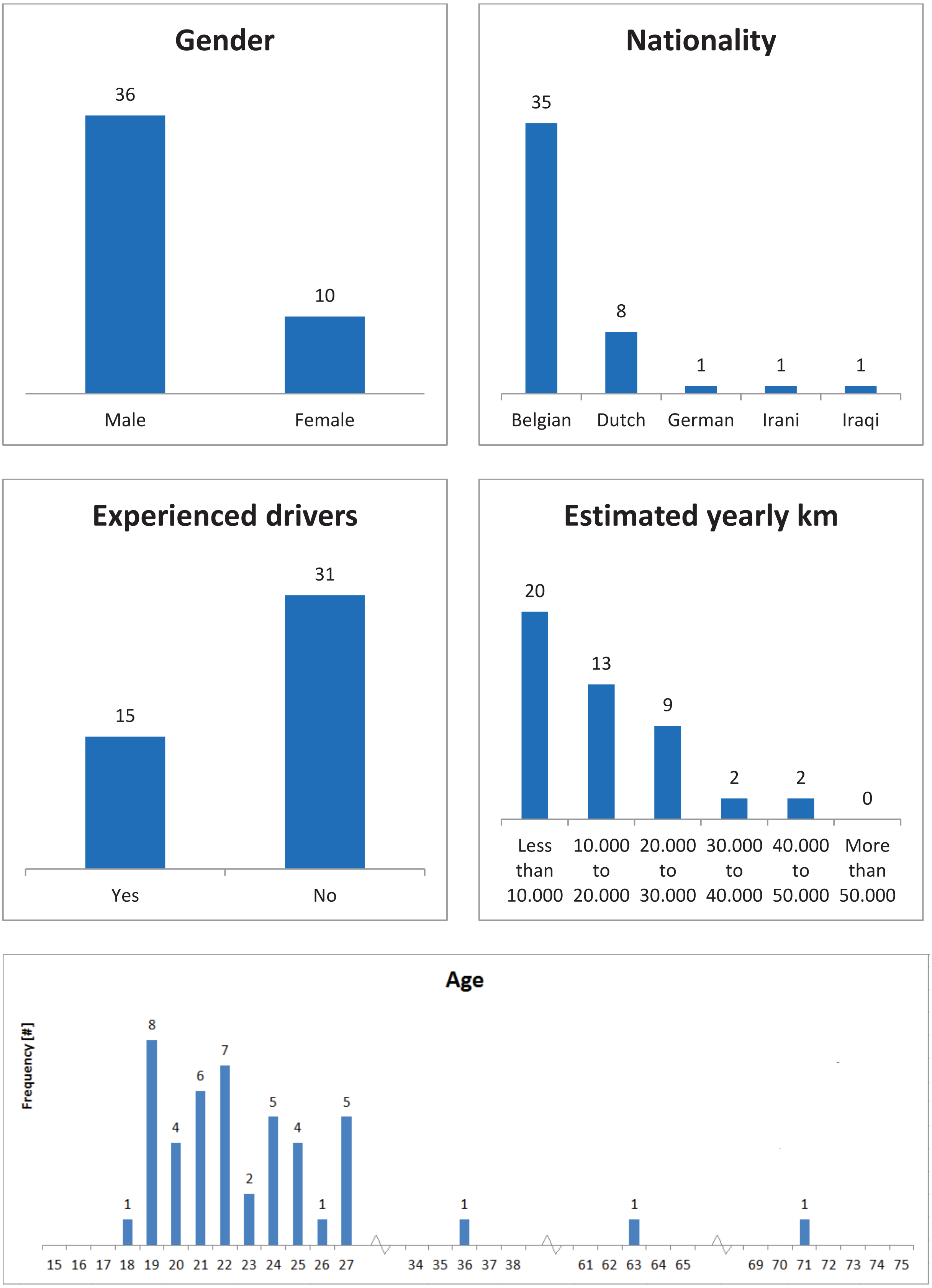
____

____

13. What do you think is the aim of the experiment?

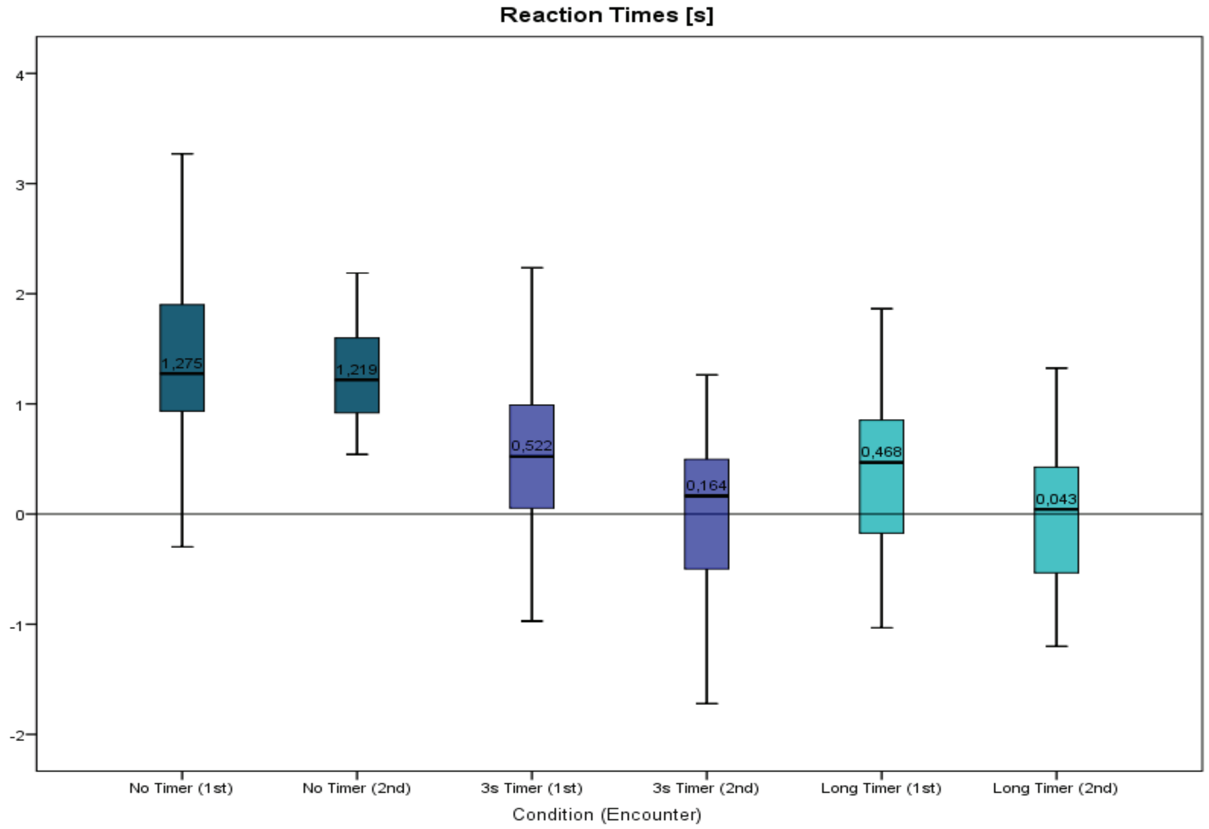
14. Do you have any remarks?

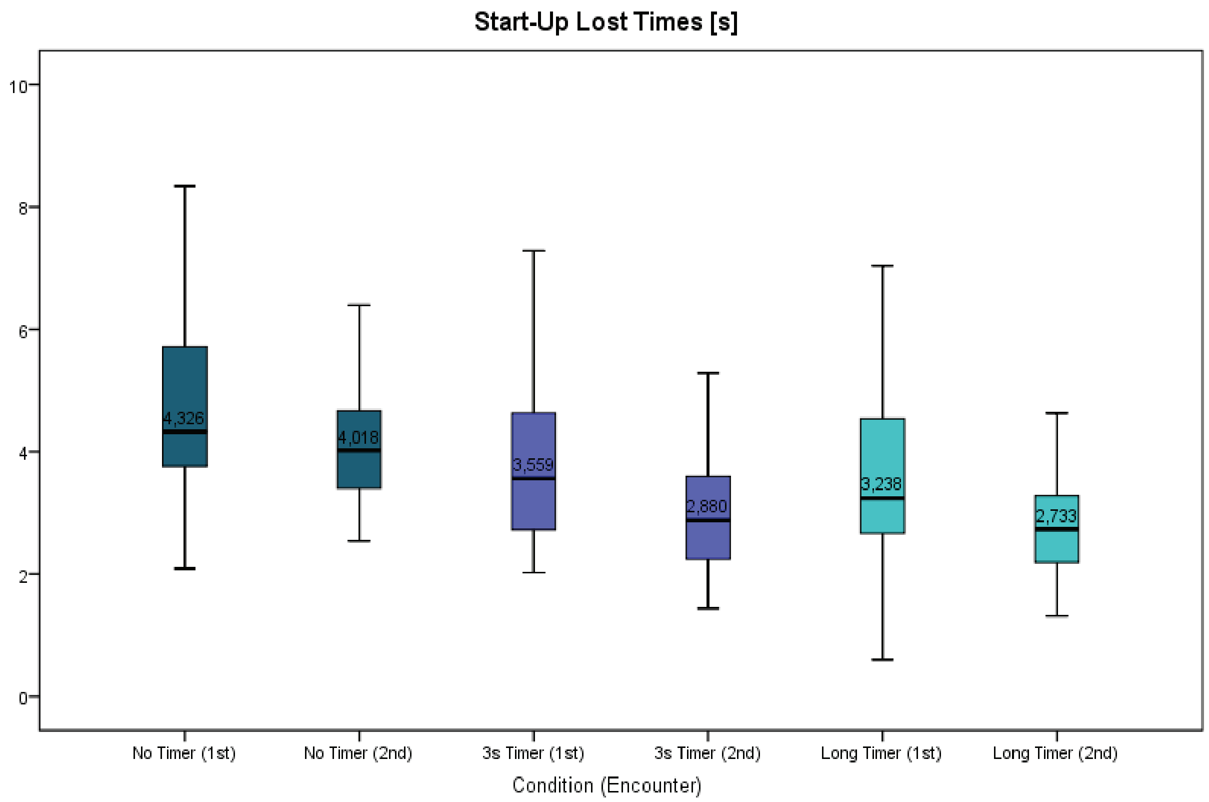
APPENDIX 3 STATISTICAL DATA PARTICIPANTS



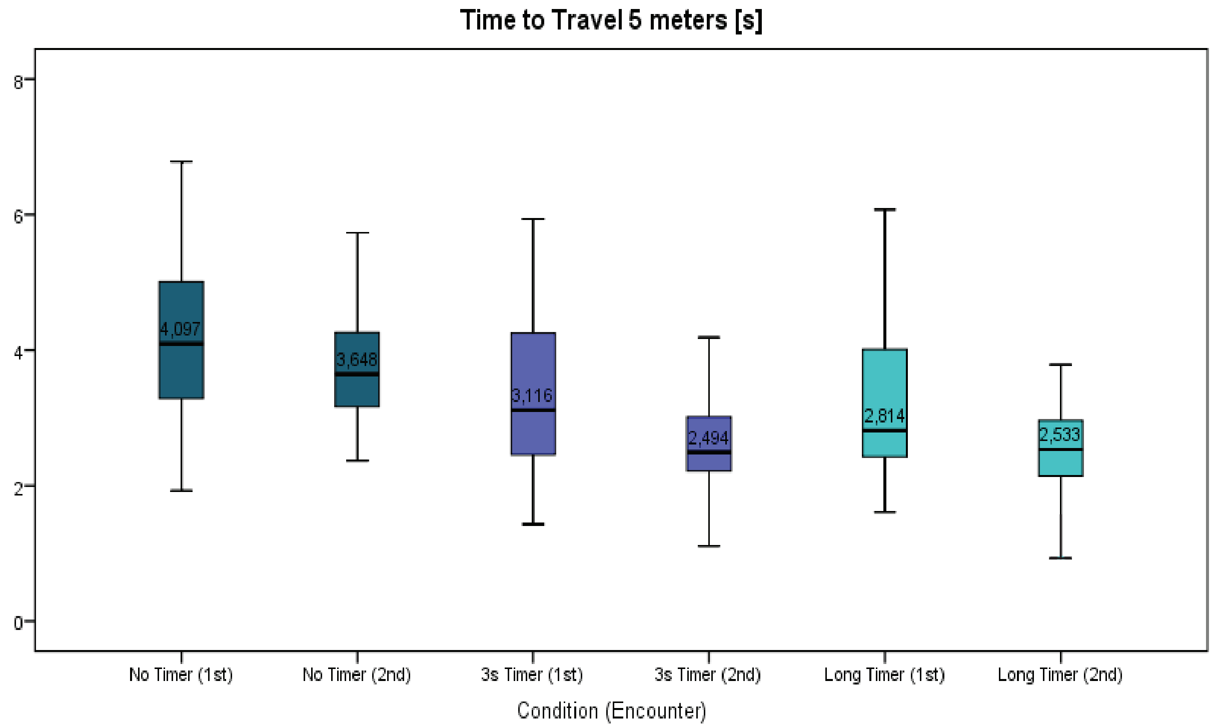
Appendix 3.1 Characteristics of the sample population.

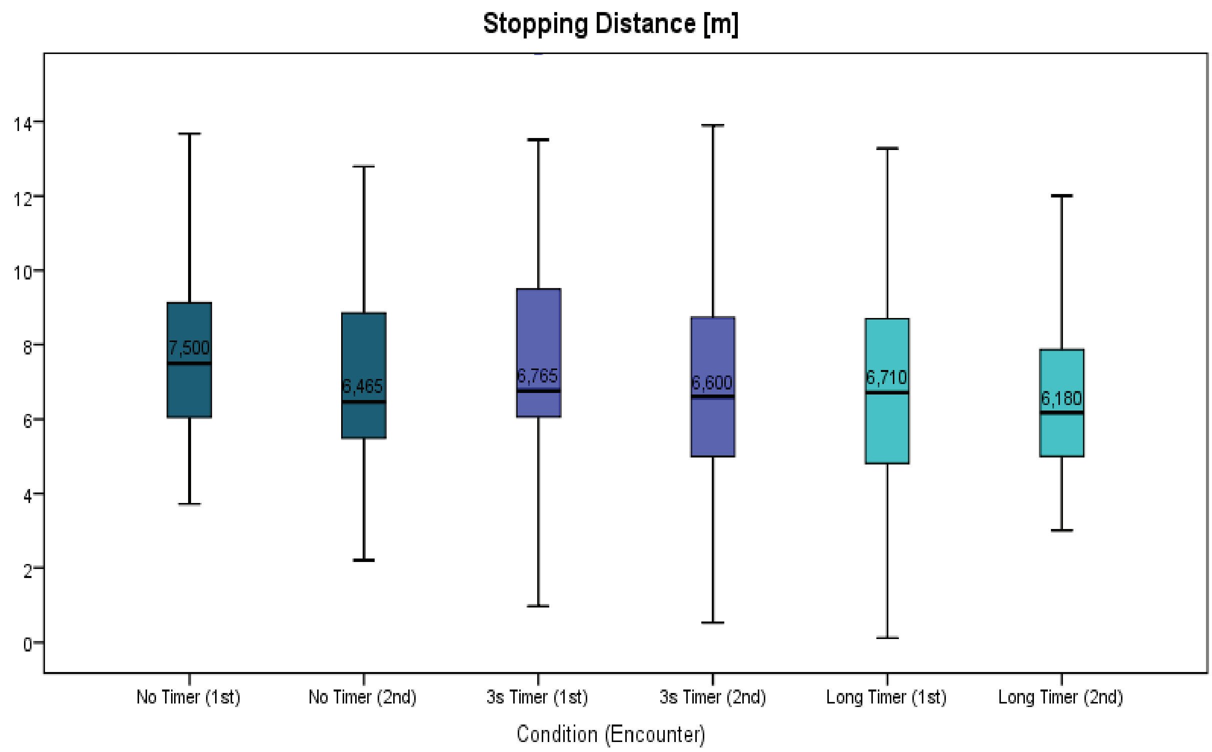
APPENDIX 4 COMPARISONS BETWEEN THE TWO ENCOUNTERS



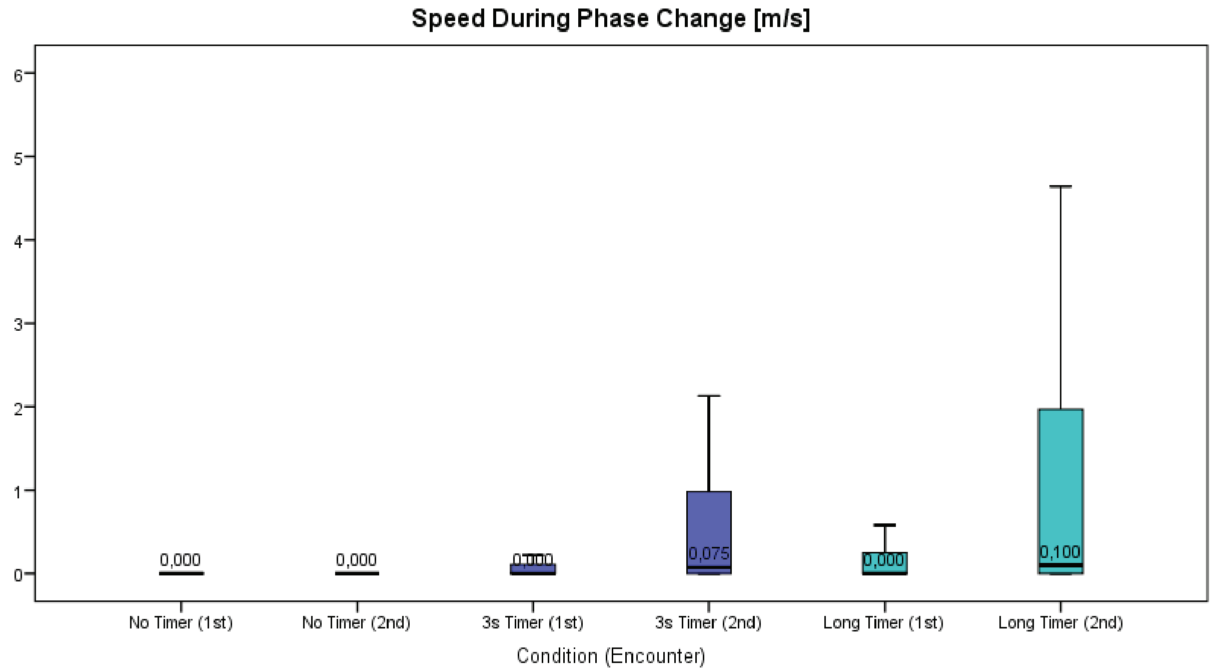


Appendix 4.1 Boxplot diagrams of the reaction times (above) and start-up lost times (below).



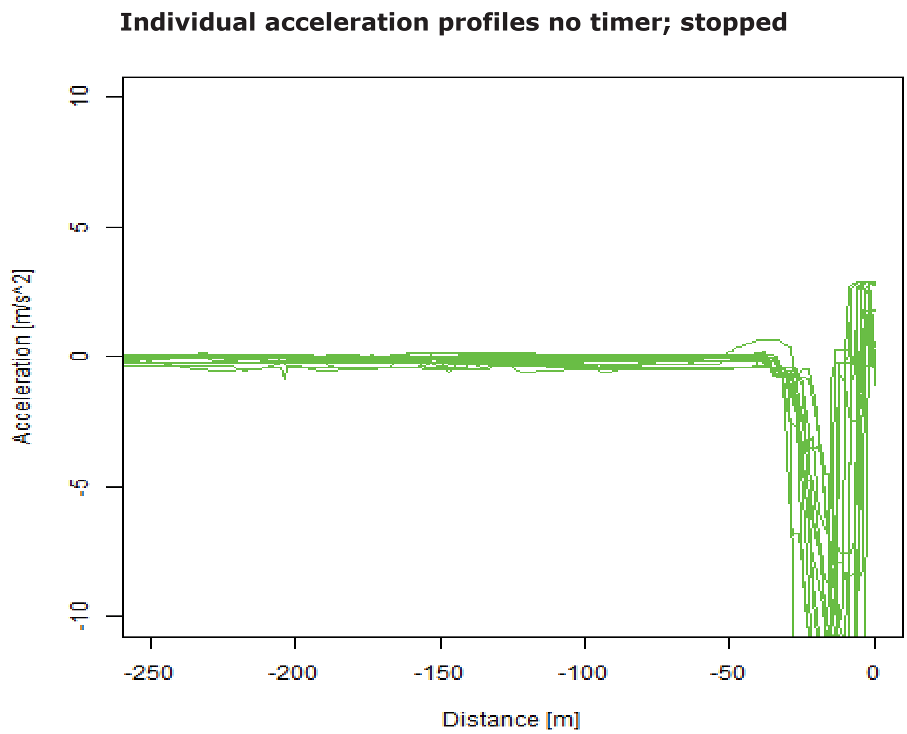


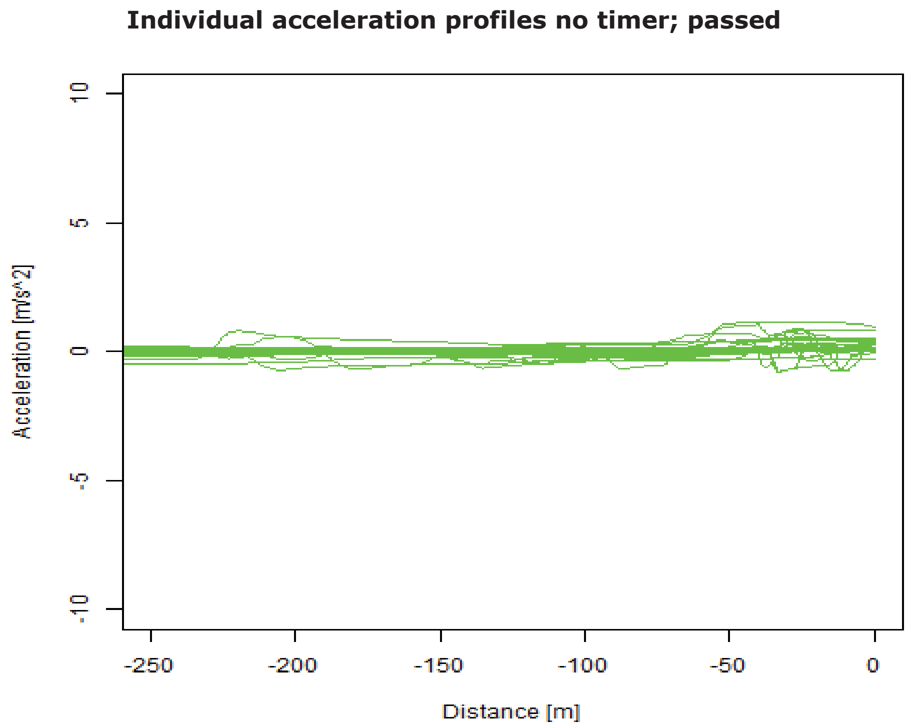
Appendix 4.2 Boxplot diagrams of the stopping distance (above) and the time to travel 5 meters (below).



Appendix 4.3 Boxplot diagrams of the speed during the phase change.

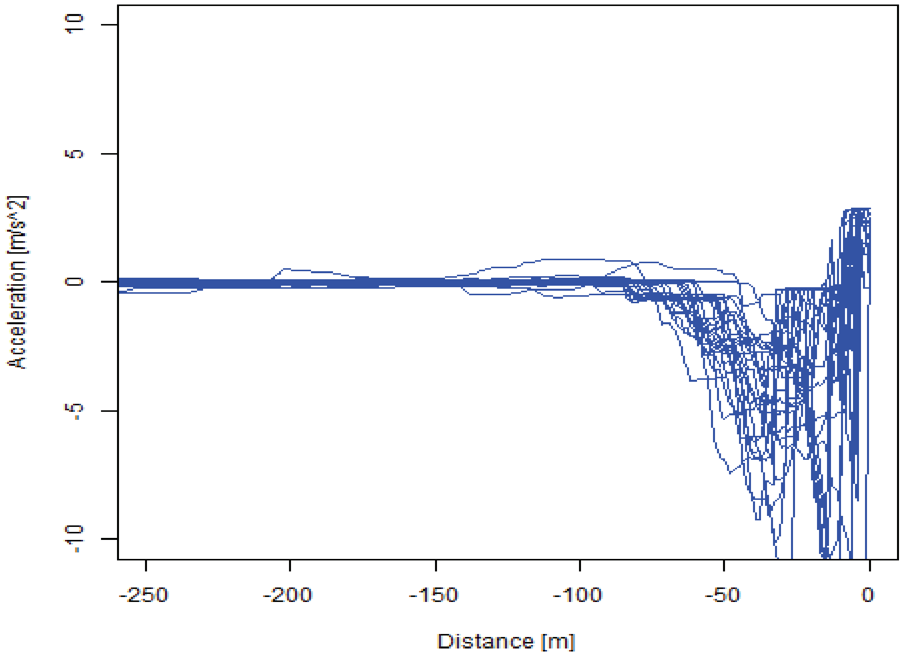
APPENDIX 5 INDIVIDUAL ACCELERATION PROFILES



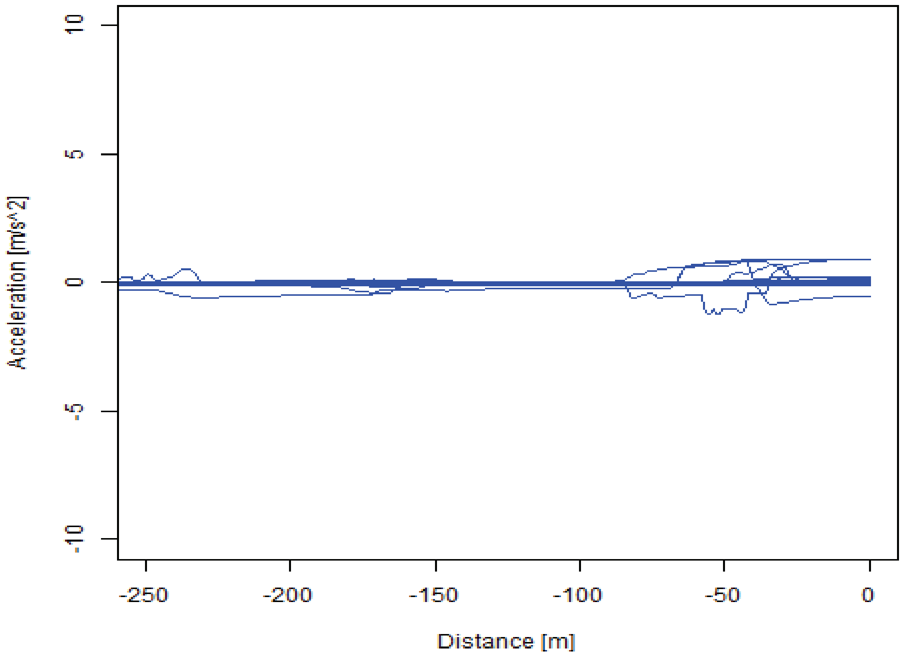


Appendix 5.1 The individual acceleration profiles of the participants when faced with the dilemma zone scenarios during the no countdown timing condition. The test drivers that stopped are included in the figure above, the ones that decided to pass in the figure below. Graph retrieved from R.

Individual acceleration profiles final-stage timer; stopped

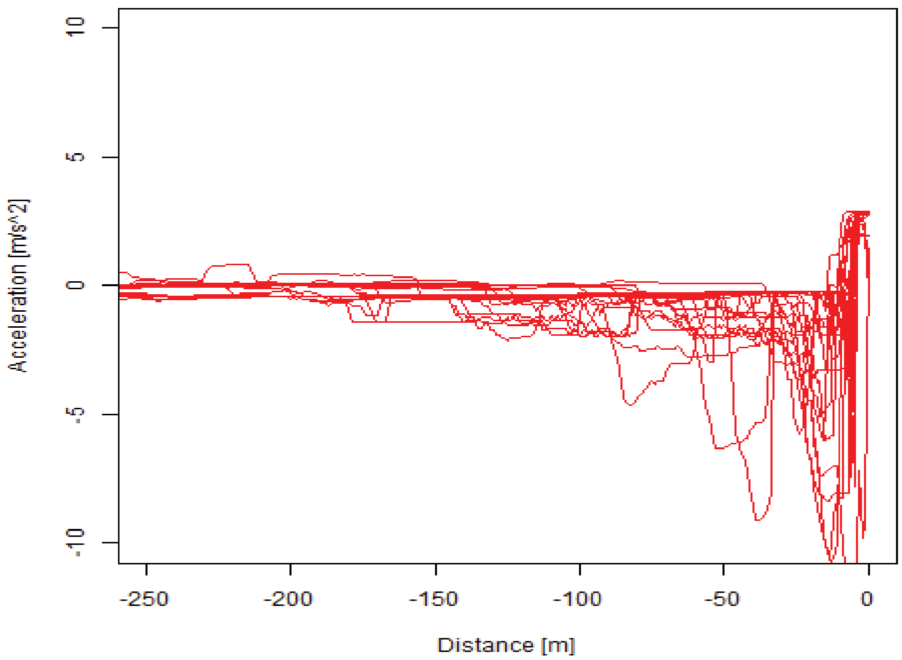


Individual acceleration profiles final-stage timer; passed

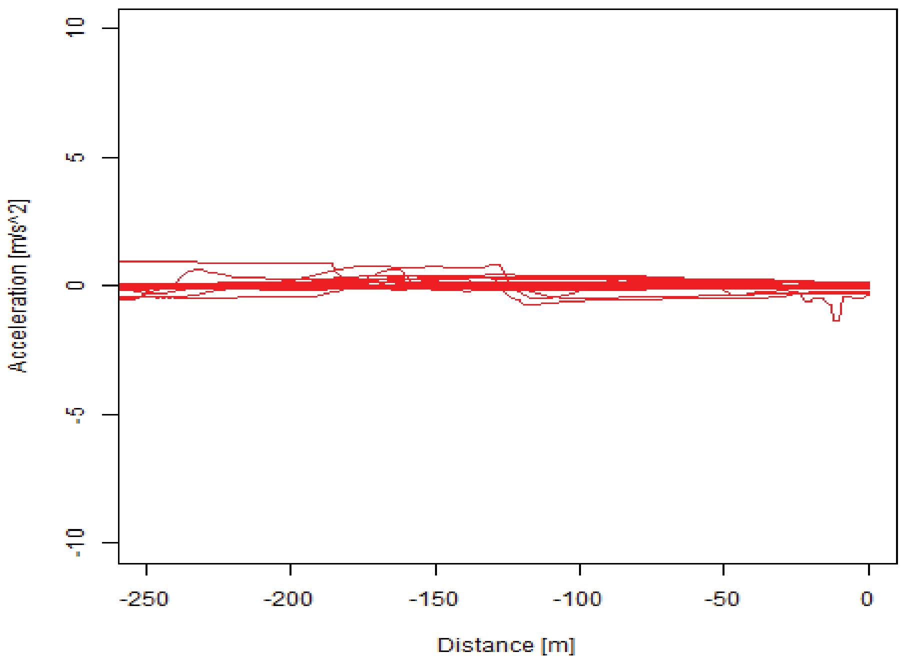


Appendix 5.2 The individual acceleration profiles of the participants when faced with the dilemma zone scenarios during the final-stage countdown timing condition. The test drivers that stopped are included in the figure above, the ones that decided to pass in the figure below. Graph retrieved from R.

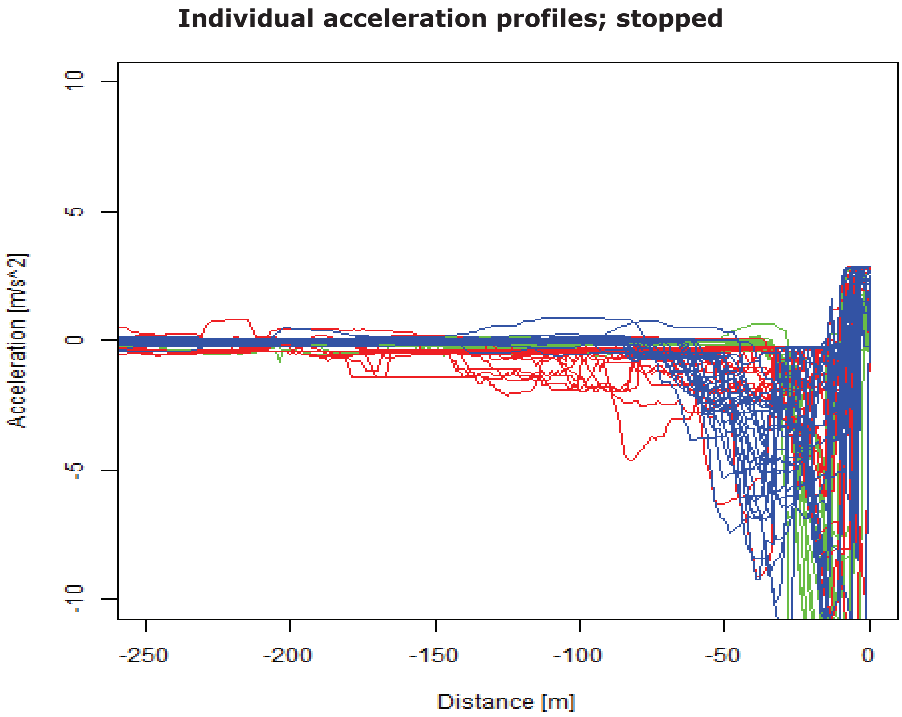
Individual acceleration profiles entire phase timer; stopped

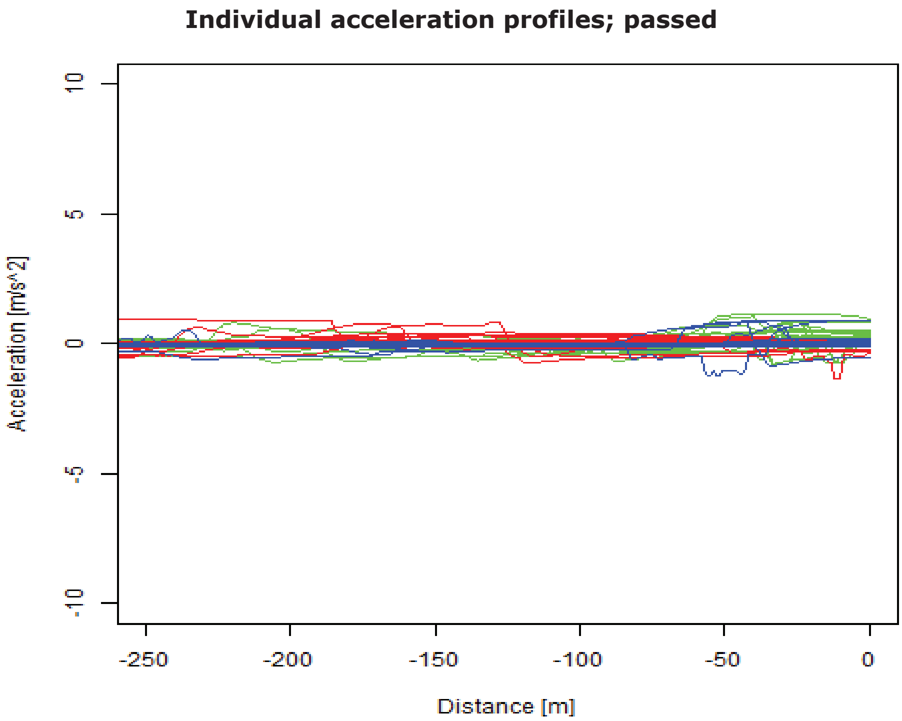


Individual acceleration profiles entire phase timer; passed



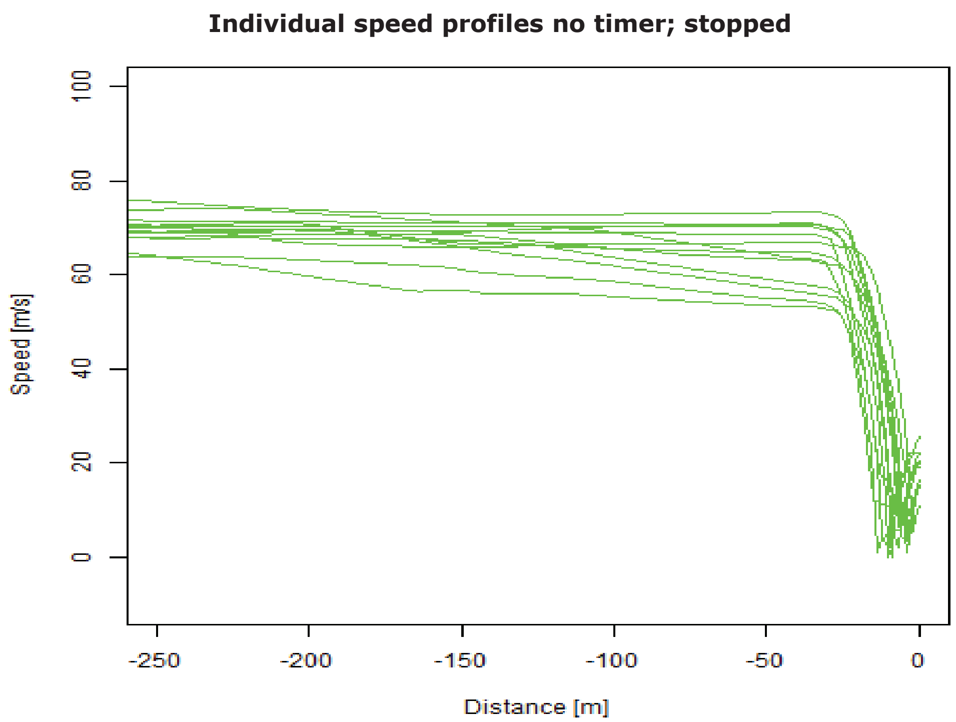
Appendix 5.3 The individual acceleration profiles of the participants when faced with the dilemma zone scenarios during the entire phase countdown timing condition. The test drivers that stopped are included in the figure above, the ones that decided to pass in the figure below. Graph retrieved from R.

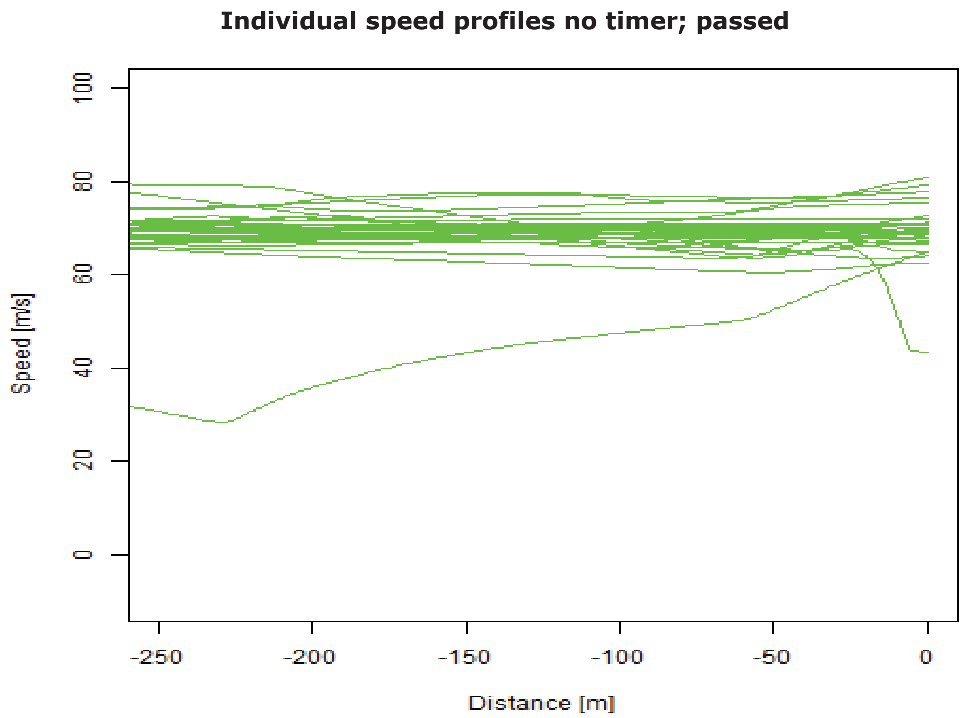




Appendix 5.3 The individual acceleration profiles of the participants when faced with the dilemma zone scenario during all conditions. Graph retrieved from R.

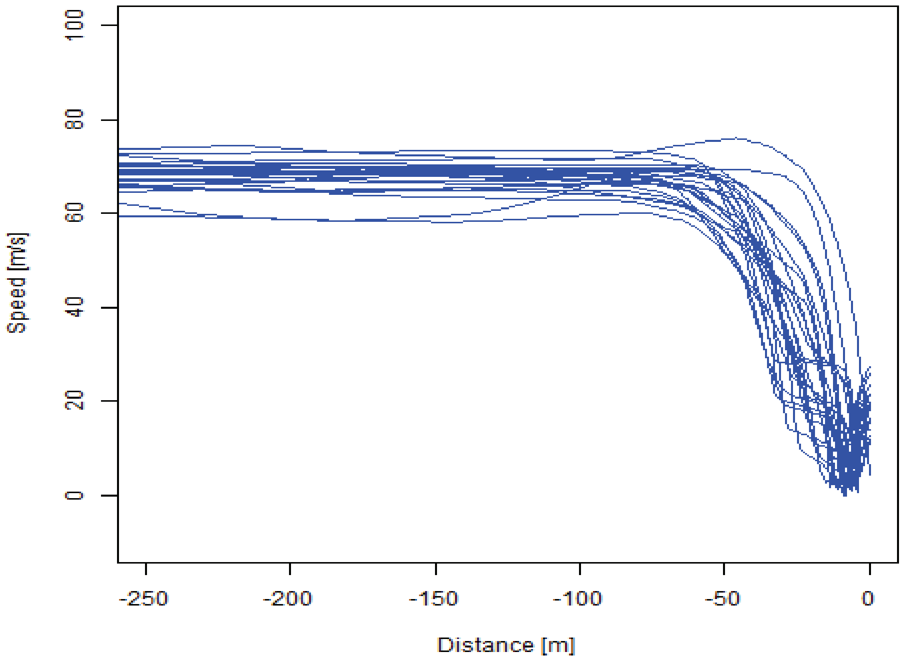
APPENDIX 6 INDIVIDUAL SPEED PROFILES



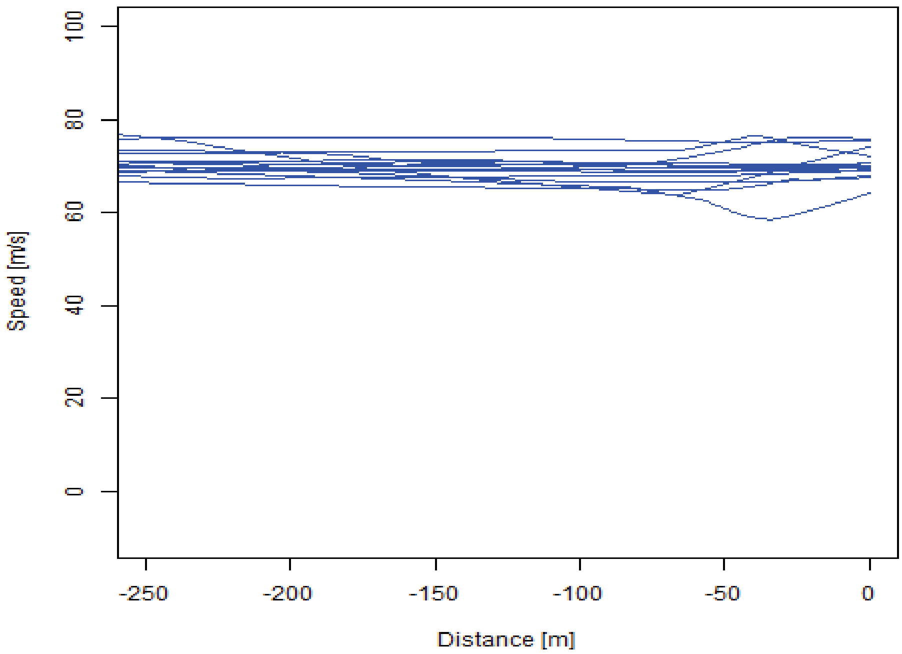


Appendix 6.1 The individual speed profiles of the participants when faced with the dilemma zone scenarios during the no countdown timing condition. The test drivers that stopped are included in the figure above, the ones that decided to pass in the figure below. Graph retrieved from R.

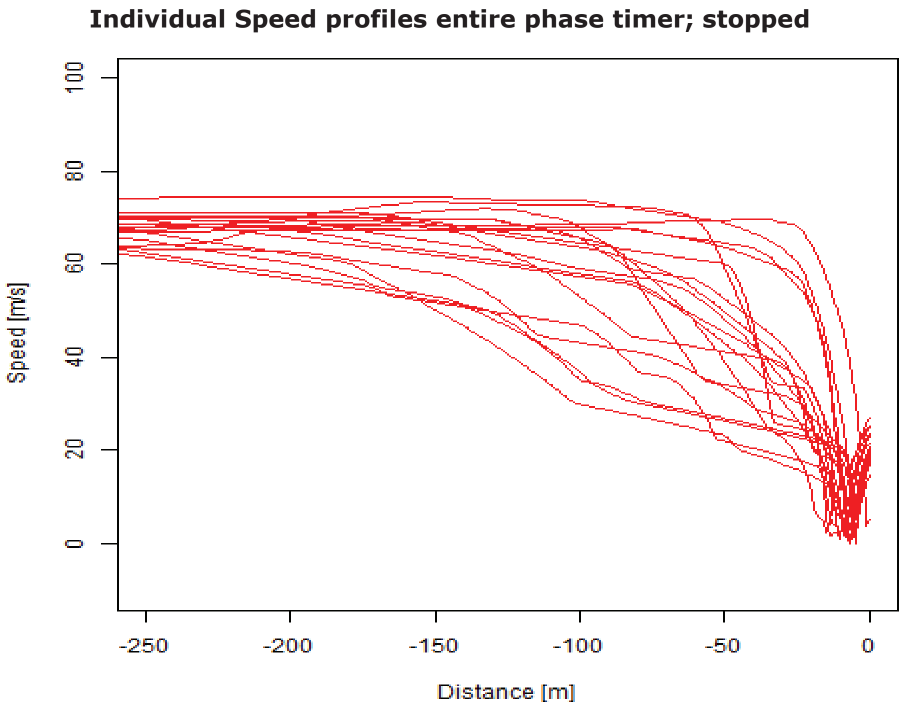
Individual speed profiles final-stage timer; stopped

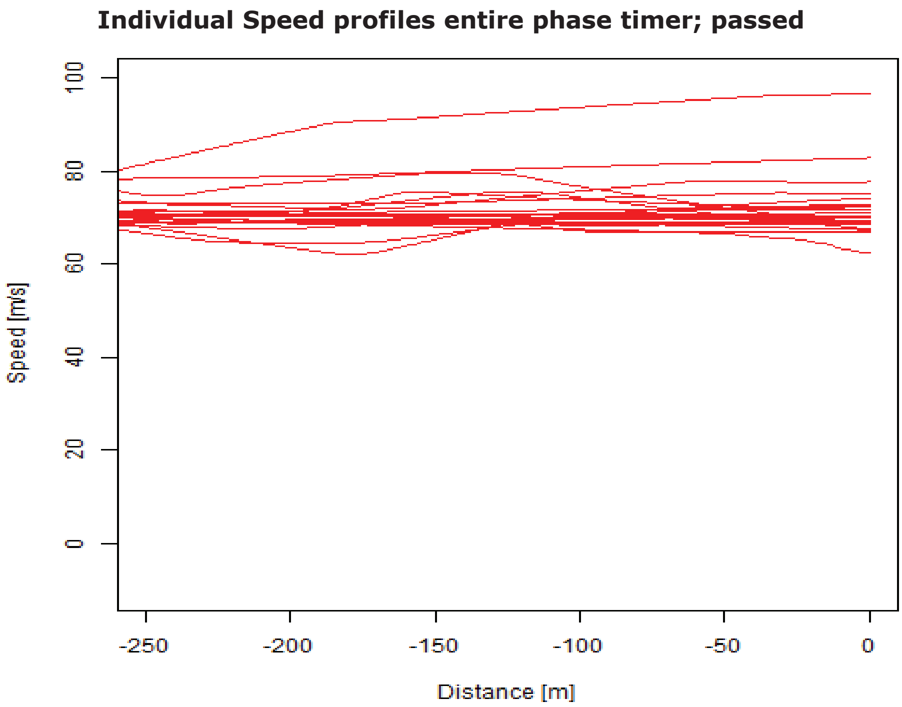


Individual speed profiles final-stage timer; passed



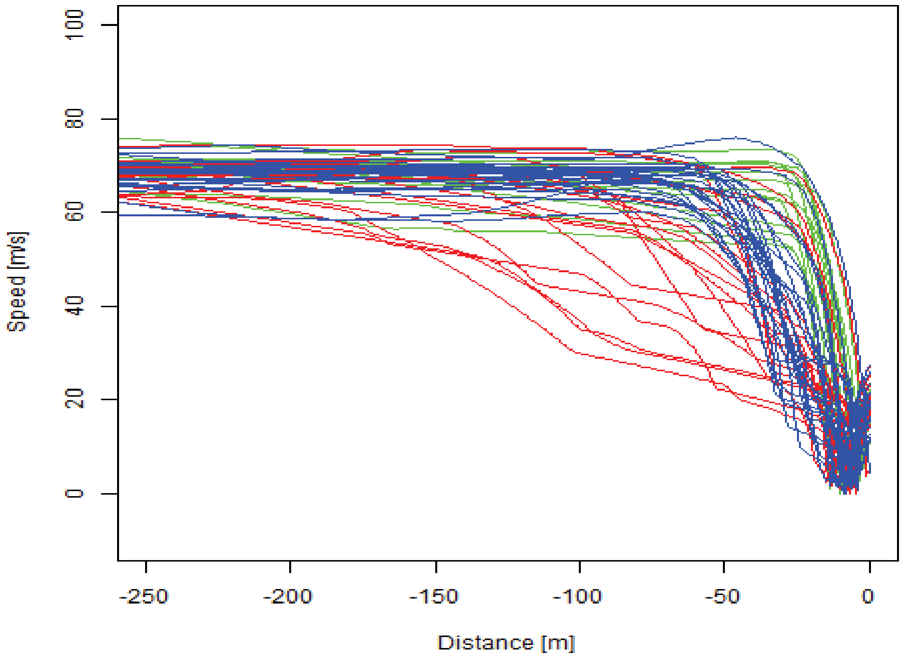
Appendix 6.2 The individual speed profiles of the participants when faced with the dilemma zone scenarios during the final-stage countdown timing condition. The test drivers that stopped are included in the figure above, the ones that decided to pass in the figure below. Graph retrieved from R.



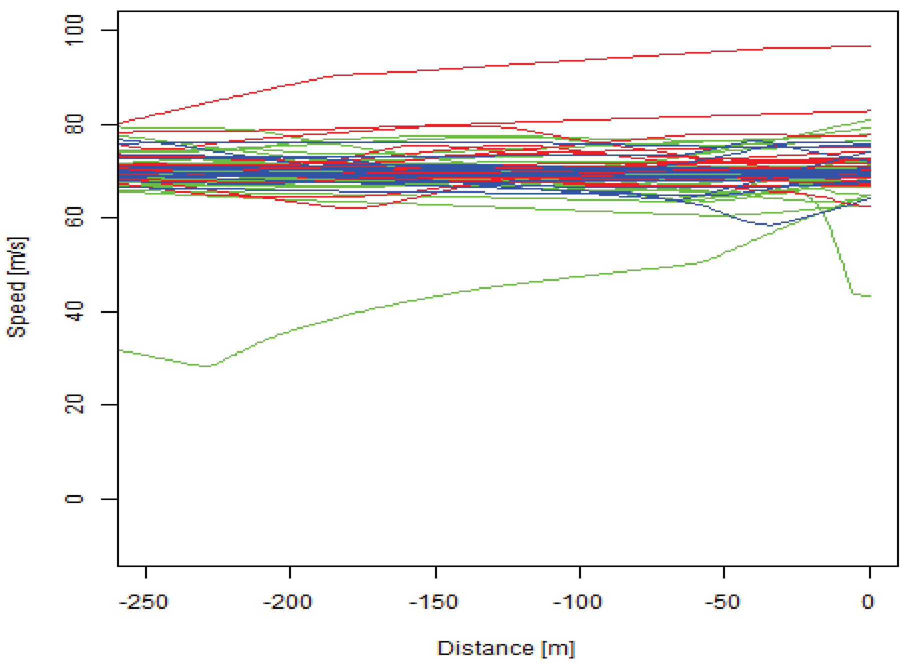


Appendix 6.3 The individual speed profiles of the participants when faced with the dilemma zone scenarios during the entire phase countdown timing condition. The test drivers that stopped are included in the figure above, the ones that decided to pass in the figure below. Graph retrieved from R.

Individual speed profiles; stopped



Individual speed profiles; passed



Appendix 6.4 The individual speed profiles of the test drivers when faced with the dilemma zone scenario during all conditions. Graph retrieved from R.

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van Haperen, Wouter

Datum: **9/06/2015**