Driving simulator study on the effectiveness of different thoroughfare configurations

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PREFACE

During my Masters in Transportation Sciences at the University of Hasselt I got the possibility to develop, execute and work out this driving simulator study. In the first Master the literature study was worked out whereas the focus in the second Master was on the development of the driving simulator scenario, the experiment itself and the analyses of the results. The subject of this driving simulator study is closely related to my interests in transport and mobility, including traffic safety, behavior and infrastructure.

The realization of this thesis was only made possible by the very good succession and coaching of my promoter Prof. Dr. Tom Brijs, my co-promoters Dr. Ellen Jongen and Dr. Kris Brijs. The instructive discussions during our meetings and the addition of innovative insights during the development of this thesis made it for a very fascinating and learning process. In addition, I would like to thank Dirk Roox for the programming of the driving simulator scenario and the assistance in the preparation of the data.

I would also like to thank all the drivers who participated in this driving simulator study and one of my fellow student Kristof Mollu for our cooperation at some points in our similar research.

Finally, I would like to thank my parents for their support and confidence during my whole school carrier and the chances they gave me during all these years. In addition, I would like to thank my fried, Philippe Pelckmans, for always being there for me and the helping hand during the development of this thesis. I would also like to thank my family and friends for their support and encouragements.

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SUMMARY

Flanders is characterized by many thoroughfares that combine an important traffic function with a significant residential function. The traffic function implies that traffic moves in a relatively smooth manner between origin and destination. The residential function lies in the fact that the road is used for numerous activities as part of the public environment. Given the residential function, adaptations of the driver's behavior – by reducing speed and increasing the allocated attention level – are desirable when entering the urban area. According to the model of Blumenthal (1968), the risk of an accident increases when the demand of attention from the environment – which depends on speed and complexity of the environment – exceeds the actual allocated level of attention of the driver. Furthermore, a higher speed increases the risk of and susceptibility to road accidents.

In a recent observational before-after-analysis with comparison group by Van Hout and Brijs (2008), large differences in safety effectiveness were found between different thoroughfares in Flanders. Based on the results, the authors hypothesized that thoroughfares characterized by a closed perspective (by the curviness of the road and a smaller road profile) and clear gate constructions when entering the built-up area have beneficial influences on safety.

This study aimed to examine the influence of gate constructions and curviness of the road on traffic safety and driver's workload in thoroughfares by means of a driving simulator. The influences of gate constructions and curviness on traffic safety and workload were expected to be additive, Curved thoroughfares with gate constructions were thus hypothesized to lead to the highest increase of the driver's allocated attention level as well as the largest speed reduction and therefore improve traffic safety more than curved thoroughfares without gate constructions, straight thoroughfares with gate constructions, or straight thoroughfares without gate constructions.

The study was conducted on a high-fidelity driving simulator (STISIM M400) which is fixed-based (drivers do not get kinesthetic feedback) with a force-feedback steering wheel, brake pedal, and accelerator. A random sample of 46 subjects (balanced according to age and gender) participated. Following a 2 (curviness: curved, straight) by

2 (gate constructions: present, absent) by 2 (secondary task: with, without) within-subjects design, 4 different thoroughfares were presented twice: once with and once without the secondary peripheral detection task. A long straight road segment between two thoroughfares functioned to decrease the level of attention and create speed adaptation. Driver performance measures of interest were mean speed, standard deviation of longitudinal acceleration and deceleration (SDL-A/D), standard deviation of lateral position (SD LP) and mean steering wheel movement frequency (SWM FREQ) of larger SWMs. Drivers' workload level was measured by driver performance measures (i.e. mean speed, SD LP and mean SWM FREQ) and performance on a secondary task presented during driving. The secondary task was a peripheral detection task (e.g. Patten et al., 2006) that required drivers to press a button as fast as possible when a red square appeared on screen without modifying their driving performance.

The results showed that curves had a speed reduction effect which was maintained throughout the whole thoroughfare, but this lower mean speed was accompanied by a higher SDL-A/D in a curved thoroughfare. The lower mean speed, the higher SD LP and the higher mean SWM FREQ in a curved thoroughfare confirm the hypotheses that curves increase workload. Although the reduced mean speed in curved thoroughfares should improve traffic safety, the higher SDL-A/D, SD LP and mean SWM FREQ could have a negative impact on traffic safety, decreasing traffic flow homogeneity and increasing the risk of collision with other road users, road furniture or parked vehicles.

Gates only have a local speed reduction effect before and after the entrance of the thoroughfare. The higher SDL-A/D around the entrance gate and before the middle of the thoroughfare indicates that the local lower speed around gates was achieved by a more abrupt decelerating maneuver before the entrance gate and a more abrupt accelerating maneuver after the gate to reach the same speed level as when no gates were present. The lower mean speed, the higher SD LP and the higher mean SWM FREQ before and after the entrance gate indicate that gates increase workload before and after the entrance. In general, the local reduced mean speed when gates were present can improve traffic safety, though the impact would be very local. The higher SDL-A/D, the higher SD LP and the higher mean SWM FREQ when gates are present can have a negative impact on traffic safety, decreasing traffic flow homogeneity and increasing the risk of collision with other road users, road furniture or parked vehicles. The desired traffic safety improvement provoked by gate construction can therefore be questioned.

Based on these results it is recommended to implement curved thoroughfares because of their speed reduction effect. The potential negative compensational behavioral adaptations by means of higher SDL-A/D, SD LP and mean SWM FREQ should be minimized by the development of forgiving roads with optimal curve radii and wider traffic lanes or recovery areas next to the traffic lane. Gate constructions on the other hand are only recommended in certain circumstances. The implementation of gate constructions should depend on the traffic function in thoroughfares and the residential function around the entrance of thoroughfares. That is, in thoroughfares those mainly have a traffic function and an important traffic flow the implementation of gate constructions will not improve traffic safety, and may even decline traffic safety because of interruption of the homogeneity of the traffic flow at these gate constructions. In that case, the local speed reduction effect does not outweigh this negative impact. However, in thoroughfares that have an important residential function which generates a large number of vulnerable road users (such as a school, a hospital or a shopping centre), the speed reduction effect will outweigh the interruption of the homogeneity of the traffic flow.

In general, it can be concluded that curves have a great potential to improve traffic safety whereas the impact of gate constructions on traffic safety highly depends on the traffic function in thoroughfares and the residential function around the entrance of thoroughfares. It is important that curves and gates are designed in such a way that all determinants of traffic safety are taken into account.

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List of abbreviations

ANOVA	Analysis of variance
AWV	Agentschap Wegen en Verkeer
ISA	Intelligent Speed Adaptation
kph	Kilometer per hour
LTM	Long-term memory
m	Meter
ms	Millisecond
RT	Response time
s	Second
SD LP	Standard deviation of lateral position
SD	Standard deviation
SDL-A/D	Standard deviation of longitudinal acceleration and deceleration
STM	Short-term memory
STSS	Short-term sensory system
SWM FREQ	Steering wheel movement frequency
SWM	Steering wheel movement
VMAE	Visual motion after-effect

Chapter 1 INTRODUCTION

1.1 Scope of the research

Since decades, the economical and societal advantages of traffic and mobility are overshadowed by road safety problems. The technological improvements have partly restricted traffic unsafety but every day there are still traffic fatalities. With the help of among others thoroughfare reconstructions, the Flemish Government tries to improve road safety and traffic livability in centre areas. The Manual of Traffic Facilities in Built-up Areas (*Vademecum voor Verkeersvoorzieningen in Bebouwde Omgeving*) (Ministerie van de Vlaamse Gemeenschap, 1997), published in 1997, summarizes a number of recommendations on reconstruction principles for centre areas. The concept of thoroughfare reconstructions will be further explained in Chapter 2.

In the past few years some studies have been conducted in relation to road safety in Flemish thoroughfares. These studies were aimed at gaining insight into different traffic, environmental and road characteristics that could be optimized by the introduction of Flemish policy regulations. Risk analysis studies have been conducted to examine the impact on the number of accidents of, on the one hand, characteristics of the transverse section (Van Hout, Hermans, Nuyts, & T. Brijs, 2005) and, on the other hand, of characteristics of the thoroughfare as a whole (Van Hout, 2006). The results showed that certain characteristics of a thoroughfare, such as traffic flow intensity, road characteristics (e.g. number of lanes, presence of pedestrian, cycle lanes or parking lanes) and environment characteristics (e.g. building density, presence of certain functions along the road), were related to road safety in that thoroughfare. Although these studies gave an indication of elements of road construction that were of influence on road safety, they did not reveal the impact of a thoroughfare reconstruction on road safety. Effectiveness studies that compare the situation before implementation with that after implementation and that make use of a comparison group are more suitable for the latter. In 2006 (Van Hout) and 2008 (Van Hout & Brijs) two effectiveness analyses have been conducted with the help of a software-tool CESam of the Policy Research Centre Mobility & Public Works, track Traffic Safety (*Steunpunt Verkeersveiligheid*). The last study found large differences in safety effectiveness between existing thoroughfares in Flanders. Based on the results, the authors hypothesized that thoroughfares characterized by a closed perspective (by the curviness of the road and a smaller road profile) and clear gate constructions when entering the built-up area have beneficial influences on road safety.

1.2 Research assignment

This study aimed to examine the influence of gate constructions and curviness of the road on driver's workload and driving behavior in thoroughfares by means of a driving simulator. As a result, the research assignment could be defined as follows:

Examine the influence of the curviness of a thoroughfare and the presence or absence of gate constructions on traffic safety and driver's workload in that thoroughfare by means of a driving simulator.

To carry out this research assignment, the exact content of this research assignment has to be understood. Hence, several research issues are defined about the themes: thoroughfares, behavioral adaptation, driving simulator studies and the analysis of the data.

1.3 Research methodology

In a driving simulator study it is absolutely necessary to do an extensive preliminary investigation to ensure that no influencing aspects are overlooked. Hence the usage of the PIAA-approach.

The first step in this approach is the *problem definition* in which the research assignment with the main research questions are phrased and a literary study is made about thoroughfares and the behavioral influences of thoroughfare reconstructions on driver's workload and speed. On the basis of this literary study, hypotheses are formulated in relation with the detailed research questions. In the second phase (*inform*) the research plan is drawn up and executed. The *analyses* of the results of the driving simulator study are discussed. Finally, *advises* are formulated in relation with the research assignment.

Chapter 2 THOROUGHFARES

Before the influences of a thoroughfare reconstruction can be examined, the concept of thoroughfares has to be clear. On the basis of a literature review, the following questions can be answered:

- What are thoroughfares?
- Are thoroughfare reconstructions in Flanders a good solution in terms of traffic safety?
- Which policy regulations exist about thoroughfares in Flanders?

2.1 Definition of thoroughfares

In the literature many definitions of a thoroughfare are available. The definition used in this study is based on the basic principle of a thoroughfare as a road in a built-up area that combines an important traffic function with a significant residential function. The traffic function implies that traffic moves in a relatively smooth manner between origin and destination. The residential function lies in the fact that the road is used for numerous activities as part of the public environment. Most roads have both a traffic function and a residential function and the design of the road has to match with the most important function. Residential areas have an important residential function and a low traffic function, whereas the opposite applies to traffic areas. In the case of a thoroughfare, where an important traffic function is combined with a significant residential function, the two functions conflict with each other and thorough considerations about the road design are necessary to reconcile both functions. In conclusion, the following definition can be defined for a thoroughfare.

A thoroughfare is a road in a built-up area which has both an important traffic and residential function and also wants to fulfill both functions.

In Flanders, build-up areas are defined by two road signs. The sign F1 indicates the entrance of the built-up area and the sign F3 is passed when leaving the built-up area.

Figure 1 Road signs F1 and F3 indicate the boundary of a built-up area
Source Verkeersweb.be (n.d.)

A thoroughfare can be structured by three distinct areas as shown in Figure 2: an outside area, a connecting area and a centre area. The areas are separated from each other by the road infrastructure, speed limit, activities, density of the buildings and other environmental characteristics. The traffic function is dominant in the outside area, whereas the residential function is the predominant factor in the centre area. These two functions coincide in the connecting area and have to be clear to all the road users. A frequently used way to stress this relation is the realization of gate effects with for example a central reservation, road narrowing, axis displacement or roundabout at the boundary between the outside and centre area. A thoroughfare encourages the readability and rhythm of a road.

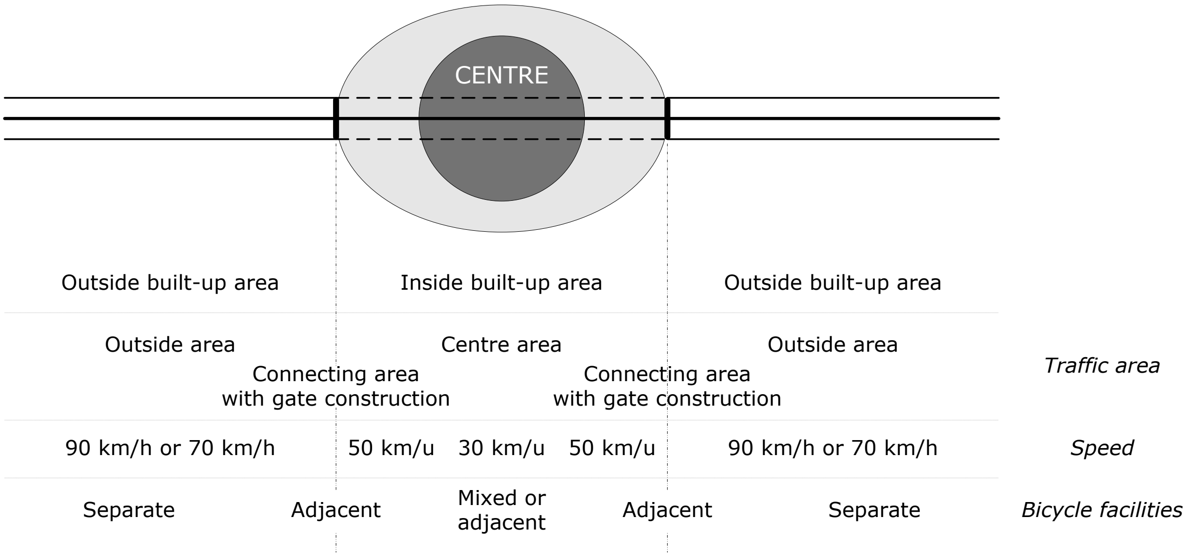


Figure 2 Scheme of thoroughfare concept
Source Ministerie van de Vlaamse Gemeenschap (1997)

2.2 Road safety in thoroughfares

A difference between roads inside built-up areas and thoroughfares is hardly made in road safety statistics. Road safety is therefore only discussed by making a difference between inside and outside built-up areas. Figure 3 shows that as the severity of the accidents increases the proportion of accidents inside built-up areas decreases. The low speed limit inside built-up areas contributes to a large extent to this. However, in 2008 there were still 126 fatalities inside built-up areas. Van Hout and Brijs (2008) have estimated that 40 to 45% of all road accidents inside built-up areas in 2005 took place at numbered roads (thoroughfares).

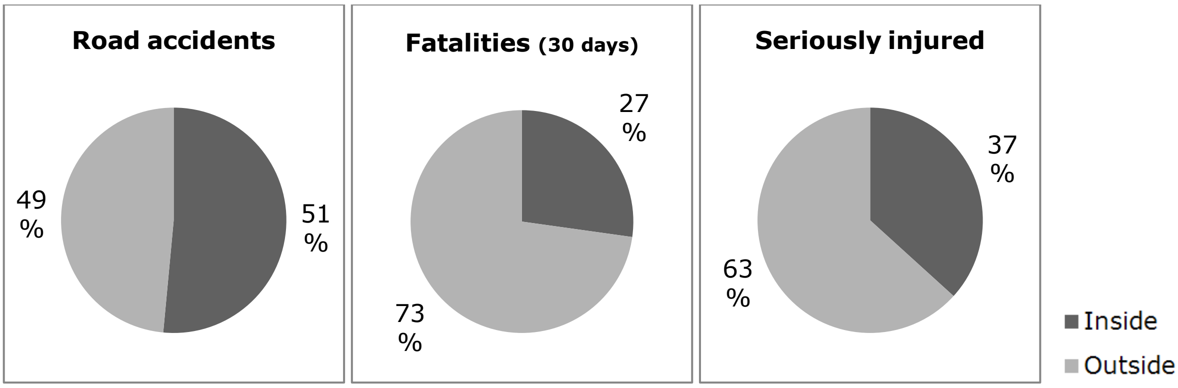


Figure 3 Number of road accidents and casualties by severity of injuries in Flanders inside and outside built-up areas (2008)
Source FOD economie – Algemene Directie Statistiek en Economische Informatie (2008)

Since 1991, the objective road safety inside built-up areas has significantly improved in contrast with the safety outside built-up areas. The number of casualties decreased in 2005 to 20% below the 1991 level and the number of fatalities even decreased with 65% (Vlaams Ministerie van Mobiliteit en Openbare Werken, 2008). According to Van Hout and Brijs (2008) the decrease in thoroughfares is more apparent in contrast with the decrease inside built-up areas.

The improvement of the road safety in thoroughfares is probably largely due to the thoroughfare policy of the Flemish government. On the basis of favorable results of a set of thoroughfare projects the Program Livable Thoroughfares (*Programma Leefbare Doortochten*) was set up in the early 90s. Due to the decentralization from regional to provincial level and the major contribution of municipalities via the mobility convent policy[1] in the thoroughfare policy, the knowledge and insights of the Program Livable Thoroughfares threatened to get lost. The existing basic principles, which had been sent by circulars until then, are therefore taken up and enlarged in the Manual of Traffic Facilities in Built-up Areas (*Vademecum voor Verkeersvoorzieningen in Bebouwde Omgeving*) (Ministerie van de Vlaamse Gemeenschap, 1997). In the mid-90s the Flemish government has reserved about 400 million euro for the thoroughfare program, of which

[1] The third module of the mobility covenant policy contains the reconstruction of thoroughfares.

40 million euro is used every year. The budget is spent on the basis of an objective need assessment of the *Agentschap Wegen en Verkeer (AWV)* which selected 600 thoroughfares in 2001 (Boterbergh, 2007; Mobiel Vlaanderen, 2002). Every year, the 25 worst scoring thoroughfares are reconstructed and this number in the future will increase to 75 (Ministerie van de Vlaamse Gemeenschap, 2001).

In addition to the Flemish thoroughfare policy a few important measures are implemented which have a major impact on the speed in built-up areas. In 1992 the speed limit has been diminished from 60 kph to 50 kph (Van Hout & T. Brijs, 2008). In addition, zones with 30 kph are in force in school neighborhoods since September 2005. Since many schools lie in built-up areas, this regulation has had a beneficial effect on road safety in built-up areas.

The Flemish thoroughfare policy is mainly focused on the reconstruction of thoroughfares. With regard to "the three E's" (Engineering, Education and Enforcement), this policy can thus be classified as 'Engineering'. An integrated thoroughfare policy also requires Education and Enforcement, but the present study focuses only on the infrastructural reconstruction of a thoroughfare (CROW, 2008).

As traffic accidents can rarely be attributed to one causal factor, the principle of Sustainable Safety is based on an integrated system of traffic components (environment, vehicle and road users) wherein the road user is the yardstick of the whole system (CROW, 2008). The five principles –functionality, homogeneity, forgiveness, recognizability and status awareness – provide a preventive and proactive approach to improve road safety. As mentioned in paragraph 2.1 thoroughfares combine an important traffic function with a significant residential function complicating the principle of functionality. Although the other four principles are present in thoroughfares the principle of homogeneity and recognizability are the most important in thoroughfare reconstructions. Speed reduction measures and the distinction of the three areas of a thoroughfare are often practiced in thoroughfare reconstructions and thus improve the recognizability and predictability. This results in a better understanding of the road so the driver knows what behavior is expected of him.

Chapter 3 BEHAVIORAL ADAPTATION VIA THOROUGHFARE RECONSTRUCTIONS

The main objective of a thoroughfare reconstruction is the improvement of road safety and traffic livability. This study focuses only on the improvement of road safety and more specifically on the reduction of speed and increase of workload that are necessary when entering the built-up area (Van Hout & T. Brijs, 2008). In this chapter behavioral adaptation in thoroughfares, attention and speed are examined on the basis of a behavioral model. With the help of this literature review the following questions will be answered:

- Do thoroughfare reconstructions influence driving behavior?
- Is there a relation between thoroughfare constructions and workload?
- What is the relation between road safety and workload?
- Is there a relation between thoroughfare constructions and speed?
- What is the relation between road safety and speed?

3.1 Behavioral model

The desired traffic safety improvements are the result of a series of internal behavioral systems in the road user which influence the driving performance. The problem with this kind of behavioral adaptation is that only the input (reconstruction of a thoroughfare) and the output (traffic safety and driver performance) can be observed directly. The processes in between that occur inside the road user and are responsible for processing the input and translating it to the output are not directly observable. This driving simulator study attempts to reveal the various relationships and focuses on the curviness of thoroughfares and the presence of gate constructions.

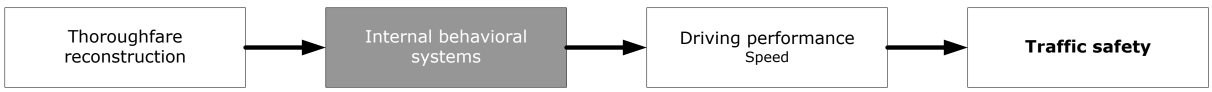


Figure 4 Black box problem of the influence of thoroughfare reconstructions on traffic safety

An attempt is made to unravel the relationship between thoroughfare reconstructions and driver performance by use of the internal behavioral systems in a behavioral model. The used model is a new composition of the models of Wickens (1992), Shinar (1978) and Endsley (1995) (in Shinar, 2007). The model (see Figure 5) depicts the road user as the control element with a limited capacity in the road user – vehicle – road environment system.

The behavioral model is discussed in detail by addressing the following element: first the stimuli and limited capacity are discussed, followed by the short- and long-term memory, the four components of the information processing and situation awareness. Finally, the responses and feedback loop are addressed.

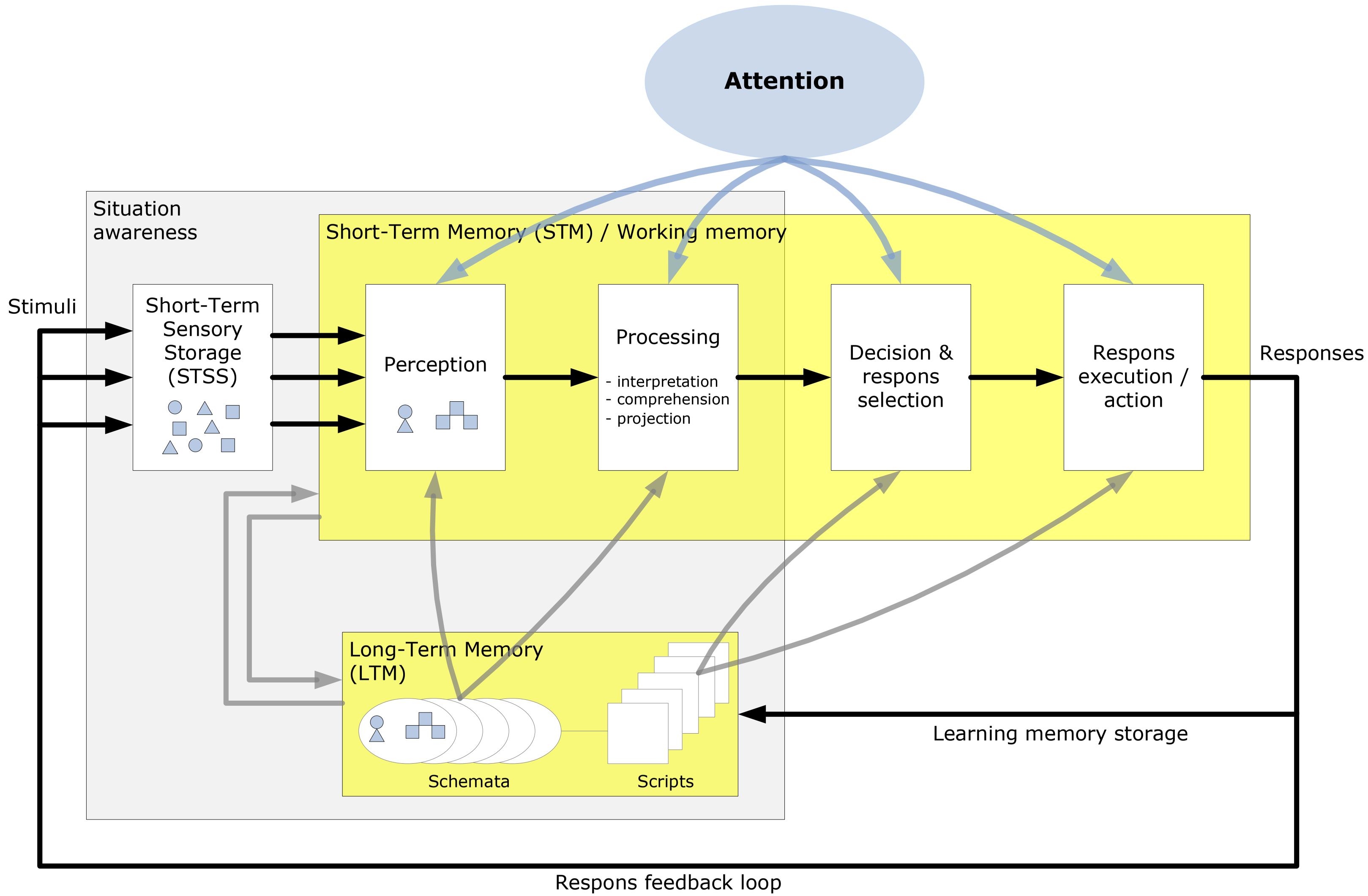


Figure 5 Behavioral model for information processing

3.1.1 Stimuli and limited capacity

During a ride the driver is exposed to a series of stimuli which are or are not connected to the driving task. Most of these stimuli are perceived visually (for example, the road environment, other vehicles, pedestrians and bicyclists, road signs, GPS, etc.) but the other sensory receptors are also used to perceive stimuli (for example pitch and yaw).

Information processing is characterized by its limited capacity. Task demands during the driving task are determined by at least two factors: speed and complexity. Firstly, when the total amount of information between two points on the road is constant, the speed at which these stimuli have to be processed depends on the driving speed. A higher speed is related to an increased amount of stimuli the driver is exposed to in a given time interval. Secondly, the more complex the road, the larger the information stream between two points on that road. A complex road environment demands more information processing capacity in comparison with a simple road environment (Shinar, 2007). According to Miermans (2006) it can be concluded that the size of the information stream is approximately directly proportional to the speed and the complexity of the environment. This limited capacity forces drivers to filter relevant information from the huge information stream (Leclercq & Zimmermann, 2002). The discussion of the behavioral model shows that the capacity is among others dependent on the level of attention (see paragraph 3.2) and the short- and long- term memory (see paragraph 3.1.2).

The accentuation of the three areas in a thoroughfare via gate constructions, the open or closed perspective and the yaw in curves are the most important stimuli in relation to this study.

3.1.2 Short- and long-term memory

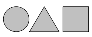
In addition to the stimuli of the road environment, which are received by the sensory receptors, the way of interpreting these stimuli determines the awareness of the road environment. This interpretation is made with the aid of the memory which is represented by two distinct storage mechanisms: short-term memory (STM) or working memory and long-term memory (LTM) or permanent storage which maintain a mutual relationship. On the one hand the STM uses the LTM to function and to collect information, whereas the STM stores information in the LTM via practice, repetition and association. The STM is always active to coordinate the human functioning and the attention division. The four components of information processing are therefore surrounded by the STM (see Figure 5).

The LTM contains all kind of information including schemata and scripts. Endsley (1995) (in Shinar, 2007) defines schemata as "experience-based frameworks for understanding various patterns of elements and events", while scripts contain instructions to react on the recognized schemata. The driver recognizes, based on his schemata, events in the flow of stimuli whereupon he tries to react 'according to his best possible way' by choosing the right script. The responses, resulting from the execution of the scripts, give feedback to the LTM via the learning memory storage. In this way new schemata and scripts are formed and existing ones are optimized. The readability of a road has to ensure that drivers, when perceiving certain stimuli such as a gate construction, immediately get the right impression of the situation by using the schemata and scripts. This way the driver knows which behavior is expected and the level of attention can be adjusted to meet the demands of the environment (see paragraph 3.2.4).

3.1.3 Four components of information processing

The limited capacity requires the road user to filter the stream of stimuli and to process the information before executing some responses. The four components of this information processing are surrounded by the attention level and the short- and long-term memory.

A. *Perception*

All stimuli (shown by  in Figure 5) are shortly stored in the short-term sensory stage (STSS) of which – due to the limited capacity – only a part is processed. Stimuli which are not processed immediately disappear from the STSS. Thus, the infinite information stream is scanned and relevant and salient features are extracted whereas part of the information is not further processed (Wickens, 1992) (in Shinar, 2007).

Detection of stimuli during the driving task is mainly visual (90%) whereas other senses are involved for a smaller part (10%) (Babbitt, Ghali, Kline, & Brown, 1990; Bartmann, Spijkers, & Hess, 1991; Sivak, 1996) (in Charlton & O'Brien, 2002). The visual perception of the road and the environment is the most import in driving simulator studies with a fixed-base driving simulator – such as this study (see paragraph 5.2) – because it is often difficult to influence other senses in a driving simulator. Hence the concentration on the visual perception of stimuli.

The fact that a stimulus is visually detected depends on two complementary factors. First, it is essential that the driver looks at the stimulus and fixes his eyes on it. In addition, it is necessary that the driver pays attention to the things he sees. The fact that only a small part in the centre of the visual field can be seen in detail and those movements can be good observed in the peripheral field of vision forces the driver to move the eyes to have a larger acuity vision (Lay, 1986) (in Godley, 1999). During the fixations (100-500 milliseconds) between two saccades (10-15 saccades) the visual information is collected in the foveal vision (Shinar, 2007; Van Knippenberg, Rothengatter, & Michon, 1989). The time of fixating the eyes is often a measure of attention to stimuli. But when the driver is distracted, the argumentation can be refuted. The phenomenon of 'looked but did not see' is present when a driver looks at something but does not pay attention to it and therefore does not see it. This phenomenon plays a role in approximately 10% of the road accidents (CROW, 2008; Shinar, 2007).

The distribution of the fixations and saccades depends on the visual search pattern of the driver. In the case of an internally driven search or "search conspicuity" the driver himself is looking for information (Martens, 2000). Expectations about the place where information can be found are very important and are supported by the LTM. The danger that only the things are seen which are expected is real. When striking or unexpected elements attract the driver's attention, this is referred to as externally driven search or "object conspicuity" (Martens, 2000). Several driving simulator studies (Shinar, Mcdowell, & Rockwell, 1977) (in Shinar, 2007) show that drivers fix their eyes on the focus of expansion on the horizon and on the right hand side of the road because road signs are placed there. They explored that drivers follow a back-and-forth pattern with their eyes when driving on a curved road. In addition, Backs et al. (2003) (in Shinar, 2007) discovered with the method of visual occlusion that drivers need more visual information on a curved road section in comparison with a straight road section.

After detecting the visual stimuli the driver tries to find a logical pattern in it by using his short- and long-term memory (e.g., schemata). The information can be further processed in the following step when the detected stimuli are recognized in a scheme of the LTM. The speed of this recognition is determined by the amount and completeness of the schemata which in turn depends on the experience of the driver.

B. Processing

The processing of the perceived stimuli consists of three consecutive steps: interpretation, comprehension and projection. The schemata in the LTM play a crucial role in this because they contain the frames with the interpretation and meaning of the perceived patterns of the stimuli. The more extensive and complete the schemata are, the easier and more correct the interpretation and comprehension is. The last step of the processing component is the projection of the information in time and space (Ma & Kaber, 2005). On the basis of the perceived information stream the driver tries to project the road, the environment and other road users in time and space. To prevent an accident the driver has to predict what the traffic situation will be like in a few seconds. On the basis of this projection the driver will take a decision about an action in the next step.

The research of Luoma (1988, 1990) shows that the processing of information can happen at different levels of attention. The fixation of an object is a precondition for the processing of information. But once fixated, the level of processing depends on other factors. According to Luoma the driver's experienced importance of the information is the most important factor.

C. Decision and response selection

During the decision process the driver is led on the one hand by the perceived information and on the other hand by its motives (CROW, 2008). It is quasi impossible to change the motives of drivers via infrastructural adaptation such as thoroughfare reconstructions. Hence these motives are not further discussed. It should however be clear that other interventions (such as education, enforcement or Intelligent Speed Adaptation (ISA)) have to support the thoroughfare reconstruction to achieve the desired traffic safety effects.

The driver's decision is based on the processed information and is derived from the scripts in the LTM. During the deciding the schemata, which contain the processed pattern, are matched with a script. The decision process is more difficult in complex situation and for inexperienced drivers. The huge information stream has to be perceived and processed in a very short time period after which the different patterns in the schemata have to match with the right scripts immediately. The strong relationships between the huge amount of schemata and scripts of an experienced driver lead to quasi automatic decisions.

The correctness of a decision depends largely on the attention level. When a driver pays insufficient attention to the driving task the perception and processing of the stimuli is diminished which results in less processed information to base decisions on. This increases the chance on wrong decisions.

D. *Response execution or action*

The script which is chosen in the previous step is executed in this last step of the information processing process. The correctness and speed of the action depend on the experience of the driver, the applied attention level, the road environment and the location of the several control elements in the vehicle.

Research of Fitts and Posner (1967), Warshawsky-Livne and Shinar (2002) and Summala, Lamble and Laakso (1998) (in Shinar, 2007) show that the reactions of drivers is very fast in optimal condition when they are not driving. The reaction time increases significantly when the conditions are more complex and the demanded attention level increases.

In conclusion, the response is highly dependent on the driver's attention level (see paragraph 3.2). The information processing cycle works according to the principle of how strong a chain is in its weakest link and the attention level determines the strength of a link. For example, when a driver allocates little attention to the perception of stimuli, less patterns can be used to get a good impression of the situation which result in difficult decision making of the right script. Although a lot of attention is spent on the following three steps the final response of the driver may contain a lot of limitations or even shortages because he did not get the right impression of the situation.

3.1.4 Situation awareness

Situation awareness (SA) is not a new element in the behavioral model; it refers / is related to the driver's competence to filter information out of the huge flow of stimuli. Endsley (1995) distinguishes three general levels of SA (in Ma & Kaber, 2005); (Walker, Stanton, & M. S. Young, 2008). The first level is the perception of the elements in the environment within a volume of time and space. The comprehension of the meaning includes the second level of SA and the third level is the projection of the status of the element in the near future. The assignment of attention to the different tasks is therefore central. In addition, the STSS and the short- and long-term memory are important.

The overall SA can be tested by suddenly stopping the drive and asking the driver to describe the environment he passed just before. When the driver gives a good description he has a good SA (SWOV, 2008).

3.1.5 Responses and feedback loop

The resulting responses of the information processing contain all possible actions which a driver executes during his driving task. The actions result in a change of the position and the speed and influence the appearance of the vehicle (for example direction indicators and lights). Because of these changes the stimuli to which the driver is exposed change. Due to the response feedback loop the driver can perceive the changes and information processing is necessary again to react properly to the changes.

3.2 Attention

3.2.1 Definition

As discussed in paragraph 3.1.1 information processing capacity is limited. Because of the limitations the driver is forced to pay attention to and thereby filter only part of the stimuli of the stream of information. The efficiency of our behavior is thus determined by the capacity of our attention system (Leclercq & Zimmermann, 2002). According to Mirsky (1989), Posner and Petersen (1990) and Parasuraman (1998) (in Leclercq & Zimmermann, 2002) attention is a complete system with specific sub processes by which the information processing, the decision processes and the behavior are controlled. That is the reason why attention has a central position in the behavioral model (see Figure 5). Klauer, Dingus, Neale, Sudweeks and Ramsey (2006) (in Shinar, 2007) define attention as a source of physical energy which people spend on each task at any time. The attention level varies continuously and is determined by stimuli and context related information processes, by brief intentions and thoughts or by long-term motivating or emotional conditions (Van Zomeren & W. Brouwer, 1994) (in Leclercq & Zimmermann, 2002).

3.2.2 Distribution of attention

According to Shinar (2007) there are two critical aspects in the allocation of attention. First, the total capacity which equals the amount of attention, which is available for a driver at a certain moment is finite, thus limited, but not constant. The amount of attention which is consumed is a function of motivation and effort in those circumstances and is often called workload (Kahneman, 1973) (in Leclercq & Zimmermann, 2002). The distribution of that total amount of attention among various driving and non-driving tasks forms the second aspect. There is a distinction between focused or selective attention and divided attention. In the case of selective attention for one task all irrelevant information is filtered and all attention is allocated to one task. Human's flexibility is in this case very important to switch from the one focused stimulus to another. And on top of that, the driver has to adapt his behavior to the changing situations. The division of attention in itself and the coordination of the different tasks also need some attention. The required attention for the execution of two simultaneous tasks is thus not equal to the sum of attention for two separate tasks (Leclercq & Zimmermann, 2002). In spite of this extra required attention humans are fairly well able to divide the attention among different task (Wickens & Hollands, 2000) (in Leclercq & Zimmermann, 2002).

Several theories are developed with relation to the distribution of attention which can be divided in two movements (Leclercq & Zimmermann, 2002). The central or single capacity theory assumes that attention is divided over the different tasks and there is only one attention tank. The limited capacity results in the fact that different tasks influence each other mutually. On the contrary, the multiple resources theory suggests that several attention tanks can be used for the different tasks and therefore these tasks do not influence each other. In this theory it is also possible that several tasks use one attention tank. Both theories are visualized in Figure 6.

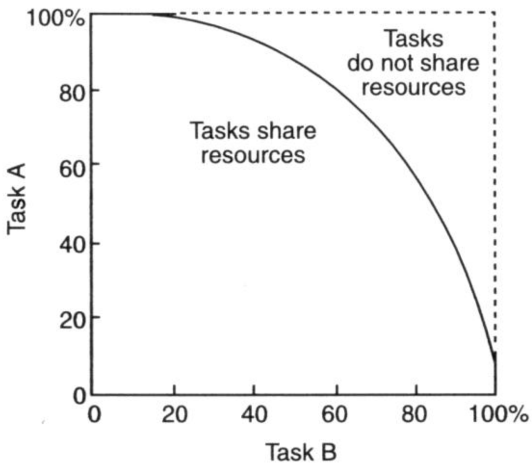


Figure 6 Task performance under the central or single capacity theory (solid line) and multiple resources theory (dotted line)
Source Cohen (1993) (in Leclercq & Zimmermann, 2002)

According to Shinar (2007) the attention level for focused or selective attention can only take place within the limits of the total amount of attention. Research from Patten, Kircher, Östlund and Nilsson (2004) (in Shinar, 2007) show that the more demanding the driving task and the environment are the less attention capacity remains for non-driving task.

The multiple resources model is further elaborated by Wickens (2002) in the four-dimensional multiple resources model or the cube model in which he assumes that there are five important dimensions that account for the variance in time-sharing performance. The dimensions are listed below and represented in Figure 7. The fourth dimension (visual processing) is nested within the visual resources.

- Stages: the cognitive stage involved in processing
  - Perception and cognition
  - Responding
- Perceptual modalities: the presentation of the stimulus
  - Cross-modal time-sharing
  - Intra-model time-sharing
- Visual channels: the area of the visual field which is used
  - Focal vision
  - Ambient vision
- Processing codes: the kind of task presented
  - Analogue or spatial processes (e.g. tracking, steering)
  - Categorical or symbolic processes (e.g. verbal)

- Responses: the kind of response to the stimulus or task
    - Manual or spatial
    - Vocal or verbal

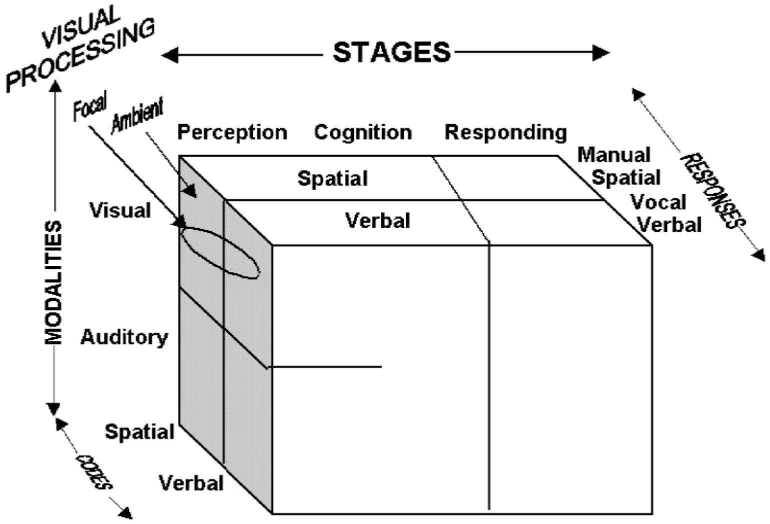


Figure 7 Three-dimensional representation of the structure of multiple resources
Source Wickens (2002)

Wickens (2002) states the following view about this model: "All other things being equal (i.e. equal resource demand or single task difficulty), two tasks that both demand one level of a given dimension (e.g. two tasks demanding visual perception) will interfere with each other more than two tasks that demand separate levels on the dimension (e.g. one visual, one auditory task)". The model can be used to predict the level of disruption or interference between two time-sharing tasks. The model can be used for the vehicle driver because it is most applicable in the high demand multi-task environment.

3.2.3 Relationship between attention level and road safety

The limited capacity leads to the fact that the distribution of attention is much more difficult than the focusing. Research (Hendrickx, Fell, & Freedman, 2001; Sabey & Staughton, 1975) (in Shinar, 2007) shows that these limitations of attention are one of the most important causes of accidents.

A. <u>Blumenthal's cognitive model of driving</u>

Blumenthal (1968) (in Shinar, 2007) based his cognitive model of driving on this and tries to represent the relationship between the attention level and road safety. This model is shown in Figure 8 after which it is discussed in detail.

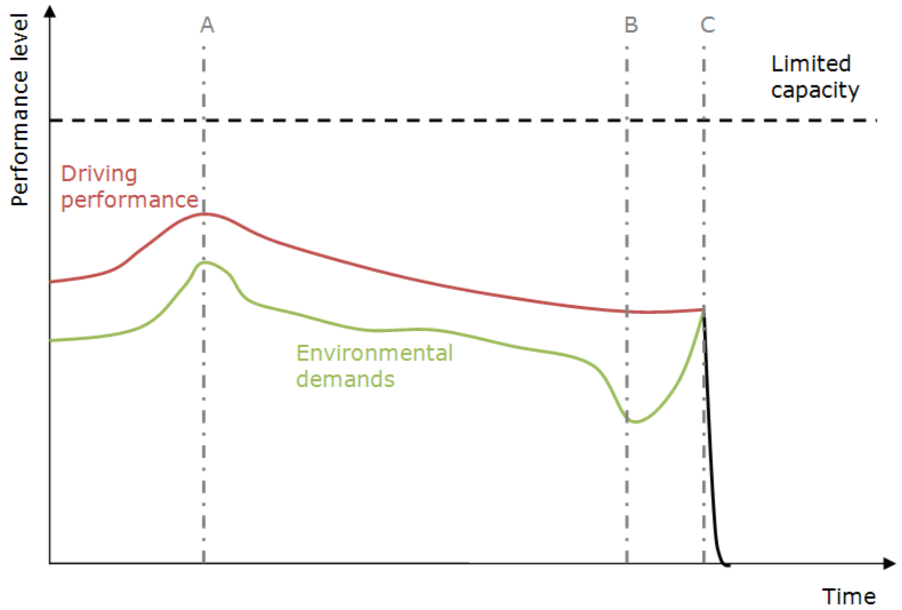


Figure 8 Blumenthal's cognitive model of driving
Source Blumenthal (1968) (in Shinar, 2007)

The model of Blumenthal gives the relationship between the moment-to-moment variations in the attention demanded by the environment and the energy or attention allocated by the driver to that environment. The green line reflects the environmental demands whereas the red line describes the driving performance. This driving performance is often specified as workload.

The driver can vary his driving performance by paying less or more attention to his non-driving tasks or to parts of the driving task. In this way the total amount of allocated attention capacity corresponds with the total amount of available attention capacity. On the other hand, the driver can choose to change his speed so the amount of incoming stimuli which should be produced in a certain time period decreases or increases. A speed reduction will result in less steep fluctuations of the environmental demands through which the driver has more time to adapt his behavior to the changing circumstances. When driving on a high speed on the other hand, the peak in the energy demand is much steeper which results in little time to respond on the changing environmental demands. Moreover the driver covers more distance during that time so a critical complex situation is more likely. If the driver does not reduce his speed in complex situations, demanded attention increase and more attention is thus required to cope with the huge fluctuations (Godley, 1999). The environmental demands are thus proportional to the speed and the complexity of the environment and are shown in Figure 9.

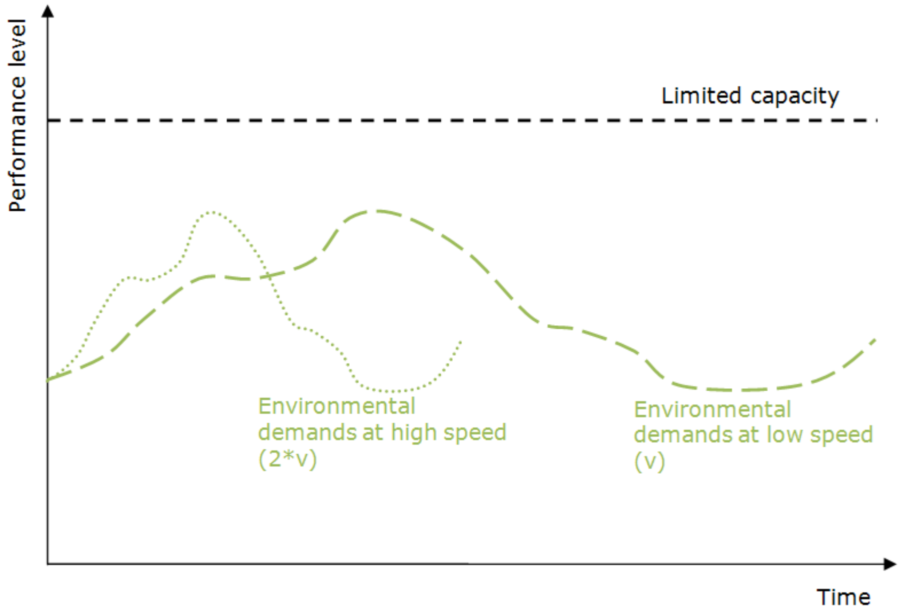


Figure 9 Environmental demands at high and low speed

In normal circumstance a driver can anticipate well on attention demanding elements because the allocated attention exceeds the environment demands (situation A). This makes it possible for the driver to rapidly comprehend the driving situation and to predict events. When the environmental demands suddenly increase (situation B) there is still some energy available to cope in an appropriate way with the complex situation. In this case the driver will reduce his attention level for the non-driving tasks and allocate the available attention to the driving task. It rarely happens that the environmental demands suddenly and unexpected increase to a level above the attention level (situation C). This can be caused by two aspects which are visualized in Annex 2. On the one hand, the attention level of the primary driving task reaches almost the limited capacity so an extra increase of the attention level is impossible. On the other hand, the driver has not enough time to reallocate the attention between the driving and non-driving tasks. The amount of attention that is allocated in these situation is lower than the amount that is needed for safe driving behavior which – dependent on the forgiveness of the road and compensation of other road users – may or may lead to an accident (Leclercq & Zimmermann, 2002; Shinar, 2007). When the exceeding of the demanded attention level and the speed is not that high it is enough to slow down or to stop completely so the incoming amount of information strongly decreases and the spare attention is allocated to the driving task.

B. *<u>Risk models of Wilde, Näätänen and Summula</u>*

The behavioral adaptations which are needed to compensate the fluctuations in environmental demands can be related to motivation models such as the risk models and workload models. In the risk models of Wilde (1982) (in Shinar, 2007); (1994; 1988) (in Weller, Schlag, Gatti, Jorna, & van de Leur, 2006) and Näätänen and Summula (1976) (in Shinar, 2007; in Weller et al., 2006) drivers compensate for their increased or decreased subjective risk by adapting their behavior in such a way that their subjective risk equals their target level of risk. The difference between Wilde's model and the model of Näätänen and Summula is the fact that the target level of risk in the last model is close to zero whereas Wilde's model uses a non-zero target level. The model of Wilde is shown in Annex 3.

The main critic about these risk models is that, in the case of objective improvements, drivers adjust their behavior so that their target level of risk remains constant which result in equal accident rates per unit time because a driver is searching for a risk homeostasis (Weller et al., 2006). In addition, Fuller (2005) supposes that the subjective risk estimation – which is the outcome of a conscious cognitive process to estimate objective risk – does not change until a certain threshold is reached. This indicates that risk models cannot explain difference in behavior below the threshold level.

C. *<u>Fuller's task-capability interface model</u>*

Fuller combined both risk models in a new task-capability interface model (Fuller, 2005) which uses approximately the same view as Blumenthal to describe the relationship between the attention level and road safety.

According to Fuller drivers do not seek risk homeostasis but task difficulty homeostasis. In Fuller's model the task demands are compared with the capability. In the case that the demands exceed the capability a loss of control can lead to a collision or a lucky escape. This is the same as what happens in the model of Blumenthal when the curve of the driving performance reaches the maximum attention level or the curve of the environmental demands. The task difficulty thus varies not only as a function of changing road demands, but also as a function of fluctuating capabilities allocated to the driving task. This is also the case in Blumenthal's model. To keep the task difficulty between selected boundaries speed choice is the primary solution. This interaction is confirmed in many studies ((e.g. Liu & Y. Lee, 2006; Shinar, Tractinsky, & Compton, 2005) (in Shinar, 2007) and (Summala, Nieminen, & Punto, 1996; Victor, Harbulk, & Engström, 2005) (in

Regan, J. D. Lee, & K. Young, 2009)) where the speed decreases as task difficulty increases. The study of Recarte and Nunes (2002) (in Shinar, 2007) is an exception on this finding.

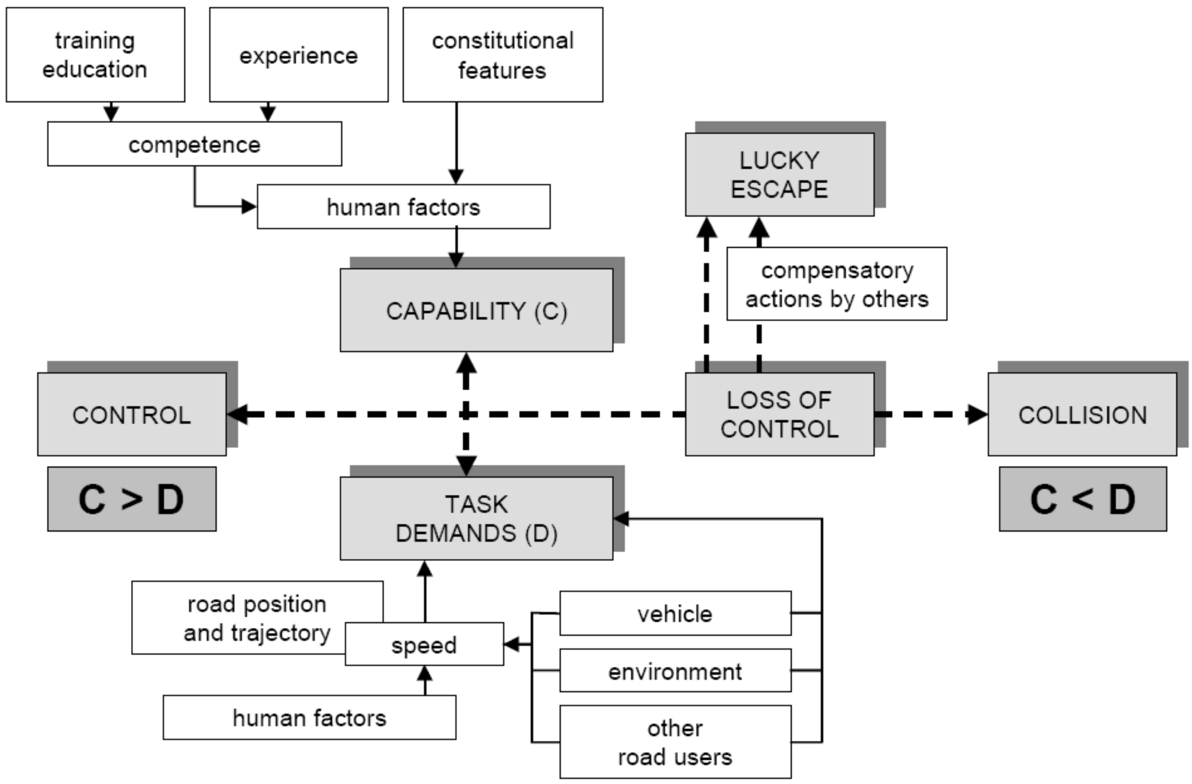


Figure 10 Fuller's task-capacity interface model
Source Fuller (2005) (in Weller et al., 2006)

3.2.4 Expectation and readability

According to the model of Blumenthal (see paragraph 3.2.3A) and Fuller (see paragraph 3.2.3C) it is important that drivers place their attention level for the driving task at a correct level so their capability to perform the driving task exceeds the environment demands. The resulting driving performance is, according to the Yerkes-Dodon law (Fuller, 2005; Van Knippenberg et al., 1989; Weller et al., 2006), dependent on the arousal or workload level at that moment and the difficulty of the task. Both very low and very high workload levels lead to lower performance levels. The performance is thus best at medium workload levels. This optimum level shifts to the right for easy tasks and to the left for complex tasks.

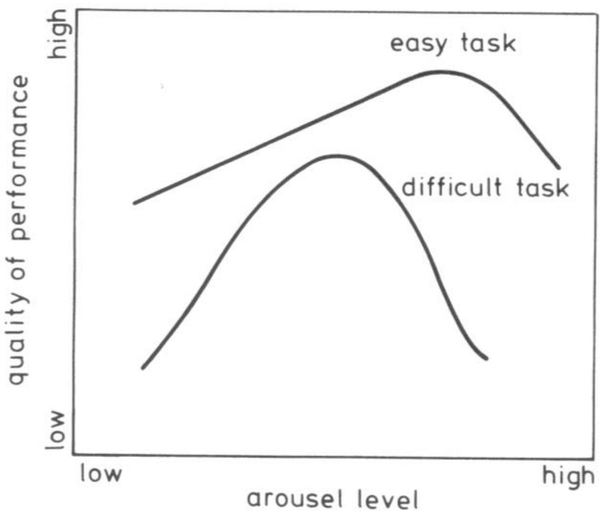


Figure 11 Yerkes-Dodson law
Source Van Knippenberg et al. (1989)

The driver himself can vary his workload level by changing his speed. This is according to Fuller (2005) also the primary solution but can provoke speeding. On the other hand, a creation of rhythm in the road environment – by for example a sequence of threes, curves, striking buildings or changing distances between buildings – also increases the workload level. A monotonous road, such as a highway or an open rural road, is the extreme counterpart of a rhythmic road and stimulates highway hypnosis in which a driver ends up at a very low arousal level or even fall asleep (Cerezuela, Tejero, Chóliz, Chisvert, & Monteagudo, 2004; Thiffault & Bergeron, 2003). In addition, there is an inverse relationship between the rhythm of a road and a desired speed reduction (Ministerie van de Vlaamse Gemeenschap, 1997).

A determinant for the allocated attention level is the expectations from the driver about the approaching road environment. A driver will increase his level of attention for the driving task or reduce his speed when he is expecting a complex traffic situation (Cnossen, Meijman, & Rothengatter, 2004). In the case of a monotonous road, the low workload level for the driving task will be compensated by an increase of the speed or by allocating more attention to non-driving tasks to achieve the optimal arousal level (Shinar, 2007).

Road designers try to find a compromise via the concept of readability which means that a road user should know which behavior is expected from him. A driver should thus well estimate the environmental demands. The schemata and schemes in the LTM are an important tool to do this. The readability of a thoroughfare can be increased by distinguishing the three areas of a thoroughfare by gate constructions. Through this the driver should know that he has to increase his attention level to cope with the complex traffic situation in the built-up area.

3.2.5 Assessment of attention

Attention is one of the most important components in the internal systems of the behavioral model. Because it is located inside the human being, it is impossible to measure the level of attention or workload directly. There are however five kinds of methods which assess workload indirectly by looking at the behavior and task performances. It is however recommended to combine different methods to estimate the attention level as good as possible (Godley, 1999; Verwey & H. A. Veltman, 1996). This multidimensionality of the assessment of attention can cause dissociation between measures of different categories. It is assumed that a different sensitivity of different measures to particular sources causes dissociation (de Waard, 1996).

A. *Primary task performance measures*

The attention level of a driver can be measured via the performance level on a primary task. The driving performance of an easy driving task is compared with the driving performance of a complex driving task. The difference in performance level between these two tasks is an indication for the extra attention that is needed to perform the complex task in comparison with the easy task. The most commonly used driving performance measures are for:

- Longitudinal control
    - **Mean speed** decreases as workload increases ((e.g. Liu & Y. Lee, 2006; Shinar et al., 2005) (in Shinar, 2007); (Summala et al., 1996; Victor et al., 2005) (in Regan et al., 2009) and (Cnossen et al., 2004)) except in the study of (Recarte & Nunes, 2002) (in Shinar, 2007)
    - **Standard deviation (sd) of speed** – as measure for speed control – increases as workload increases (Horrey & Wickens, 2004; Reed & Green, 1999)
    - **Mean headway** (distance or time based) increases when workload increases (Greenberg et al., 2003; Östlund et al., 2004)
- Lateral control

- **Sd of lateral control** – as a measure of tracking control or vehicle swerving – increases as workload increases (Cnossen et al., 2004; Drews, Pasupathi, & Strayer, 2008; Horrey & Wickens, 2004)
- **Mean SWM angle** increases as workload increases drivers have less attention for their driving task (Thiffault & Bergeron, 2003)
- **Sd of steering wheel movement (SWM) angle** increases as workload increases (Liu & Y. Lee, 2006)
- **Mean SWM frequency of larger SWM**[2] increases as workload increases (Matthews & Desmond, 2002; Thiffault & Bergeron, 2003)
- **Mean SWM velocity** increases as drivers have less attention for their driving task (Rauch, Kaussner, Krüger, Boverie, & Flemisch)
- **Steering reversal rate (SRR)** – as the average time between successive SWM – increases as workload increases (Verwey & H. A. Veltman, 1996)

B. *Secondary task performance measures: the dual task paradigm*

In the second assessment method for the attention level drivers have to perform a secondary (non-driving) task on top of the primary driving task. The method of measuring the attention level depends on the instruction which is given to the driver about the priority of the different tasks. The rationale is that performance on a low-priority task reflects the workload induced by a concurrent high-priority task because both task influence each other. This is automatically the case in the central or single capacity theory and– according to Wicken's cube model (see paragraph 0) – in the multiple resources model this is most likely the case when both tasks use the same level of a dimension in the cube model. Because the perception of the driving environment is for 90% via the visual sensory, it is preferable to use a visual secondary task. There is however a variety of auditory tasks used in driving research.

The approach of the dual task paradigm is visualized in Figure 12. The main requirement in this method is the fact that, when performing both tasks, the maximum capacity is exceeded. When this is not the case differences in performance level – and thus level of attention – cannot be determined.

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[2] The definition of a large SWM depends on the concerning paper: Thiffault and Bergeron (2003): SWM with an angle between 6 and 10° and Matthews and Desmons: SWM with an angle between 2 and 10°.

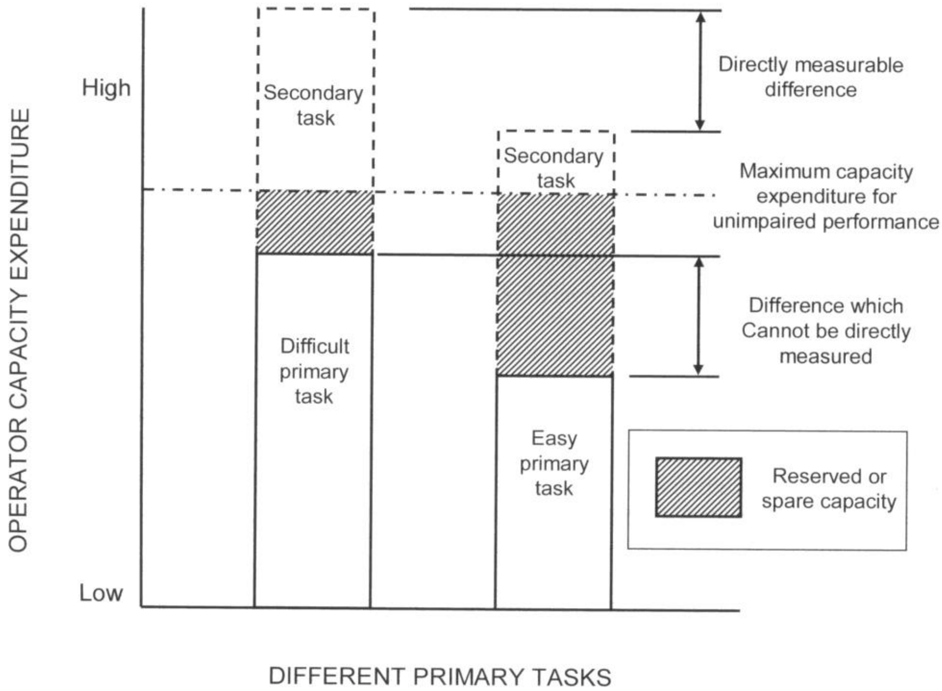

Figure 12 Dual task paradigm
Source O'Donnel and Eggemeier (1986) (in Shinar, 2007)

When the primary driving task has the highest priority (Hancock, Wulf, Thom, & Fassnacht, 1990; Hogema & J. Veltman, 2002; Verwey & H. A. Veltman, 1996), this task should – for a given driving situation – be performed equal with and without secondary task. Differences in the performance level of the secondary task give an assessment of the fluctuations in the attention level for the driving task over the various driving situations. The inverse is true when the secondary task has high priority. The differences in the performance level of the driving task in various driving conditions give an indication of the fluctuations of the attention level for that driving task over the various conditions. This last approach is quasi equal to the method in paragraph 3.2.5A except the fact that this approach introduces the secondary non-driving task.

In the literature a variety of secondary tasks can be found. In the majority of the secondary non-driving tasks drivers should respond as fast and accurately as possible on visual or auditory stimuli. The visual stimuli can be divided in two groups (Regan et al., 2009):

- **Object and event detection methodologies**: drivers respond to object or events encountered in the road environment while driving (for example: braking when lead vehicle decelerates (Lamble, Kauranen, L. Laakso, & Summala, 1999))

- **Artificial signal detection tasks**: drivers respond to stimuli which are not a natural part of driving task (for example: Peripheral Detection Task (PDT) (Jahn, Oehme, Krems, & Gelau, 2005; Martens & van Winsum, 2000; Patten, Kircher, Östlund, Nilsson, & Svenson, 2006; Patten et al., 2004))

Three types of responses can be distinguished and the choice of a secondary task depends highly on the technical and temporal limitations of the study.

- **Detection task**: The driver should respond to each stimulus and he does not have to make a choice about which response he has to give.
  For example: PDT (Jahn et al., 2005; Martens & van Winsum, 2000; Patten et al., 2006; Patten et al., 2004) or Paced Serial Addition Task (PASAT) (Daniels, Vanrie, Dreesen, & T. Brijs, 2010; Fisk & Archibald, 2001; Leclercq & Zimmermann, 2002)
- **Discrete choice task**: The driver should respond to each stimulus but – depending on the type of stimulus – he has to give another response.
  For example: rotated figures task (Young & Stanton, 2002a, 2002b, 2007a, 2007b)
- **Go and no-go task**: The driver should only respond to the target stimuli in a series of stimuli.
  For example: Oddball task (Rosenfeld, Bhat, Miltenberger, & Johnson, 1992; Wester, Böcker, Volkerts, Verster, & Kenemans, 2008), L-counting task or Continuous Memory Task (CMT) (Verwey & H. A. Veltman, 1996)

A response occur as a physical movement (for example: pressing a bottom) or as an internal process of which the result at the end is important (for example: count the amount of target stimuli). The final result of this internal process provides also a measure for the performance level (for example: CMT). When responding with a physical movement (for example: PDT or L-counting), the response time and the accuracy is registered after which one can compute the mean response time and the hit rate as measures for the performance level of the secondary task.

- **Mean response time (RT)** increases as the task demand increases (Jahn et al., 2005; Lansdown, Brook-Carter, & Kersloot, 2004; Martens & van Winsum, 2000; Patten et al., 2004; Strayer & Johnston, 2001)
- **Sd response time (SDRT)** increases as the task demand increases (e.g. Wester et al., 2008)

- **Mean hit rate** increases as the task demand decreases (Jahn et al., 2005; Lansdown et al., 2004; Martens & van Winsum, 2000; Patten et al., 2004; Strayer & Johnston, 2001)

In addition to secondary tasks with stimuli, there are also secondary tasks where the driver has to perform a task such as making a phone call (Cooper & Strayer, 2008; Drews et al., 2008; Horrey & Wickens, 2006; Patten et al., 2004), operation an in-vehicle radio (e.g. Lansdown, 2002) or reading a map (Cnossen et al., 2004). The performance level of these tasks is thus a measure for the attention level for the driving task (in the case that the secondary task has the lowest priority).

C. *Psycho-physiological measures*

The psycho-physiological measures give an indication of the stress that goes with the mental task pressure. Examples of this method are the diameter of the pupil, blinking behavior, heart rhythm variability (HRV), skin conductance responses (SCR) and electric evoked brain potentials via electroencephalogram (EEG) (Godley, 1999; Shinar, 2007; Van Knippenberg et al., 1989; Weller et al., 2006).

D. *Self-report measures*

In the fourth method drivers have to indicate on a rating scale how they experience their mental workload. It is therefore a subjective assessment instead of an objective. Thanks to individual differences between drivers differences between the objective and subjective measures can happen (Meshkati & Loewenthal, 1988). This problem can be solved by using a within-subject design. In driving simulator studies a variety of methods is used such as the NASA Task Load Index (NASA-TLX), the Rating Scale Mental Effort (RSME), the Subjective Workload Assessment (SWAT) or even so the simple question of 'overall perceived workload' (Daniels et al., 2010; Godley, 1999; Shinar, 2007; Weller et al., 2006).

E. *Drivers' visual behavior*

The last method is based on the fact that drivers get most of their information via the visual sensory. The visual occlusion technique measures how long a driver is willing to drive continue without having the possibility to look at the road and the environment. The more demanding the tasks, the longer the driver would like to see the road environment (Weller et al., 2006). The distribution of the eye movements can also give an indication about the visual workload. The longer the eye fixations and the more saccades, the higher the workload (Gawron, 2000).

3.3 Speed

Thoroughfare reconstructions have the intention to cause speed reductions and attention level increases with the eventual objective to improve road safety in built-up areas. Because the level of attention is the central component of the behavioral model it is discussed in paragraph 3.2. This paragraph concerns about speed. The first part deals with the relationship between speed and road safety. Speed as part of driving behavior is discussed in the second part and the last part considers speed treatments at the rural-urban threshold.

3.3.1 Relationship between speed and road safety

Two pillars form the basis in the relationship between speed and road safety (Shinar, 2007; SWOV, 2009). Firstly, the risk of an accident increases as the speed increases. This is the result of a longer braking distance and a shorter time to process and react on the fast information stream from the environment. This effect is more important in complex situations (such as a thoroughfare) in comparison with less complex situations (such as a motorway) (SWOV, 2009). Secondly, the seriousness of an accident increases in an exponential manner as the speed increases which results from the huge impact forces. In addition to the speed difference the difference in mass between road users plays also an important role. In general, the energy absorption is inversely proportional to the mass of the road user.

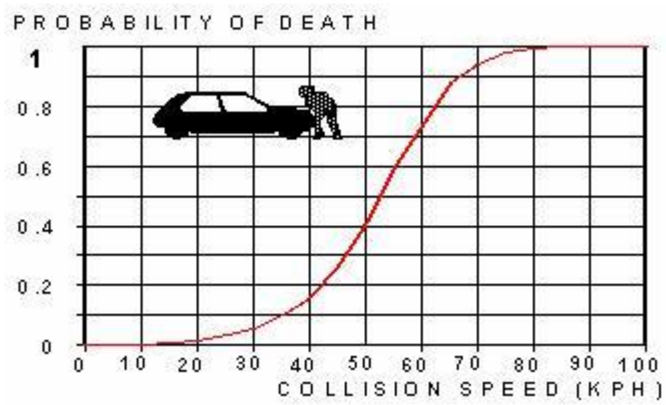

Figure 13 Exponential increase of the seriousness of a collision when speed increases
Source European Road Safety Observatory (2007)

Since thoroughfares hold both a traffic and a residential function, a good speed reduction is necessary to minimize the impact forces between vehicles and vulnerable road users. The investigations of Nilsson (1982) (in SWOV, 2009) show that when speed measurements are implemented both the risk and the seriousness of an accident decrease stronger on roads with a low categorization in comparison with road with a high categorization.

3.3.2 Speed behavior

As shown in Figure 5 the driver's actual speed choice is the result of the stimuli with is processed by the internal behavioral systems. Both internal factors (such as age, sex, risk acceptance, habits, motives and attitudes) and external factors (such as road environment, speed signs, weather conditions and element which divert the driver's attention from the driving task) influence these internal systems (Ariën, Mollu, Nowicki, & Volont, 2009; De Pelsmacker & Janssens, 2007; World Health Organization, 2004). Because it is quasi impossible to change the driver's habits, motives and attitudes via thoroughfare reconstructions, these internal factors are not further discussed. Nevertheless, the information processing of the driver – in which the attention level plays a central role – in relationship with the perception of speed and the processing of speed signs, is discussed.

A. *Perception of speed*

Each time a driver consults a speedometer, the actual speed can be compared with the perceived speed. Research of among others Triggs (1986), Evans (1970), Milosevic and Milic (1990) and Recarte and Nunes (1996) (in Godley, 1999 and Evans, 2004) show that – despite the repetitive practice of consulting a speedometer during driving – drivers are not that good in judging the actual driving speed. According to Shinar (1978) (in Godley, 1999) speed is observed by the perception of the optical flow from the visual environment. This optical flow originates at the focus of expansion, a fixed point at the horizon, and expands outwards in the visual field of the driver. Figure 14 shows the optical flow.

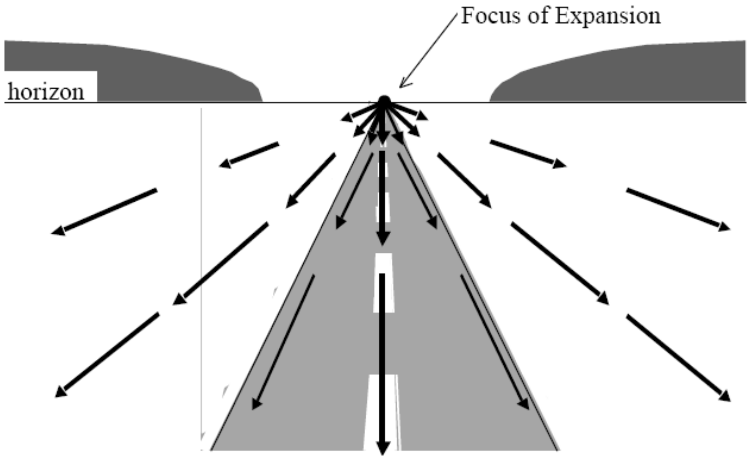

Figure 14 Motion perspective of elements in a visual field when moving forward on a straight road Source Gibson (1950) (in Godley, 1999)

The arrows represent the direction of the flow through the bearing whereas the relative velocity of the elements in the visual field is shown by the length of the arrows. In 1965 Gordon (1965) defined the motion paradox which follows from the fact that, if looking straight ahead when moving, the velocities of the elements are inversely proportional to the distance they are from the observer. It is thus the peripheral visual field which forms the main cue for speed perception (see also paragraph 3.1.3A). This finding is confirmed by Salvatore (1967, 1968) (in Godley, 1999) who found that speed estimations from peripheral vision are higher and more accurate than they are through foveal vision. This can be explained by the differences in the range of change of the visual angle – defined as the angular velocity – to elements in the driver's visual field. The central vision records smaller angular velocities than the peripheral vision with the largest angular velocities in the most extreme portions of the peripheral vision (Godley, 1999). This gives an explanation for the fact that driver's speed is higher in an open perspective in comparison with a closed perspective. In addition, lower speeds are chosen when the vertical elements (such as trees and buildings) are higher than the width of the road (SWOV, 2009). The above explanation is worked out in detail in Annex 1.

In addition to the fact that drivers generally underestimate their speed and that the peripheral vision the main cue for speed is, the visual field shrinks and gets deeper with increasing speed (Bartmann et al., 1991) (in Charlton & O'Brien, 2002). This results in less peripheral information about the vehicle's movement which leads to a speed overproduction (Denton, 1969; Recarte & Nunes, 1996; Tada, Kitamura, & Hatayama, 1969) (in Godley, 1999).

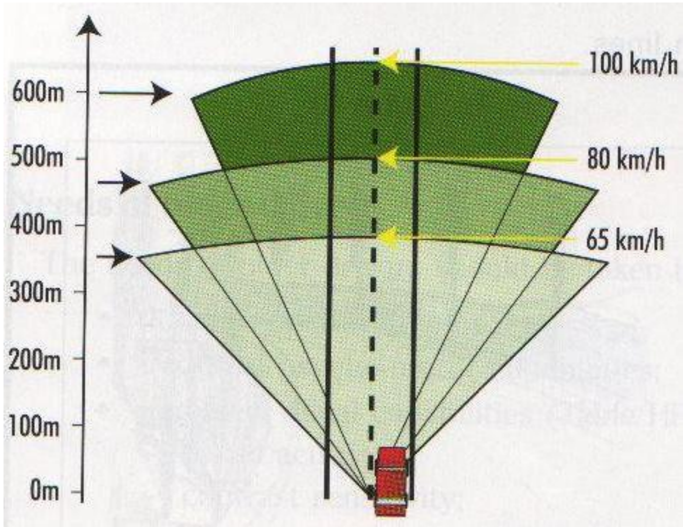

Figure 15 Narrower and deeper visual field with increasing speeds
Source PIARC (2003)

Besides, a motion at a constant (high) velocity for a prolonged time results in speed adaptation. Drivers perceive their speed to be slower than usual ((Denton, 1976) (in Godley, 1999); (Evans, 1970; Recarte & Nunes, 1996; Snider, 1967) (in Charlton & O'Brien, 2002)) and this effect is more pronounced after rapid deceleration because of the visual motion after-effect (VMAE) (Denton, 1976; Schmidt & Tiffin, 1969) (in Godley, 1999). The results of Denton (1976) (in Godley, 1999) also suggest that this underestimation will increase as the exposure to a constant speed lasts longer.

The greater speed underestimations due to speed adaption can have important negative consequences for road safety. This is especially the case at the end of long constant velocity roads, such as at exit ramps on motorways or at the entrance of a built-up area after driving on an open rural road at a constant speed. Speed underestimation is an important contributor to excessive speed which is in turn a major contributing factor for road accidents (Godley, 1999). Speed treatments to reduce the speed underestimation at the beginning of the built-up area are discussed in paragraph 3.3.3.

B. <u>Speed signs</u>

As discussed in paragraph 3.3.1 speed is an import factor in the risk and the seriousness of a road accident. To improve road safety, speed signs are introduce which determine the speed limit on a road segment. According to the Sustainable Safety principles (see paragraph 2.2) the speed limit should be in agreement with the function, form and use of the road. In ideal circumstances speed signs should consequently be superfluous because drivers have to assess the desired speed. This is however very difficult because drivers underestimate their speed (see paragraph 3.3.2). Drivers should obey to the speed limit to maintain a safe speed in normal condition on that road segment. The processing of speed signs is thus the first step in obeying the speed limit. Gartner, Messer and Rathi (1992) provide a useful model of traffic device information processing which is in line with the first two steps of the behavioral model in paragraph 3.1.3.

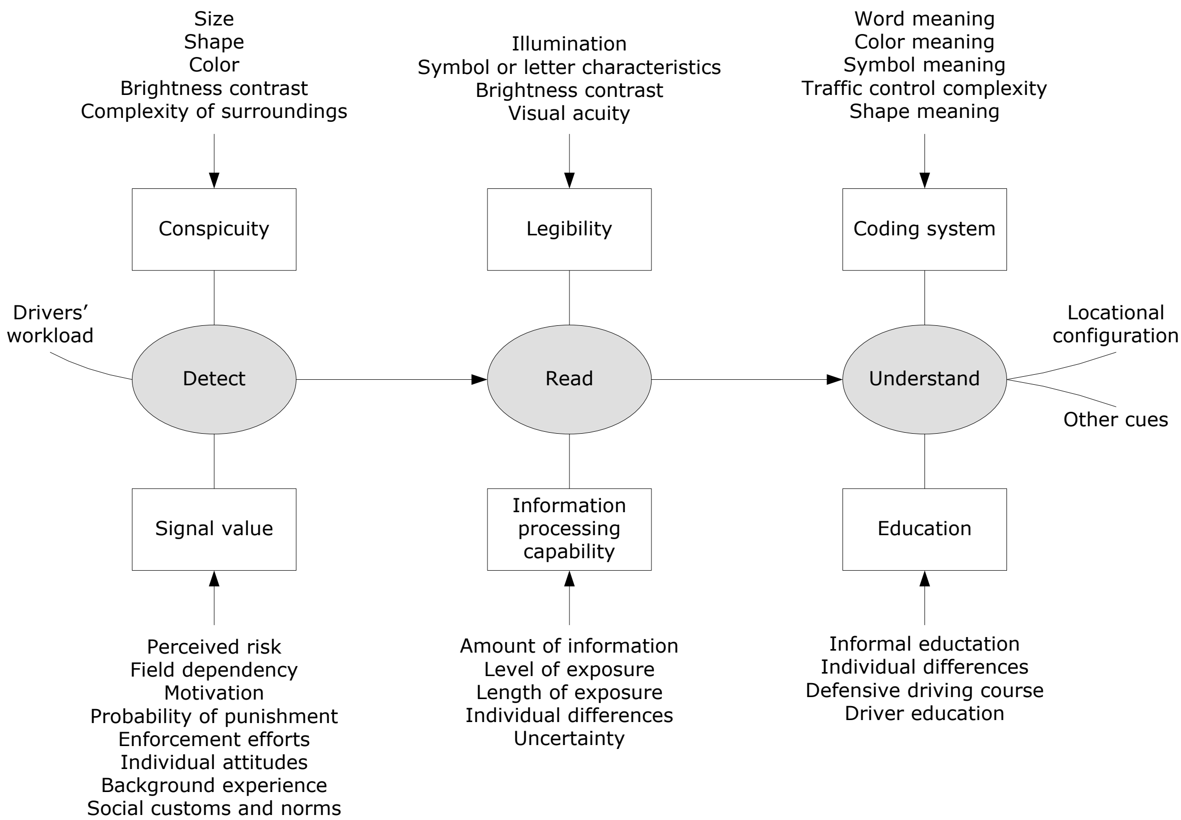

Figure 16 A model of traffic control device information processing
Source Gartner et al. (1992)

The stimuli which are originating from the speed signs are firstly detected by the driver. This detection process depends on the conspicuity and the signal value of the sign which at their part are determined by several other factors. As already stated in paragraph 3.1.3A is the distribution of the eye fixations determined by the object and search conspicuity. Speed signs, which are important for every driver, should have high object conspicuity because the design has to attract the driver's attention. Signs which only have to attract the attention of drivers who are searching for orientation, such as route guidance signs, need only search conspicuity (Martens, 2000). The signs which border the built-up area (F1 and F3) (see Figure 1) are characterized by the huge contrast between the white background, the black inscriptions and the red line[3]. This color combination is also used in the traditional round speed signs with a red border, white background and back number which indicate the speed limit in kilometers per hour. In spite of these color contrasts, research of Hughes and Cole (1984) and Shinar and Drory (1983) (in Charlton & O'Brien, 2002) show that only 1 in 10 traffic signs are noticed by drivers. However, a total of 15% to 20% of the driver's attentional capacity is consumed by traffic signs and other traffic control devices (Hughes & Cole, 1986) (in Charlton & O'Brien, 2002).

When the speed sign is detected by the driver, it has to be read. The readability of the sign and the information processing capabilities of the driver are the most important factor for this reading process. The last step in the information processing of speed signs is the understanding which is determined by the coding system of the signs and the education of the driver. The signs F1 and F3 contain a lot of import information about the following road segments. First, the driver should recognize the buildings on the sign with indicate the beginning of a built-up area. In a second step the driver should understand that he has to make some behavioral adaptations including an increase of the driver's attention level and obeying the speed limit of 50 km/h. It is very important that the driver understands the speed limit because the sign F1 indicate the beginning of a zone with a speed limit of 50 km/h. The speed limit is thus not repeated after each intersection. Once a driver missed the sign F1, he can be in a state of suspense which does not improve the road safety. In ideal circumstances, the driver however has to 'feel' which behavior – thus also speed behavior – is expected from him.

3.3.3 Speed treatments at the rural-urban threshold

Many drivers find it difficult to slow down from the higher speed on an open rural road to a lower speed of 50 km/u when entering a built-up area. The deceleration maneuver is common at this rural-urban threshold and it becomes a problem when visual cues induce drivers to underestimate their speed which results in a failure to decelerate to an appropriate speed. Gate constructions in the connecting area of a thoroughfare try to combat this speeding problem. Several studies show however that the effectiveness of such rural-urban threshold treatments seem to be variable (e.g.Charlton & O'Brien, 2002; Lamberti et al., 2009). According to the Department of Transport (2005) (in

[3] The red line is only present at sign F3 which marks the end of the built-up area.

Lamberti et al., 2009) can gateways be particularly effective when (a) speeds when approaching small villages are high and (b) city centers where the beginning point of the built-up area is not clearly recognizable. Detailed figures about the effectiveness of gate constructions are shown in Annex 2.

Charlton and O'Brien (2002) discuss three interpretation of the best method of rural-urban threshold treatments to achieve the goal of slowing drivers down. The first method is the enhancing of the attention-capturing capability of the speed sign. Common sense would suggest that the introduction of larger speed signs will increase the search conspicuity. This should result in a speed deceleration because the driver's attention is attracted by the sign. The counteraction to speed adaption via an increase in the structure and complexity of the visual environment is a second method (Weller et al., 2006). The last method is the creation of driver intimidation which will slow the driver down. When they feel threatened in a driving situation, they will rely more on sensory input to perceive and maintain their current speed (Fildes & Jarvis, 1994) (in Charlton & O'Brien, 2002). Oversized signs at the rural-urban threshold can slow drivers down via two ways. First, the signs provide a small but critical amount of angular velocity which increases the peripheral information. Second, the intimidation of the oversized signs forces drivers to estimate their speed to rely only on sensory input which creates a perceptual situation.

In this study one type of gate construction is applied (see paragraph 5.3.2). In addition to the normal signs which indicate the entrance and exit of the built-up area (F1 and F3), gates which create a lateral displacement of the vehicle are installed. The three interpretations of Charlton and O'Brien (2002) can be applied in some way to this kind of gate construction. The LTM of the driver reminds him of the common combination of a gate construction with the signs F1 and F3. Furthermore, the gate constructions increase the structure and complexity of the environment significantly and drivers get intimidated of the deviant road design. It is thus suggested that gate constructions accomplish the desired speed reduction at the entrance of a built-up area.

Chapter 4 HYPOTHESES

On the basis of the literature study above detailed research questions with corresponding hypotheses can be formulated. It is important to keep the general research assignment of this study in mind to define the optimum research questions which will be answered via the driving simulator study.

Examine the influence of the curviness of a thoroughfare and the presence or absence of gate constructions on the attention level and the speed in that thoroughfare by means of a driving simulator.

4.1 Dependent and independent variables

From the research assignment it can be deduced that this driving simulator study explores the relationship between different thoroughfare configurations (independent variables) and the driving behavior (dependent variables). The curviness of a thoroughfare (straight or curved) and the presence or absence of gate constructions are the independent variables. This results in four combinations of independent variables. According to the Flemish thoroughfare policy the attention level and the speed as dependent variables are influenced by the independent variables.

Table 1 Dependant (in italic) and independent (in bold) variables

		Gate constructions	
		Absent	**Present**
Curviness of a thoroughfare	**Straight**	*Attention level* *Speed*	*Attention level* *Speed*
	Curved	*Attention level* *Speed*	*Attention level* *Speed*

These dependent and independent variables form the basis for the detailed research questions which are answered in the driving simulator study.

- Do gate constructions influence the speed in a thoroughfare?
- Do gate constructions influence the attention level in a thoroughfare?
- Does the curviness of a thoroughfare influence the speed in a thoroughfare?
- Does the curviness of a thoroughfare influence the attention level in a thoroughfare?

Before addressing the hypotheses which will be examined in the driving simulator study the knowledge of the literature study is applied on the curviness and the absence and presence of gate constructions.

4.2 Influence of gate constructions on the attention level and the speed

Gate constructions play a very important role in the behavioral adaptations of a driver at the entrance and the exit of the thoroughfare. In this paragraph the influence of the absence and presence of gate constructions is discussed. Because the driving behavior after the exit gate – thus outside the built-up area – does not influence the road safety inside the thoroughfare the focus of this study is on the entrance gate.

4.2.1 Thoroughfare without gate constructions

In the case of a thoroughfare without gate constructions the driver can derive from the signs F1 and F3 and the changing environment that he is approaching or leaving a thoroughfare. By fixating visual attention on the environment and the sign the driver recognizes a thoroughfare with a speed limit of 50 kph in his LTM and knows that he can expect a complex thoroughfare. The driver than realizes that he has to adapt his driving behavior by lowering speed and increasing the attention level.

The chosen driving speed in the thoroughfare however depends largely on the habits, motives and attitudes of the driver which are quasi impossible to change by road infrastructure (see paragraph 3.3.2). When a driver decides – on the basis of the processed stimuli – to reduce his speed the resulting speed reduction will be less than the driver thinks. This is the result of the speed adaption which is set up in the monotonous outside area. The insufficient speed reduction results in a fast moving information stream which can result in an overload of the driver's attention capacity and end in a road accident.

In addition, highway hypnosis – caused by the monotonous road outside the built-up area – diminishes the driver's attention level dramatically (see paragraph 3.2.4). The restricted size and object conspicuity of the signs F1 and F3 in combination with the low attention level make it difficult for the driver to perceive the signs which contain very important information for the driver. Besides, Flemish roads are characterized by ribbon building before, after and even between built-up areas. This diminishes much of the stimuli of the changing environment between outside and inside the built-up area and creates a lack of driver intimidation (see paragraph 3.3.3). This complication can only partially be compensated by the driver's internally searching behavior to the sign F1. He knows by experience that a thoroughfare in Flanders is often preceded by ribbon building. The adaptations of the attention level and the speed are shown in Figure 17 and Figure 19.

4.2.2 Thoroughfare with gate constructions

As discussed in paragraph 3.3.3 gate constructions are applied to accentuate the link between the centre area and the outside area and therefore increase the readability of the road. The visual stimuli of the signs F1 and F3 and the changing environment between the monotonous road outside the built-up area and the complex thoroughfare are still present but are supported by a gate construction.

Gate constructions provide the driver both with visual and physical stimuli that it is necessary to reduce his speed and increase his attention level. These behavioral adaptations are in a first place necessary to pass the complex gate construction safely. It should be noted that gate constructions are complex obstacles in the road environment but the manageable complexity does not endanger the road safety at the gate construction. This complexity however intimidates the driver who will decrease his speed. In addition, the speed reduction is largely the result of the lateral g-forces in the gate construction which feel uncomfortable and unsafe at high speeds. The speed reduction solves thus the problem of the speed adaptation which is set up in the monotonous outside area. These behavioral adaptations are irrespective of the absence or presence of ribbon building.

Initially the immediate behavioral adaptations at the gate seem to have little influence on the road safety inside the built-up area but still they play an important role. On the one hand the gate construction in combination with the sign F1 should make clear to the driver that the speed limit is diminished to 50 kph. The driver does not increase his diminished speed again after the gate construction. A consistent road environment for that speed limit and additional speed measures should advise the driver not to speed up again. On the other hand the gate construction in combination with the changing environment should generate the expectations that the driver approach a thoroughfare. The driver does not decrease his increased attention level to be prepared for the increased environment demand in the complex thoroughfare. This creates an equilibrium in the road environment between the predictability (the driver knows he is approaching a complex road environment) and the stimulating influence of the unknown (the driver does not know which situations he may expect). Complexity and rhythm in the road environment should maintain the increased attention level and the reduced speed. The adaptations of the attention level and the speed are shown in Figure 18 and Figure 20.

4.3 Influence of the curviness of a thoroughfare on the attention level and the speed

According to Van Hout and T. Brijs (2008) influences the curviness of a thoroughfare the road safety in that thoroughfare. Hypotheses about these influences are provided below.

4.3.1 Straight thoroughfare

The open perspective of a straight thoroughfare enables the driver to look far ahead and to observe the approaching traffic situation very well. The expectations about the route are quasi the same as what the driver perceives so a large processing time is available. The gap between the attention level and the environmental demands is thus very small. This can result in an overload of the driver's attention capacity and end in a road accident when suddenly an unexpected situation occurs.

The driver can oppose the weakening of the attention level by speeding up. The resulting faster information stream encourages the driver to increase his attention level. The higher speed however shortens the information processing time which can lead up to an overload resulting in an accident. Moreover, a driver has hardly a reason to increase his attention level when gate constructions and ribbon building are absent. In addition, the speed adaptation will not be interrupted. Gate constructions can induce a speed reduction and an increase of the attention level but additional speed measures in the thoroughfare are needed to prevent speeding up and a lowering of the attention level. The adaptations of the attention level and the speed are shown in Figure 17 and Figure 18.

4.3.2 Curved thoroughfare

The closed perspective in a curved thoroughfare makes it impossible for the driver to look far ahead. The driver does not know very well what he may expect because the environment provides him with little information. To cope with this uncertainty the driver increases his attention level and decreases his speed. The speed reduction lengthens the limited processing time through which the driver does not have to raise his attention level to the extreme. Moreover, the reaction time and braking distance is reduced.

Despite the fact that curves increase the attention level and reduce the speed of the driver, curves can create dangerous situations. The attention level is still very low when a driver approaches the first curve in a thoroughfare without gate constructions. In addition, speed adaptation results in/causes a higher speed than expected. Road safety get thus into danger when the first curves comes as a surprise. The desired speed reduction and increase of the attention level remain thus absent until the first curve. Afterwards the behavioral adaptations are maintained throughout the thoroughfare. The first curve has thus the same influence on the driving behavior as a gate construction. The disadvantage is however that the adaptations only occur in the thoroughfare itself and not before approaching the complex traffic situation. The road safety in the first curve can thus be improved by the construction of an entrance gate. Since a driver should have the change and time to process the road environment the design of the curves (e.g. radius, no complex situation in or just after the curve) has to prevent a capacity overload. The adaptations of the attention level and the speed are shown in Figure 19 and Figure 20.

4.4 Conclusion

4.4.1 Detailed research questions

On the basis of the application of the literature study on the curviness of a thoroughfare and the absence and presence of gate construction the research questions in paragraph 4.1 can be specified in detailed research questions which will be examined in three different analyses.

A. Do gate constructions influence the speed in a thoroughfare?
   1. Do gate constructions influence the absolute speed in a whole thoroughfare?
   2. Do gate constructions influence the speed change at the entrance of a thoroughfare?
   3. Do gate constructions influence the absolute speed throughout the thoroughfare?

B. Do gate constructions influence the attention level in a thoroughfare?
   1. Do gate constructions influence the attention level in a whole thoroughfare?

2. Do gate constructions influence the change of the attention level at the entrance of a thoroughfare?
3. Do gate constructions influence the attention level throughout the thoroughfare?

C. Does the curviness of a thoroughfare influence the speed in a thoroughfare?
   1. Does the curviness of a thoroughfare influence the absolute speed in a whole thoroughfare?
   2. Does the curviness of a thoroughfare influence the speed change at the entrance of a thoroughfare?
   3. Does the curviness of a thoroughfare influence the absolute speed throughout the thoroughfare?

D. Does the curviness of a thoroughfare influence the attention level in a thoroughfare?
   1. Does the curviness of a thoroughfare influence the attention level in a whole thoroughfare?
   2. Does the curviness of a thoroughfare influence the change of the attention level at the entrance of a thoroughfare?
   3. Does the curviness of a thoroughfare influence the attention level throughout the thoroughfare?

4.4.2 Hypotheses

The hypotheses below try to present answers that may be expected from the driving simulator study.

It is expected that the low attention level and the high speed of the monotonous road outside the built-up area make it difficult for the driver to properly decrease his speed and increase his attention level at the entrance of a thoroughfare where gates are absent. Gate constructions will increase the readability of the road by accentuation the link between the outside area and the centre area. It is expected that the intimidating effect of the gate construction and the lateral g-forces reduce the effect of speed adaptation which results in lower speeds after the entrance gate. In addition, the driver is prepared for the complex road environment in the thoroughfare and therefore increases his attention level. Speed may increase again and the attention level may decrease again when complexity, rhythm and additional speed measures are lacking in the thoroughfare.

The open perspective of a straight thoroughfare enables the driver to create very precise expectation about the approaching road environment whereby it is expected that the driver will maintain the low attention level of the monotonous outside area. In addition, the straight road perspective does not interrupt the speed adaptation which will result in a higher speed than estimated. The higher attention level and the lower speed induced by a gate construction will decrease along the way in a straight thoroughfare when no additional speed measures are present. A curved thoroughfare introduces complexity and rhythm in the road environment and it is expected that the driver increases his attention level and reduces his speed to cope with the unexpected road situation after a curve. These behavioral adaptations will be maintained throughout the thoroughfare. The road safety in the first curve of a thoroughfare may be improved by the construction of an entrance gate.

The central assumption in these hypotheses is the fact that the low workload and the high speed in the monotonous road environment outside the built-up area is in contrast with the high workload and the low speed in the complex environment of the thoroughfare. It is hypnotized that the curviness and the absence or presence of gate constructions influence the difference in workload and speed between outside and inside the built-up area.

These hypotheses are visualized in

Table 2 where the amount of arrows give an indication about the attention level and speed in a section of the route compared with the attention level and speed before that section. Vertical arrows upwards indicate an increase of the workload or speed level in the present road section compared to the previous one, whereas vertical arrows downwards represent a decrease and horizontal arrows indicate a maintenance of the previous workload or speed level. The colors represent the impact of these changes on traffic safety: red indicates a negative impact, yellow represent a limited positive impact whereas green stands for a positive impact on traffic safety. The sections are as follows:

- Whole thoroughfare compared with monotonous outside area
- After the entrance of the thoroughfare compared with before the entrance of the thoroughfare
- The road section before the middle of the thoroughfare compared with the road section after the middle of the thoroughfare

Table 2 Hypotheses about the attention level and the speed in different thoroughfare configurations

			Gate construction			
			Absent		**Present**	
		Analysis	Attention level	Speed	Attention level	Speed
Curviness of a thoroughfare	**Straight**	*Outside versus inside built-up area*	↑	↓	↑↑	↓↓
		Before versus after entrance	↑	↓	↑↑↑	↓↓↓
		Before versus after middle	↓	↑	↓	↑
	Curved	*Outside versus inside built-up area*	↑↑	↓↓	↑↑↑	↓↓↓
		Before versus after entrance	↑	↓	↑↑↑	↓↓↓
		Before versus after middle	→	→	→	→

Table 2 shows – according to the hypotheses – that a straight thoroughfare without gate constructions scores the least in terms of road safety. The opposite is however true for a curved thoroughfare with gate constructions. The other two thoroughfare configurations have a moderate score in terms of road safety. Nevertheless, they have a different influence in the different sections of a thoroughfare.

Finally, the behavioral adaptations in each thoroughfare configuration are shown. The model of Blumenthal illustrates the changes in the attention level of the driver whereas the speed changes are shown by trajectory in a tx-diagram. The angle of the trajectory to the horizontal axe defines the speed with a large (small) angle for a high (low) speed. The dotted lines outline the changes in the attention level and speed when suddenly a complex situation appears (for example a pedestrian crossing, slam open door).

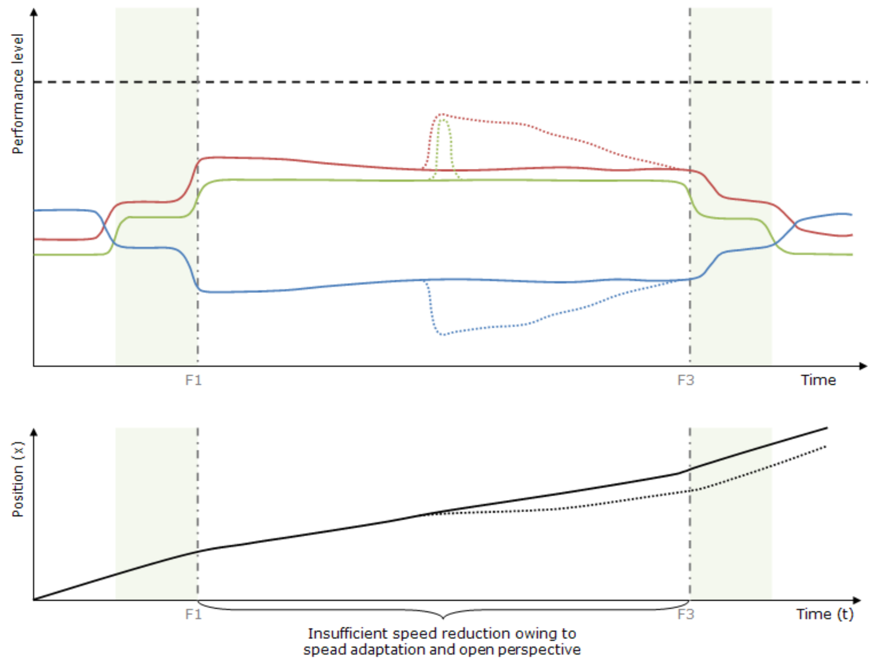

Figure 17 Adaptations of the attention level and speed in a straight thoroughfare without gate constructions

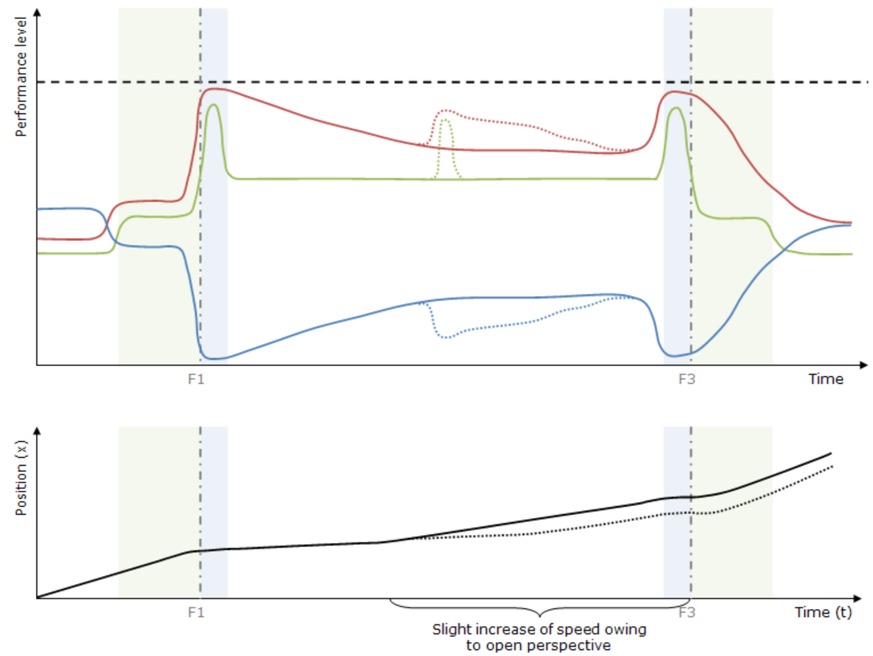

Figure 18 Adaptations of the attention level and speed in a straight thoroughfare with gate constructions

- Environmental demand
- Attention level for driving task
- Attention level for secondary non-driving tasks
- Environmental demand during and after a sudden complex situation
- Attention level for driving task during and after a sudden complex situation
- Attention level for secondary tasks during and after a sudden complex situation
- Limited capacity
- Trajectory
- Trajectory during and after a sudden complex situation
- Ribbon building before and after built-up area
- Gate constructions

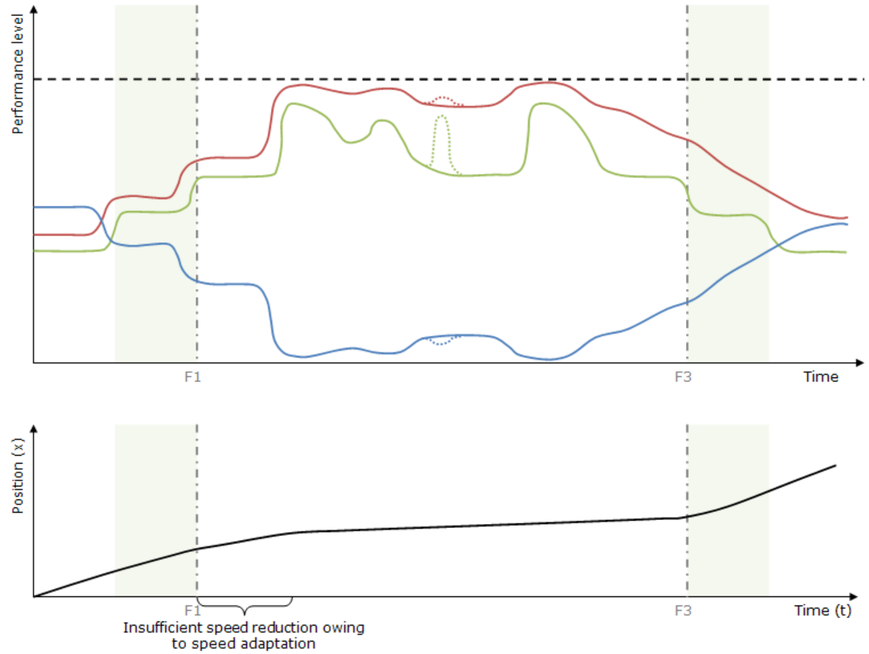

Figure 19 Adaptations of the attention level and speed in a curved thoroughfare without gate constructions

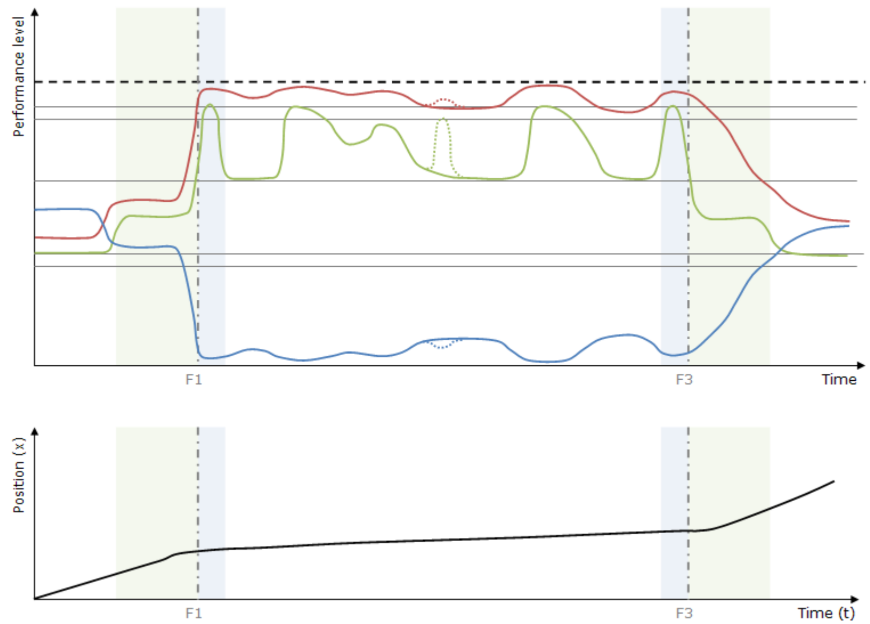

Figure 20 Adaptations of the attention level and speed in a curved thoroughfare with gate constructions

Environmental demand	Environmental demand during and after a sudden complex situation
Attention level for driving task	Attention level for driving task during and after a sudden complex situation
Attention level for secondary non-driving tasks	Attention level for secondary tasks during and after a sudden complex situation
Limited capacity	Ribbon building before and after built-up area
Trajectory	Gate constructions
Trajectory during and after a sudden complex situation	

Chapter 5 METHOD

In the PIAA-model is the second phase (*inform*) reached where the research plan is draw up and executed. Successively the participants, the driving simulator, the scenario design and the procedure are presented.

5.1 Participants

The driving simulator study involved 55 volunteers in a within-subject design. The advantage of a within-subject design is that individual differences are ruled out because each participant is exposed to all levels of the independent variables. This means however that the examination time per subject is long and that the different scenarios have to be presented in a counterbalanced order between subjects (Field, 2005). The participants were recruited via flyers, posters and email in schools and organizations and they gave all informed consent (see Annex 6).

In a first phase five participants were excluded: three subjects (one man and two women) discounted the experiment due to simulator sickness and two men exaggerated the speed limits seriously. The remaining 50 subjects were equally divided over five age categories (20-29, 30-39, 40-49, 50-59, 60 or older) and as many man as woman took part in each age category. Four subjects were defined as outliers in the analysis data (see paragraph 6.1.2). Thus 46 subjects remained in the sample. The overall mean age was 45.3 years with a standard deviation of 16 years. The average travel distance as driver per year was approximately 16 000 km with a standard deviation of 11 500 km. Annex 6 shows the mean and standard deviation of the age and travel distance per year for each age category.

5.2 Driving simulator

The experiment was conducted on a high-fidelity driving simulator (STISIM M400) which is fixed-based (drivers do not get kinesthetic feedback) with a force-feedback steering wheel, brake pedal, and accelerator. The simulation includes vehicle dynamics, visual and auditory feedback and a performance measurement system. The visual virtual environment was presented on a large 180° field of view seamless curved screen, with rear view and side-view mirror images. The sounds of traffic in the environment and of the participant's car were presented. The projection screen offered a resolution of 1024 × 768 pixels on each screen and a 60 Hz refresh rate. Data about the driving performance and the secondary task were collected at frame rate (K. Brijs, Jongen, Wets, & T. Brijs, 2009).

Figure 21 IMOB-driving simulator on the basis of the STISIM Drive™-technology

The main advantages and disadvantages of driving simulator studies are described by Nilsson (1993) (in Godley, 1999) and are shortly enumerated. Experimental control is the main advantage in a driving simulator experiment since the researcher has total control over the independent variables and the environmental conditions. In addition, a driving simulator study is safe and cost efficient. Data can be collected very easy and new (technological) developments can be evaluated. The disadvantages associated with driving simulator studies are the physical limitations and realism of the driving simulator, the possibility of simulator sickness and the validity of the driving simulator. Törnros (1998) (in Godley, 1999) stated that relative validity is necessary in a driving simulator study whereas absolute validity is not essential.

5.3 Scenario design

The scenario design is one of the most important issues in a driving simulator study because all the knowledge of the literature study has to be integrated in the appropriate way to formulate an answer on the research questions. Besides, creative solutions have to be found to solve the limitations of the experiment such as the restricted time per participant and the technical limitations of the driving simulator. In the first paragraph, the used parameters are described after which the scenario is presented in the second paragraph.

5.3.1 Description of the parameters

The logged parameters of the driving simulator should give an answer on the research questions stated in paragraph 4.4.1. It is thus important that the two dependant variables, speed and attention level, are measured.

A. <u>Parameters for speed</u>

The speed is constantly logged during each drive. The **mean speed [kph]** describes the absolute speed whereas the **standard deviation of the acceleration and deceleration [m/s²]** reports the variations in these accelerations and decelerations. On the basis of these parameters the research questions A and C (see paragraph 4.4.1) will be answered.

B. <u>Parameters for attention level</u>

The attention level can be measured by a variety of methods (see paragraph 3.2.5). Because it is recommended to combine different methods to measure the attention level primary and secondary task performance measures are used. The analyses of these parameters will provide an answer on the research question B and D (see paragraph 4.4.1). It is however important to note that this multidimensionality of the assessment of attention can cause dissociation between measures of different categories (de Waard, 1996).

The used **driving performance measures** can be divided in longitudinal control measures and lateral control measures:

- Longitudinal control
    - Mean speed [kph]
- Lateral control
    - Standard deviation lateral position [m]
    - Mean SWM frequency of larger SWM[4] [number of SWM/s]

The parameters for speed are thus both used for the assessment of speed and the attention level. All these measure are quasi immediately derived from the logged data

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[4] Matthews and Desmond (2002) divide the SWM in three categories according to the size of the angle: small: < 2°, large: >= 2° and < 10° and extreme: >= 10°. Thiffault and Bergeron (2003) on the other hand make the following three categories: small: 1-5°, large: 6-10° and extreme: >10°. Because the scenario of this study contains a lot of straight road segments, this categorization of Matthews and Desmond (2002) is used.

except from the mean steering wheel movements frequency (SWM FREQ). The computation of this parameter is shown in Annex 7. The interpretation of these measures in relation with the attention level is described in paragraph 3.2.5A.

The secondary task measures are based on the **peripheral detection task (PDT)**. This detection task was developed by Miura (Miura, 1986, 1990) and Williams (1985, 1995) and modified by van Winsum, Martens and Herland (1999) (in Jahn et al., 2005; Regan et al., 2009). The key idea behind the PDT was the examination of the narrowing of the visual field when task demand increases. Despite the discussion that this narrowing is the result of visual or cognitive tunneling the sensitivity of the PDT to changes in demands of the driving task was shown in driving (simulator) studies (e.g. Burns, Knabe, & Tevell, 2000; Crundall & Underwood, 1998; Harms & Patten, 2003; Nakayama, Futami, Nakamura, & Boer, 1999; Olsson & Burns, 2000) (in Jahn et al., 2005; Martens & van Winsum, 2000; Patten et al., 2006; Patten et al., 2004).

The PDT involves responding as soon as possible to a visual stimulus that is presented in the upper-left visual field. Patten et al. (2006; 2004) and Jahn et al.(2005) project red light emitting diodes (LED) on the windscreen whereas Martens and van Winsum (2000) present small red squares on the simulator screen. The random presentation of the stimuli ranges between 5° and 25° to the left of the centre of the steering wheel and approximately 2 to 5° above the horizon. In general, the stimuli are presented within an interval that varied random between 3 and 5 seconds. As reaction action the driver has to press a microswith that is attached to the index finger of the dominant hand (Jahn et al., 2005; Martens & van Winsum, 2000; Patten et al., 2006; Patten et al., 2004; Regan et al., 2009). A training session where the subject practices the PDT is recommended by Regan et al. (2009).

In this study the setting from Martens and van Winsum (2000) were partial adopted. A red small square appeared randomly on the screen of the driving simulator in the area of 11 to 23° to the left of the centre of the steering wheel and 2 to 4° above the horizon. The red square could appear at six possible locations in this area. A black bar as large as this area was also presented on the screen to avoid invisibility of the red square against the background. This black bar was present throughout the whole road segment where the PDT should be performed. Due to practical constraints of the driving simulator and the scenario, the stimuli were presented with random variation between 4 and 6 seconds. Because the stimuli were programmed in intervals based on distance, the variation between 4 and 6 seconds was only achieved when the driver drove at approximately the speed limit. Driving slower than the speed limit increases the interval between stimuli whereas driving faster decreases the interval. The drivers had to respond to the red squares by pressing the horn with the left thumb. It was instructed to place the left hand during the whole drive in the driving simulator – thus also when the PDT should not be performed – on the horn so variations between drivers without and with PDT were minimized. The right hand was thus still available to change gear and to operate the steering wheel.

Figure 22 Position of the PDT stimuli

As discussed in paragraph 3.2.5B the instruction about the priority of the different tasks determines the way of measuring the attention level. In this experiment the driver got the following PDT-instruction:

"The driving task has priority and may not be affected by the secondary task."

The PDT is thus the subsidiary task and the performance of this task reflects changes in resource demand for the primary driving task. Patten et al. (2006; 2004) and Jahn et al. (2005) used the same priority levels for the primary driving task and the secondary PDT. This is however only the case when drivers comply with the PDT-instructions and the driving performance is not affected by the PDT. It is assumed that drivers obey the PDT-instruction through which their driving performance level is not influenced by the presence or absence of the PDT. When drivers disobey the PDT-instruction, it is expected that when PDT is present the driving performance measures are influenced in the same direction as when task demands increase (see paragraph 3.2.5A). Despite that Patten et al. (2006; 2004) and Jahn et al. (2005) did not examine the influence of the PDT on the driving performance this assumption will be evaluated in paragraph 8.1. The performances of the PDT are expressed in the **mean response time [ms]** and the **mean hit rate [% correct responses]** (see paragraph 3.2.5B).

The choice for the PDT as secondary task is based on a variety of reasons. Because the within-subject design makes it mandatory to expose all the participants to each level of any independent variable, the time per level of independent variable per participant is limited. To collect a sufficient amount of responses for the statistical analyses, a response on each stimulus is necessary. The usage of a go and no-go task is therefore ruled out because more response data can be collected over the same distance when a detection or discrete choice task is used (see paragraph 3.2.5B). Based on Wicken's cube model (see paragraph 0) a visual secondary task is preferable because this low-priority secondary task (see PDT-instruction above) reflects the workload induced by the high-priority driving task when both tasks uses the same level of a dimension in the cube model. Given the dual task paradigm (see paragraph 3.2.5B) it is easier to observe the instruction with a detection task in comparison with a discrete choice task because during this last method the driver has to make a choice which response is correct. Moreover, Regan et al. (2009) and Jahn et al. (2005) suggest that the driving performance is hardly obstructed by the PDT. The continuousness of the PDT makes it possible to signalize short peaks of workload that may be missed by methods that use larger intervals between stimuli (Jahn et al., 2005; Regan et al., 2009).

5.3.2 Description of the scenario

The experimental drive had a total length of 34 km and the weather was sunny and dry. Following a 2 (curviness: curved, straight) by 2 (gate constructions: present, absent) by 2 (PDT: with, without) within-subjects design, 4 different thoroughfares were presented twice: once with and once without the secondary peripheral detection task. The codes and descriptions of the eight different thoroughfare configurations are shown in Table 3.

Table 3 Codes and descriptions of the different thoroughfare configurations

Code	Description	Code	Description
1 C-G-PDT-	Straight thoroughfare without gate constructions without PDT	101 C-G-PDT+	Straight thoroughfare without gate constructions with PDT
2 C-G+PDT-	Straight thoroughfare with gate constructions without PDT	102 C-G+PDT+	Straight thoroughfare with gate constructions with PDT
3 C+G-PDT-	Curved thoroughfare without gate constructions without PDT	103 C+G-PDT+	Curved thoroughfare without gate constructions with PDT
4 C+G+PDT-	Curved thoroughfare with gate constructions without PDT	104 C+G+PDT+	Curved thoroughfare with gate constructions with PDT

Each thoroughfare had a length of 1270 m and was bordered by the signs F1 and F3 (see Figure 1). The speed limit of 50 kph was thus in force. To create the perception that the driver was driving in 4 different thoroughfares 4 different F1 and F3 signs were placed at the border of the built-up area. Besides these signs the road environment gave also an indication of the type of area the driver drove. The ribbon building, which was present 200 m before and after the thoroughfare, was turned into contiguous buildings inside the built-up area. Another environmental element that changed at the border of the thoroughfare was the light poles which had an industrial character outside the built-up area and a romantic character in the thoroughfare.

A long straight road segment between two thoroughfares functioned to decrease the level of attention and create speed adaptation. The speed limit on this road segment was lay down at 70 kph and was indicated by the sign C43. The monotonous road environment with fields was occasionally alternated with a stretch of forest and had a length of 2930 m. In conclusion, one experimental road segment had thus a length of 4200 m of which 1270 m inside the built-up area and 2930 m outside the built-up area. The first straight road segment in the experimental drive was preceded by a 400 m long starting segment where drivers had the possibility to accelerate to their desired speed.

Four curves were present in a curved thoroughfare: a first curve of 30° to the right, followed by two curves of 40° to the left and the last curve was again 30° to the right. In each thoroughfare configuration (both straight and curves) a curve of 20° was located 300 m before and after the thoroughfare, thus 100 m before and after the ribbon building. Because the effectiveness of the absence and presence of gate construction is investigated and not the effectiveness of different types of gate construction, one type of gate construction is used in the whole experiment. According to CROW (2008) is a gate construction with non-parallel axis displacement and central reservation the best alternative beside a roundabout and a parallel axis displacement (see Figure 23). The gate constructions had a length of approximately 30 m and were located just after and just before the signs F1 and F3 respectively. Bushes and yellow poles are placed on the central reservation to highlight the gate construction.

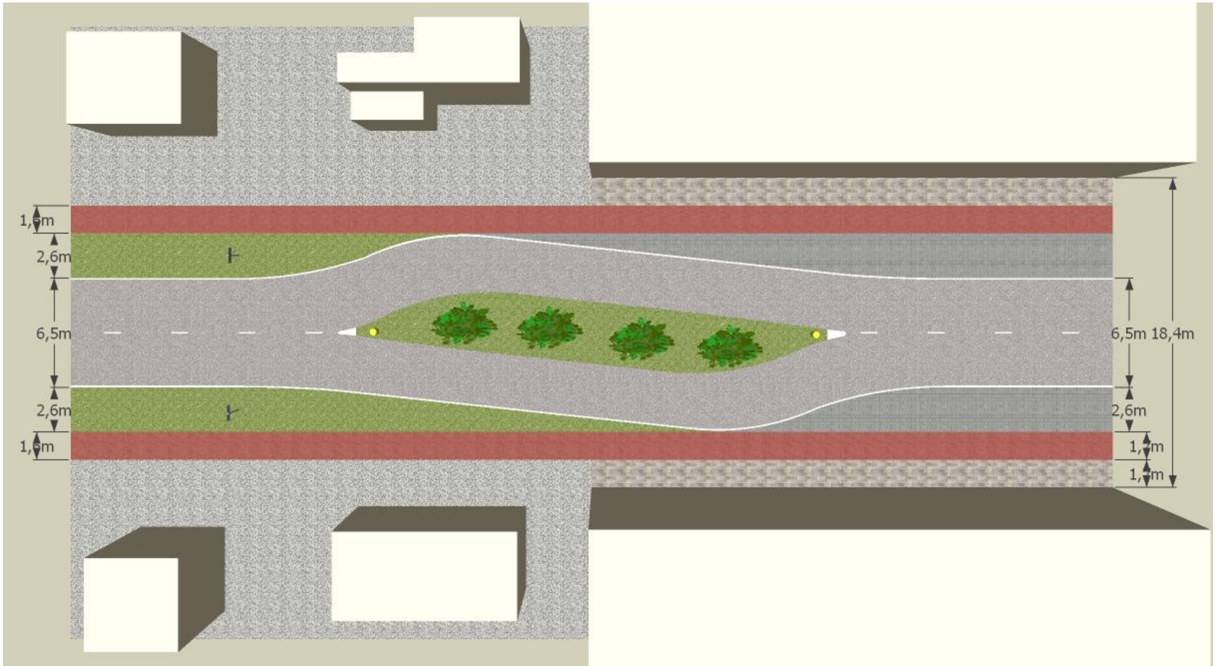

Figure 23 Applied gate construction with non-parallel axis displacement and central reservation

In the sections where the PDT should be performed 24 stimuli were presented outside the built-up area of which 18 were used in the analyses and 18 stimuli were presented in the thoroughfare. The six different presentation locations for the stimuli were each called six times in the 32 stimuli which are included in the analyses. There was sought that the stimuli were not present just before the entrance of the built-up area or in a gate construction to avoid a seriously visual overload in the gate construction.

The road was divided in two lanes with one lane for each travel direction. The cycle lanes were separated from the traffic lanes by a green strip outside the built-up area and by a parking lane inside the built-up area. At intersections the separated cycle lanes turned into adjacent lanes. Footpaths were only present inside the built-up areas and nine zebra crossings were situated in the thoroughfare: two at each intersection and one in the middle of the thoroughfare at the towers. Four intersections were present inside the built-up area but drivers had right of way over these side streets because the intersections were preceded by the signs B15a, B15c and B15f. Outside the built-up area the priority was indicated by the sign B9 (see Annex 8). This shift was based on the priority schemes in Flemish practical examples. Due to limitations of the driving simulator the church – as landmark in a thoroughfare – was replaced by two towers which raise high above the other buildings in the thoroughfare.

The traffic flow in the thoroughfare was based on the measurements of Van Hout and Brijs (2008) with 320 vehicles per hour in each travel direction of which 10.3% lorry traffic. To avoid driver distraction of other traffic in his drive direction no vehicles in front or in the back were present. The bicyclists flow was recorded at 13 cyclists per hour in each travel direction. Pedestrians were randomly located on the footpaths and none of them crossed the main road.

The whole scenario of one monotonous road segment followed by a thoroughfare is shown in Annex 9. It has to be emphasized that in this experimental design only the levels of the independent variables (straight or curved and gate construction absent or present) and the absence or presence of the PDT were changed over the different thoroughfare configurations. The other traffic and environmental elements remained the same.

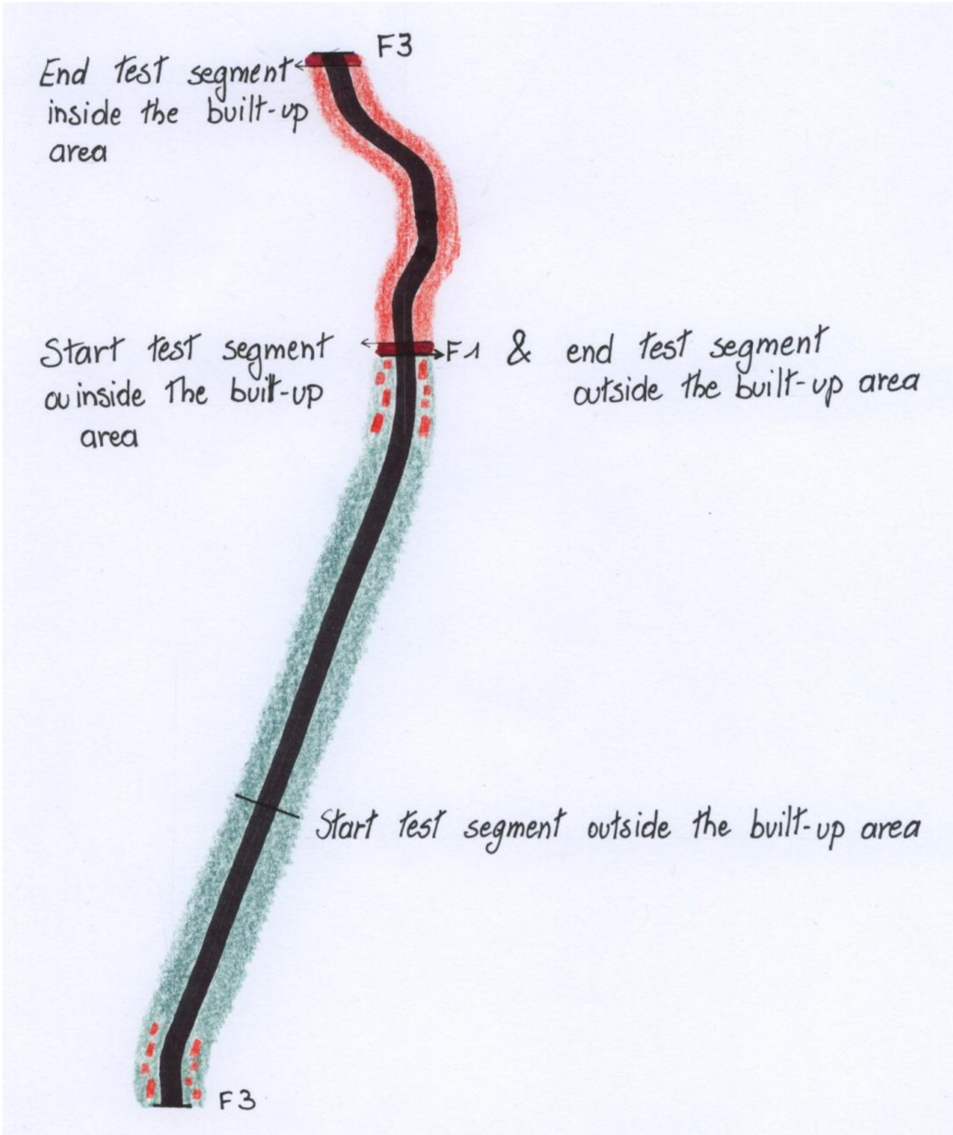

Figure 24 Sketch of the driving simulator scenario for a curved thoroughfare with gate constructiong

5.4 Procedure

Before starting the experiment the participants were asked to wait in a waiting room and to go through a consent form and to fill it in (see Annex 6). After that they were accompanied to the driving simulator room where the researcher shows the participant round the driving simulator. Once the participant sat down comfortably in the driving simulator car a presentation was started. With the assistance of this presentation the whole experiment was completed.

In the first part of the presentation the participant got acquainted with the driving simulator by showing all control elements of the simulator car. Afterwards, the general instructions of the experiment were explained. These instructions involved that the participant should behave as he normally would behave in traffic and that the participant should follow the road. In addition, the way of holding the steering wheel was explained.

Once the participant understood the instructions very well he got the possibility to make two training drives. The first training drive had a length of 2.4 km and consisted of one curved thoroughfare with gate constructions. To get the participant used on the driving simulator he was asked to stop approximately 200 m before the entrance of the built-up area and accelerate again. During the second training drive the participant got the possibility to further practice driving in the driving simulator but in addition, the PDT should be performed. This secondary task was thus explained in detail before the second training drive started. The instruction about the way of holding the steering wheel was repeated and the PDT-instruction (see paragraph 5.3.1B) was introduced and the importance of it was strongly emphasized. The PDT was omnipresent in the second training drive. The drive had a length of 4.4 km and consisted of one straight thoroughfare with gate constructions and one curved thoroughfare without gate constructions. In these training drives the monotonous road section outside the built-up area, with exception of the segments with ribbon building, were removed from the experimental road section. In addition, the thoroughfares were passed in the opposite direction than in the experimental drive to create the perception that the participant was driving in a different road environment. Each participant got thus the possibility to practice the driving simulator for approximately 8 minutes and the PDT for approximately 5 minutes. The participants were however not told that these two drives were practice drives.

Before the experimental drive started, the instructions were highlighted again. In the experimental drive of 34 km the 4 different thoroughfares were presented twice: once with and once without the secondary PDT. In the first half of the experimental drive the 4 different thoroughfare configuration got a chance of which two with and two without PDT. In the second half the other 4 thoroughfare configurations were passed. Moreover, the order of the different thoroughfare configurations was counterbalanced between the subjects via the Latin square design. One half of the participants started without PDT and the other half started with PDT and blocks of two thoroughfares without PDT are alternated with blocks of two thoroughfares with PDT. This alternation had to minimize the learning effects of the PDT (Wester et al., 2008). The assignment of the participants on the various orders of the different thoroughfares occurred randomly but each order is at least once passed in each age category. The various orders are shown in Table 4.

Table 4 Various orders of thoroughfare configuration in experimental drive

Order								
A	1	2	104	103	4	3	101	102
B	2	3	101	104	1	4	102	103
C	3	4	102	101	2	1	103	104
D	4	1	103	102	3	2	104	101
E	101	102	4	3	104	103	1	2
F	102	103	1	4	101	104	2	3
G	103	104	2	1	102	101	3	4
H	104	101	3	2	103	102	4	1

At the end of the experiment the participants were asked to answers some questions about the experiment such as: "Do you have an idea about the purpose of this experiment?" and "How do you perceive the red squares of the PDT, in the corner of your eye or do you have to turn your eyes to the stimuli?". Afterwards, the participants were tanked for their participation. When all drivers participated in the experiment, each participant got informed about the purpose of this driving simulator study by mail or letter. In Table 5 is an overview of the procedure of the experiment shown.

Table 5 Overview of procedure of experiment

Description activity	Duration [min]
Go through & fill in consent form	5
Show the participant round the driving simulator Presentation: - Show all control elements of the simulator car - General instructions of the experiment	5
First training drive: C+G-PDT-	3
Presentation: - Explain PDT with instructions	5
Second training drive: C-G+PDT+ & C+G+PDT+	5
Presentation: - Highlight instructions again	2
Experimental drive: 8 thoroughfare configurations	35
Subsequent discussion with some questions	5
TOTAL	*65*

Chapter 6 DATA ANLYSES

6.1 Preparing data

6.1.1 Data queries

The STISIM driving simulator registered the data for each participant in a .Dat file at frame rate. By transforming these files to an Access database, it was easy to define queries which result in the desired tables for the analysis in SPSS and Excel.

6.1.2 Outliers

Before the statistical analysis can be executed, outliers have to be eliminated. The method to label participants as an outlier differs between the measures about the PDT and the driver performance measures.

A. <u>Outliers in PDT measures</u>

To eliminate outliers in the PDT data, two steps have to be executed. In the first step, the response times below 150 ms and above 2000 ms were labeled as missers, too late or false alarms and as a result were excluded. It assumed that drivers who responded faster than 150 ms reacted accidentally without perceiving and processing the stimulus. The upper bound of the response time was set on 2000 ms because this value was common used for the PDT (Jahn et al., 2005; Patten et al., 2006; Patten et al., 2004). In the second step, the outliers were defined as the participants of who at least 12 response times were left, both inside and outside a thoroughfare. This means that a participant was not labeled as an outlier when its response time for 12 of the 18 stimuli (or 66.66%) (see paragraph 5.3.2) was between 150 and 2000 ms. In conclusion, for each participant, there were at least 12 valid response times in each analysis section, otherwise the participant was labeled as an outlier. The PDT data showed clearly that there was one significant outlier, namely participant 15 which is a 45 years old woman.

The mean response time for the 49 remaining participants was 664.81 ms with a standard deviation of 264.153. Figure 25 shows clearly the left skewed distribution around the mean response time.

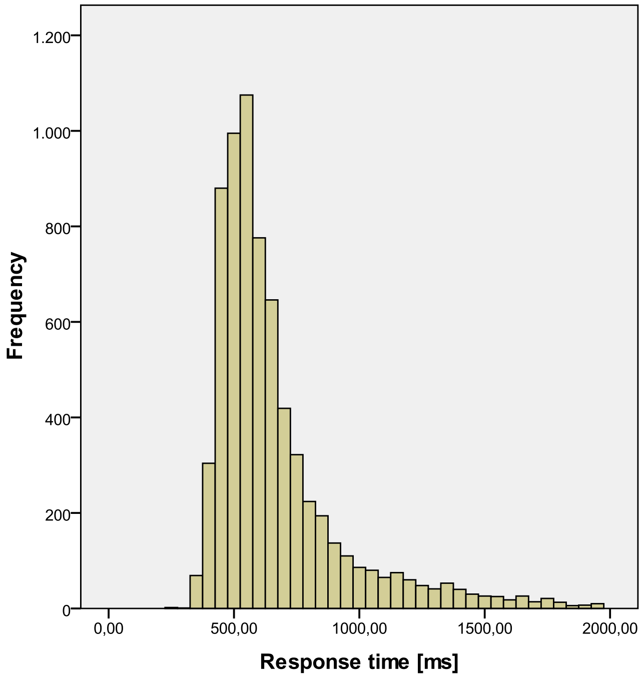

Figure 25 Histogram of response time between 150 and 2000 ms (n = 49 – participant 15 excluded)

B. *Outliers in driving performance measures*

The detection of outliers in the data about the driving performance measures was done on the basis of 16 box plots[5] for each parameter. Asterisks in a box plot showed the participants of which the parameter value exceeded three rimes the inter quartile distance. When a participant had 6 or more asterisks in 16 box plots of one parameter, it will be labeled as an outlier. The dots on a box plot indicate outliers between 1.5 and 3 inter quartile distances which will not be interpreted as an outlier in this study. Because participant 15 is a significant outlier for the PDT data, it will be excluded in the construction of box plots. The amount of asterisks per participant in the box plots per driving performance measure are shown in Annex 10. With the threshold of 6 or more asterisks per 16 box plots, participants 9 (man, 51 years), 44 (woman, 39 years) and 50 (woman, 44 years) are labeled as outliers.

C. *Conclusion*

These findings lead to the selection of 4 outliers whereby the data of 46 participants is used for the statistical analyses. A detailed description of the participants is given in paragraph 5.1.

[5] The design of 2 Curves x 2 Gates x 2 PDT x 2 Built-up area/Entrance/Middle gives 16 box plots.

6.2 Analysis method

Following a 2 (curviness: curved, straight) by 2 (gate constructions: absent, present) by 2 (PDT: with, without) within-subject design each participant drove through eight different thoroughfare configurations. To formulate an answer on the different research questions it is important to analyze the data of the road segments which were concerned in the research questions. The first research question refers to the whole road section inside the built-up area, whereas in the second research question emphasize on the area around the entrance of the thoroughfare. The focus in the last research question is on the evolution throughout the thoroughfare and emphasizes on the road sections before and after the middle of the thoroughfare. These three research questions were thus answered by three different analyses in which three factors Curves, Gates and PDT were always present and the fourth factor relied on the concerning road sections.

6.2.1 Division into road sections for each analysis

The test segments in each thoroughfare configuration were divided in a number of zones of the same length. The total length of the test segment is 3210 m of which 1940 m is lying outside the built-up area and 1270 m is situated inside the built-up area between the signs F1 and F3. The two gate constructions were part of the road segment inside the built-up area. The behavior in the gate constructions was not of the interest of this study whereby the road segments between F1 and the end of the entrance gate and between the beginning of the exit gate and F3 were excluded for each thoroughfare configuration, including the thoroughfares without gate constructions. In result, the test segment (1940 m outside the built-up area and 1164 m inside the built-up area) was divided in 32 zones of 97 m of which 20 zones (zone 1-20) were located outside in the built-up area and 12 zones (zone 21-32) were lying inside the built-up area. In the statistical analyses the parameters were averaged over a number of zones to examine the proposed hypotheses on the concerning road sections.

The exact start and end distance of each zone of 97 m and the concerning road sections for each analysis is shown in Figure 26. The visualization of the difference road sections in each analysis shows that there was some overlap between analysis 1 and analysis 3. A main or interaction effect with the factor Built-up area in analysis 1 had for the level 'inside the built-up area' the same value as in analysis 3 where no main or interaction effect of the factor Middle were present. Analysis 1 was however still performed because it had the opportunity to evaluate the assumption which deals with the contrast between the monotonous road environment outside the built-up area and the complex environment in a thoroughfare (see 4.4.2).

The analyses of the mean RT and mean hit rate were executed in the same way by assigning each stimulus data to a zone of 97 m. The interval of 4 to 6 seconds between two stimuli in combination with the driving speed result in an dissimilar distribution of the stimuli over the zones. Outside the built-up area some zone did not contain any stimulus whereas inside the built-up area some zone contained two stimuli. This inequality was however no problem for the analyses whereas in analysis 1 18 stimuli outside the built-up area and 18 stimuli inside the built-up area were averaged. In analysis 3 the first 9 stimuli in the built-up area were presented before the middle and the last 9 stimuli were presented after the middle. Analysis 2 is not executed for these two parameters because the analysis should only be based on three stimuli (one before the entrance and two after the entrance) which is not reliable.

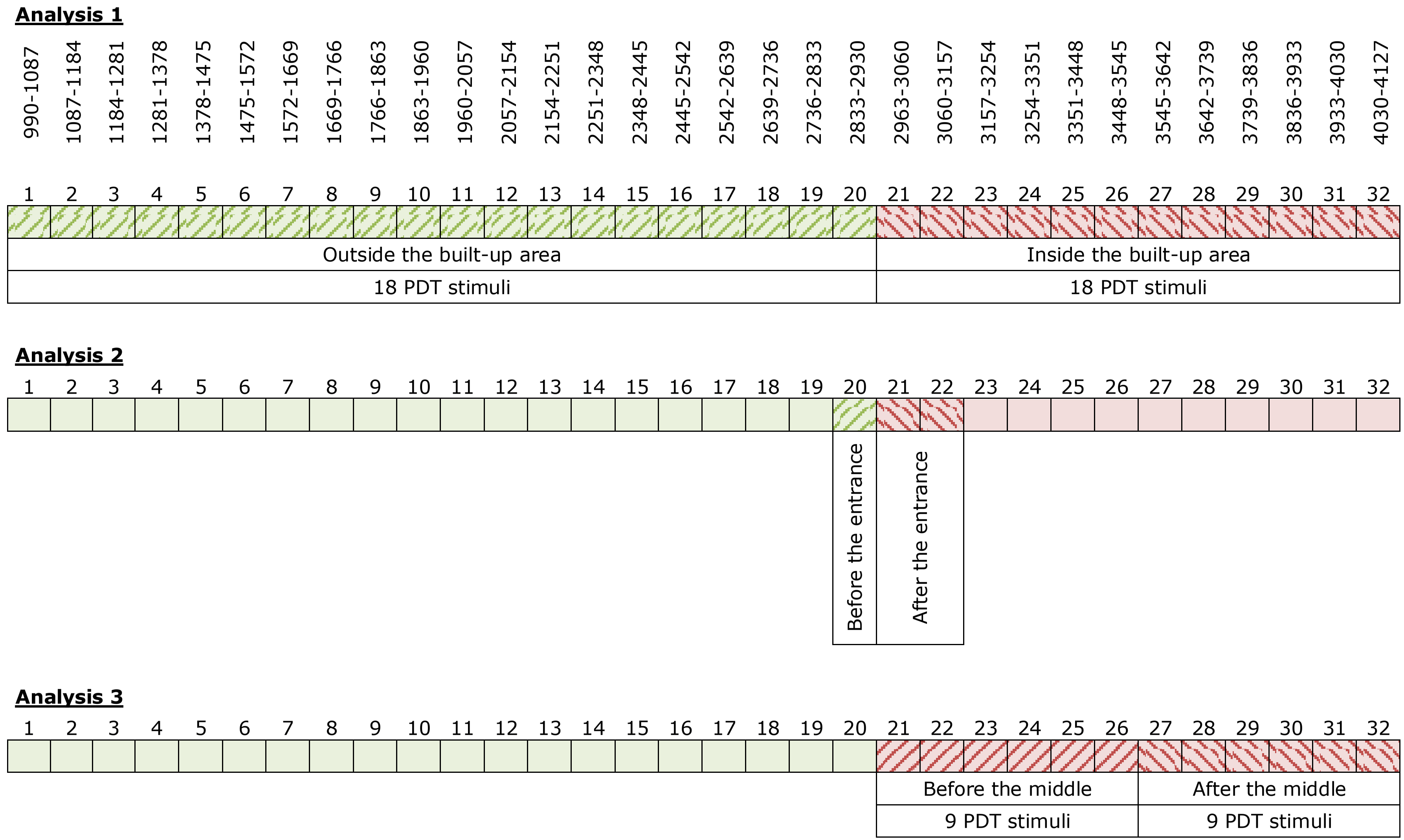

Figure 26 Division into road sections for each analysis based on 32 zone of 97 m

6.2.2 Statistical analyses

The parameter data of 46 subjects was analyzed by means of a repeated measures analysis of variance (ANOVA) in which four factors were included: Curves (no, yes), Gates (no, yes), PDT (no, yes) and a factor for the concerning road section (Built-up area: outside, inside / Entrance: before, after / Middle: before, after). The two-way interaction effects resulting from this repeated measures ANOVA were further analyzed by a Paired-Samples T Test. The three- and four-way interaction effects on the other hand were further examined in separate tests via repeated measures ANOVAs for each level of a factor of interest. These separate tests were repeated until only the main effect of interest remained. A significant two-way interaction in these separate test were therefore not analyzed by a Paired-Samples T Test. The significance level was established at 5% and, dependent on the used test, F- or t-values were described.

Chapter 7 RESULTS

Before showing the results of the statistical analyses it is recommended to first have a look at the parameter values in the zones of 97 m. This gives a representation of what can be expected from the statistical analyses. The description of each parameter for the three analyses is followed by a conclusion for that parameter.

7.1 Mean speed

7.1.1 Overview of mean speed in zones of 97 meter

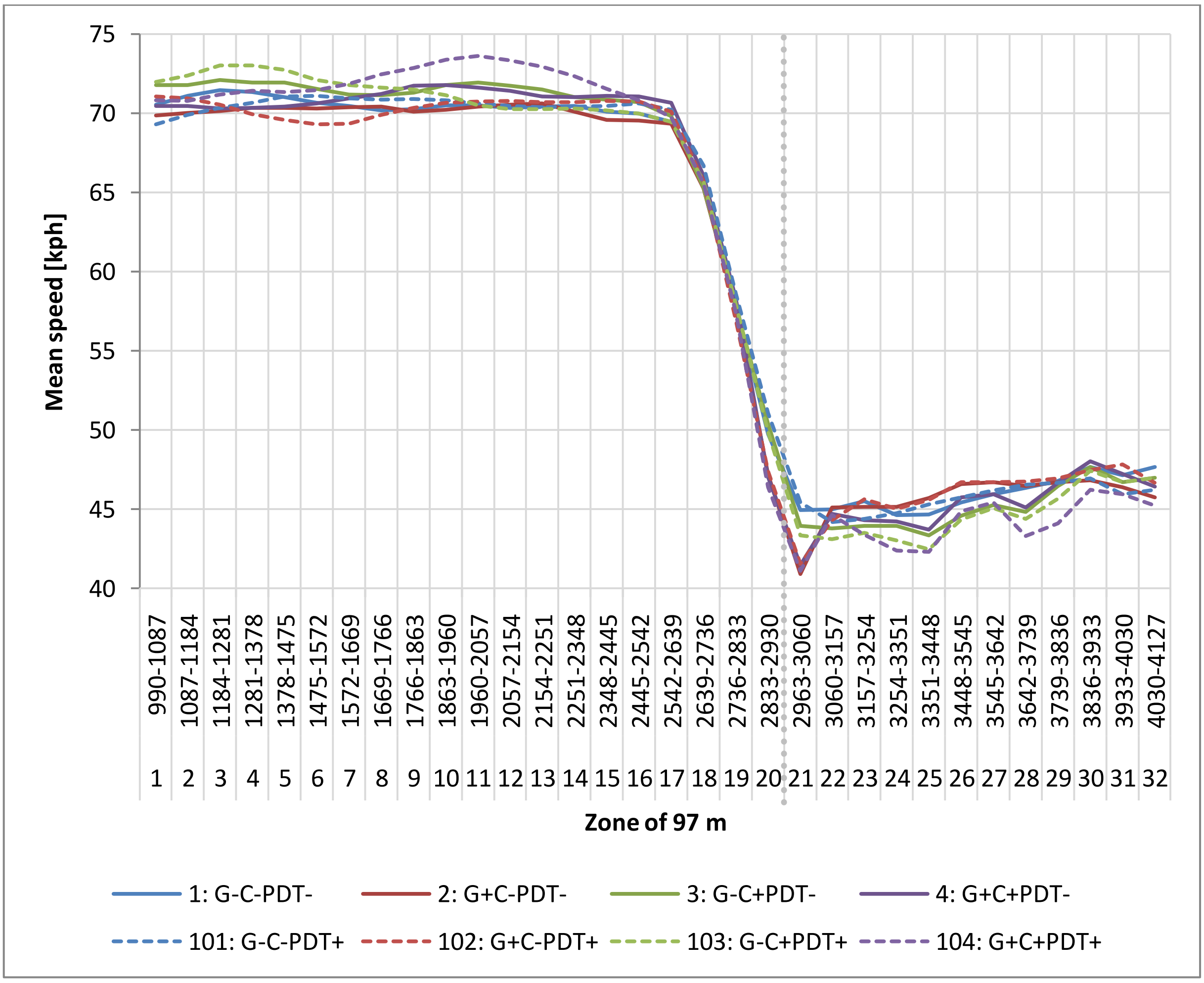

Figure 27 Mean speed per zone of 97 m (n = 46)

In all the thoroughfare configurations the mean speed outside the built-up lies around the speed limit of 70 km/h. Still, the speed limit is exceeded in some instances. About

300 m (zone nr 17[6]) before the built-up area mean speeds decrease constantly from about 70 km/h to approximately 40 to 45 km/h after the entrance of the built-up area (zone nr 21). This speed decrease is expected, because drivers slow down before entering the curve at 200 m before the built-up area (zone nr 17-18). The ribbon building and the entrance of the built-up area that is visible already in the distance stimulated the driver to continue slowing down.

It seems that drivers decrease speed more when gate constructions are present but very fast after entering the thoroughfares they accelerate to approximately the same mean speed as when no gates are present. Within the thoroughfare mean speeds increase again to approximately 45 to 48 km/h in all thoroughfare configurations. However there seem to be some slight differences in the first half of the thoroughfare between the different configurations. The speed in the curved thoroughfares seems to be lower in the first half of the thoroughfare in comparison with the straight thoroughfares. In addition, the mean speeds in the curved thoroughfares have a fluctuating pattern that is related to the occurrence of curves. The highest mean speed within the built-up area across the different configurations occurs at the end of the thoroughfare. Mean speed does not reach the speed limit of 50 km/h in any of the thoroughfares. Only small differences occur between mean speed with PDT and without PDT.

7.1.2 Influence of the curviness of a thoroughfare and the presence or absence of gate constructions in the whole thoroughfare

Mean speed was lower inside the built-up area than outside (main effect Built-up area: $F(1, 45) = 1581.005$, $p < .0005$).

Table 6 Mean speed for Built-up area (n = 46) (zone 1-20 & zone 21-32)

Built-up area	Mean	SE
Outside	68.857	.661
Inside	45.302	.723

There was an interaction of *Curves x Built-up area* ($F(1, 45) = 10.267$, $p = .002$) (see Figure 28). When this interaction was further examined mean speed outside the built-up

[6] Zone nr 17 is lying 388 to 291 m before the built-up area.

area was higher when curves were present than when there were no curves (t(45) = -2.390, p = .021). The opposite was true inside the built-up area where mean speed was lower when curves were present than when there were no curves (t(45) = 3.240, p = .002). Mean speed decreased thus more between outside and inside the built-up area when curves were present (t(45) = 31.180, p < .0005) than when there were no curves present (t(45) = 45.216, p < .0005).

Table 7 Mean speed for interaction Curves x Built-up area (n = 46) (zone 1-20 & zone 21-32)

Curves	Built-up area	Mean	SE
No	Outside	68.441	.677
	Inside	45.806	.695
Yes	Outside	69.272	.691
	Inside	44.798	.782

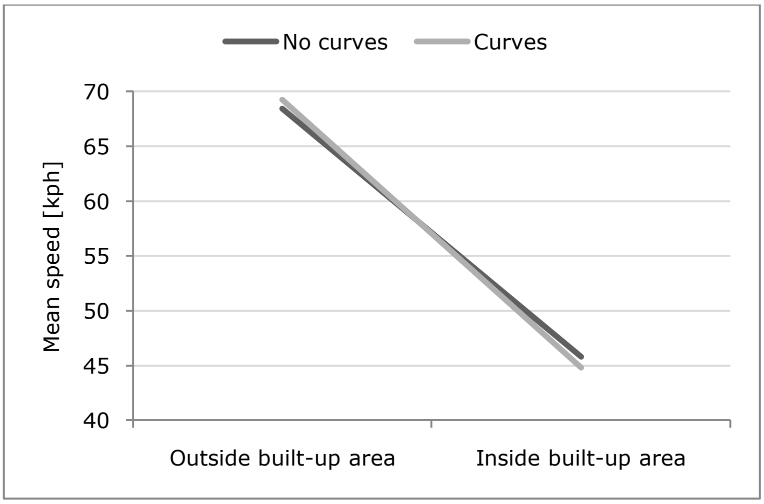

Figure 28 Mean speed for interaction Curves x Built-up area (n = 46) (zone 1-20 & zone 21-32)

7.1.3 Influence of the curviness of a thoroughfare and the presence or absence of gate constructions at the entrance of a thoroughfare

Mean speed was lower when curves were present than when there were no curves (main effect Curves: F(1, 45) = 4.369, p = .042), lower when gates were present than when there were no gates (main effect Gates: F(1, 45) = 28.535, p < .0005) and lower after the entrance than before the entrance (main effect Entrance: F(1, 45) = 61.447, p < .0005).

Table 8 Mean speed for Curves, Gates and Entrance (n = 46) (zone 20 & zone 21-22)

Curves	**Mean**	**SE**
No	46.393	.760
Yes	45.851	.824
Gates	**Mean**	**SE**
No	47.249	.770
Yes	44.996	.848
Entrance	**Mean**	**SE**
Before	48.646	.917
After	43.599	.767

There was an interaction of *Gates x Entrance* ($F(1, 45) = 9.947$, $p = .003$) (see Figure 29). Separate tests showed that mean speed was lower after the entrance than before when gates were present ($t(45) = 5.439$, $p < .0005$) and when no gates were present ($t(45) = 8.725$, $p < .0005$) and that mean speed was lower when gates were present than when no gates were present, before the entrance ($t(45) = 5.143$, $p < .0005$) and after the entrance ($t(45) = 3.135$, $p = .003$). Thus although the speed reduction was stronger when no gates were present, mean speed after the entrance was lower when gates were present than when no gates were present.

Table 9 Mean speed for interaction Gates x Built-up area (n = 46) (zone 20 & zone 21-22)

Gates	**Entrance**	**Mean**	**SE**
No	Before	50.276	.948
	After	44.222	.727
Yes	Before	47.016	.992
	After	42.976	.853

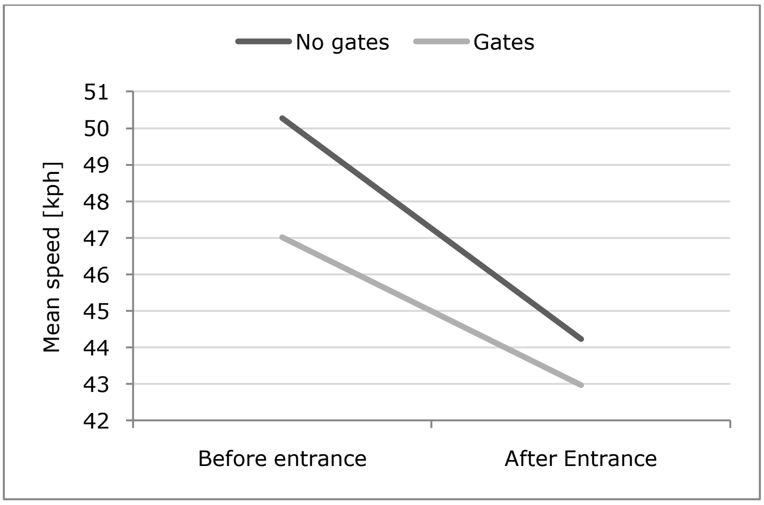

Figure 29 Mean speed for interaction Gates x Entrance (n = 46) (zone 20 & zone 21-22)

7.1.4 Influence of continued driving in a thoroughfare

Mean speed was lower when curves were present than when there were no curves (main effect Curves: $F(1, 45) = 10.500$, $p = .002$), marginally lower when PDT was present than when there was no PDT (main effect PDT: $F(1, 45) = 3.591$, $p = .065$) and lower before the middle of the thoroughfare than after the middle (main effect Middle: $F(1, 45) = 104.957$, $p < .0005$).

Table 10 Mean speed for Curves, PDT and Middle (n = 46) (zone 21-26 & zone 27-32)

Curves	**Mean**	**SE**
No	45.806	.695
Yes	44.798	.782
PDT	**Mean**	**SE**
No	45.509	.723
Yes	45.095	.740
Middle	**Mean**	**SE**
Before	44.244	.750
After	46.360	.710

7.1.5 Conclusion

In the whole thoroughfare, mean speed was lower inside than outside the built-up area. Furthermore, a comparison of the first and second part inside the thoroughfare showed that mean speed increased throughout the thoroughfare, independent of Curves, Gates and PDT. Regarding the effect of curves and gates, results showed that:

Curves: At the entrance mean speed was lower when curves were present than when there were no curves before and after the entrance. This speed difference was continued throughout the thoroughfare. Finally, in the whole thoroughfare the difference in mean speed between the inside and outside of the build-up area was larger when curves were present than when there were no curves, due to (1) a higher mean speed outside the built-up area and, more importantly (2) a lower mean speed inside the built-up area.

Gates: Speed decreased more across the entrance when no gates were present, but speed was lower before and after the entrance when gates were present. This speed reduction effect of gates around the entrance was only a local effect that was not continued throughout the thoroughfare.

7.2 Standard deviation of longitudinal acceleration and deceleration

7.2.1 Overview of SDL-A/D in zones of 97 meter

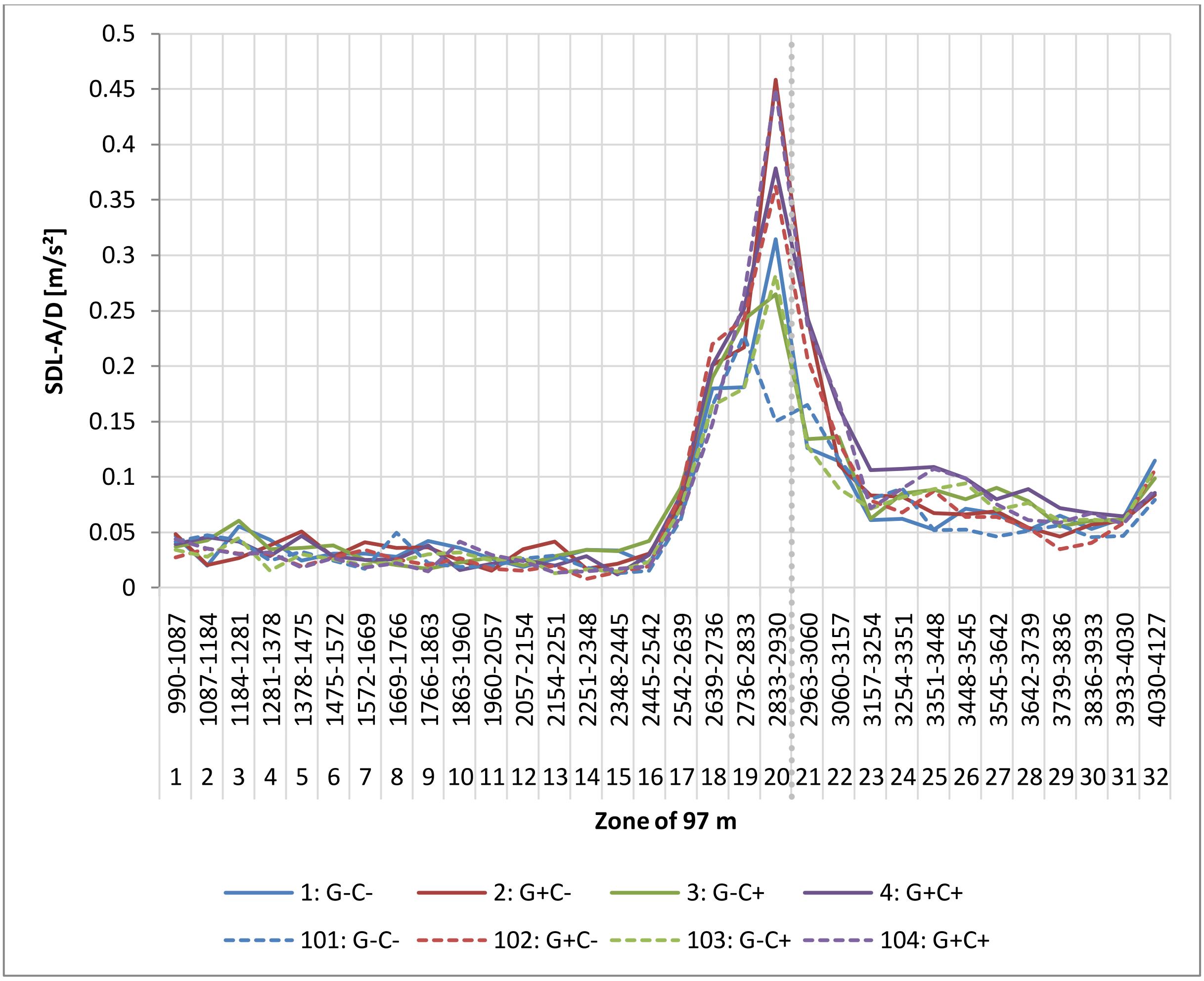

Figure 30 SDL-A/D per zone of 97 m (n = 46)

In all the thoroughfare configurations the standard deviation of longitudinal acceleration and deceleration (SDL-A/D) on the monotonous road outside the built-up area fluctuates around the same low SDL-A/D. About 400 m (zone nr 16) SDL-A/D starts to rise in each thoroughfare configuration. This raise is expected because drivers slow down before entering the curve at 200 m before the built-up area (zone nr 17-18) by means of a brusque decelerating maneuver in comparison with the homogeneous accelerating and decelerating maneuvers at the straight monotonous road segment.

Before the entrance of the thoroughfare (zone nr 20) SDL-A/D reaches a peak in each thoroughfare configuration though SDL-A/D is the highest when gates were present. The peak indicates that drivers decelerate before they pass the sign F1. This higher SDL-A/D when gates were present is maintained in the first 200 m after the entrance gate (zone nr 21-22). Inside the built-up area SDL-A/D is in general higher than on the monotonous road outside the built-up area. The small fluctuations of SDL-A/D inside the built-up area seem to be higher when curves were present. At the end of the thoroughfare SDL-A/D rise again in each thoroughfare configuration. Only small differences occur between SDL-A/D with PDT and without PDT.

7.2.2 Influence of the curviness of a thoroughfare and the presence or absence of gate constructions in the whole thoroughfare

Standard deviation of longitudinal acceleration and deceleration (SDL-A/D) was lower when no curves were present than when there were curves (main effect Curves: $F(1, 45) = 11.666$, $p = .001$), lower when no gates were present than when there were gates (main effect Gates: $F(1, 45) = 18.833$, $p < .0005$), lower when PDT was present than when there was no PDT (main effect PDT: $F(1, 45) = 9.971$, $p = .003$) and lower outside the built-up area than inside (main effect Built-up area: $F(1, 45) = 14.199$, $p < .0005$).

Table 11 SDL-A/D for Curves, Gates, PDT and Built-up area (n = 46) (zone 1-20 & zone 21-32)

Curves	**Mean**	**SE**
No	.071	.004
Yes	.079	.004
Gates	**Mean**	**SE**
No	.069	.004
Yes	.081	.005
PDT	**Mean**	**SE**
No	.078	.005
Yes	.072	.004
Built-up area	**Mean**	**SE**
Outside	.064	.004
Inside	.086	.006

There was an interaction of *Curves x Built-up area* ($F(1; 45) = 6.780$, $p = .012$), indicating a larger increase in SDL-A/D when curves were present than when there were no curves (see Figure 31). Separate test showed that SDL-A/D was lower inside the built-up area when no curves were present than when there were curves (t(45) = -3.738, p = .001). Outside the built-up area there was no effect of Curves (t(45) = -.262, p = .794). Separate tests showed that SDL-A/D was lower outside the built-up area than inside the built-up area, when no curves (t(45) = -2.544, p = .014) and curves were present (t(45) = -4.310, p < .0005). These relations indicated a larger increase in SDL-A/D from outside to inside the built-up area when curves were present than when there were no curves.

Table 12 SDL-A/D for interaction Curves x Built-up area (n = 46) (zone 1-20 & zone 21-32)

Curves	Built-up area	Mean	SE
No	Outside	.063	.004
	Inside	.079	.006
Yes	Outside	.064	.005
	Inside	.093	.006

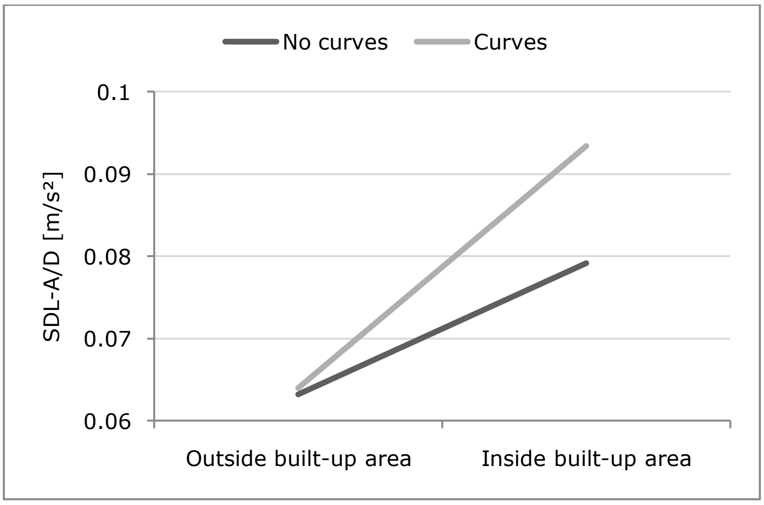

Figure 31 SDL-A/D for interaction Curves x Built-up area (n = 46) (zone 1-20 & zone 21-32)

7.2.3 Influence of the curviness of a thoroughfare and the presence or absence of gate constructions at the entrance of a thoroughfare

SDL-A/D was lower when no gates were present than when there were gates (main effect Gates: F(1, 45) = 22.721, p < .0005) and lower after the entrance than before the entrance (main effect Entrance: F(1, 45) = 26.100, p < .0005).

Table 13 SDL-A/D for Gates and Entrance (n = 46) (zone 20 & zone 21-22)

Gates	Mean	SE
No	.189	.022
Yes	.300	.026
Entrance	**Mean**	**SE**
Before	.333	.037
After	.157	.011

However, here also was an interaction of *Gates x Entrance* (F(1, 45) = 4.393, p = .031) (see Figure 32). When this interaction was further examined SDL-A/D was lower when no gates were present than when gates were present, before the entrance (t(45) = -3.703, p = .001) and after the entrance (t(45) = -4.857, p < .0005). SDL-A/D decreased more between before the entrance and after the entrance when gates were present (t(45) = 5.132, p < .0005) than when there were no gates present (t(45) = 3.385, p = .001).

Table 14 SDL-A/D for interaction Gates x Entrance (n = 46) (zone 20 & zone 21-22)

Gates	Entrance	Mean	SE
No	Before	.253	.039
	After	.126	.012
Yes	Before	.412	.046
	After	.188	.014

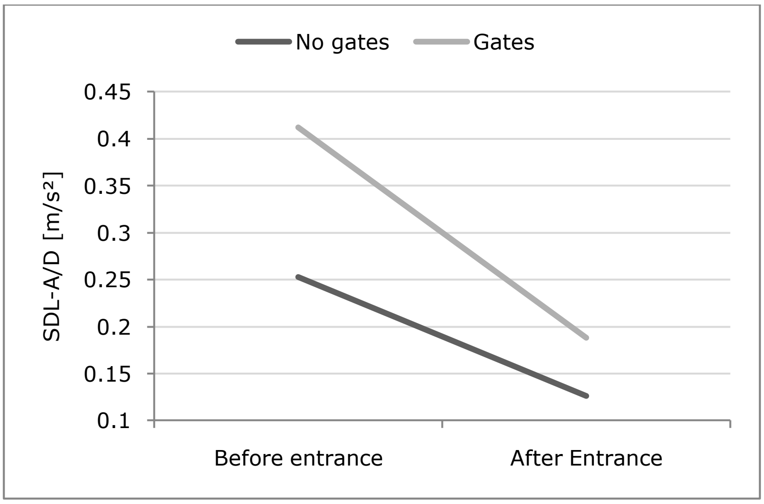

Figure 32 SDL-A/D for interaction Gates x Entrance (n = 46) (zone 20 & zone 21-22)

There was a three-way interaction of *Curves x PDT x Entrance* (F(1, 45) = 5.285, p = .026) (see Figure 33).

- Separate tests for each level of PDT showed that

  - When no PDT was present there was no interaction of *Curves x Entrance*, but SDL-A/D was lower after the entrance than before the entrance (main effect Entrance: $F(1, 45) = 18.401$, $p < .0005$).
  - When PDT was present there was no interaction of *Curves x Entrance*, but SDL-A/D was lower after the entrance than before the entrance (main effect Entrance: $F(1, 45) = 19.624$, $p < .0005$).
- Separate tests for each level of Curves showed that
  - When no curves were present there was an interaction of *PDT x Entrance* ($F(1, 45) = 6.617$, $p = .013$).

    Separate test for each level of Entrance showed that
    - When before the entrance SDL-A/D was lower when PDT was present than when there was no PDT (main effect of PDT: $F(1, 45) = 8.364$, $p = .006$).
    - When after the entrance there was no main effect of PDT.

    Separate test for each level of PDT showed that
    - When no PDT was present SDL-A/D was lower after the entrance than before the entrance (main effect Entrance: $F(1, 45) = 21.905$, $p < .0005$).
    - When PDT was present SDL-A/D was lower after the entrance than before the entrance (main effect Entrance: $F(1, 45) = 6.613$, $p = .013$).
  - When curves were present there was no interaction of PDT x Entrance, but SDL-A/D was lower after the entrance than before the entrance (main effect Entrance: $F(1, 45) = 18.495$, $p < .0005$).
- Separate tests for each level of Entrance showed that
  - When before the entrance there was an interaction of *Curves x PDT* ($F(1, 45) = 5.266$, $p = .026$).

    Separate tests for each level of PDT showed that
    - When no PDT was present there was no main effect of Curves.
    - When PDT was present SDL-A/D was lower when no curves were present than when there were curves (main effect Curves: $F(1, 45) = 3.313$, $p = .075$).

    Separate tests for each level of Curves showed that

  - When no curves were present SDL-A/D was lower when PDT was present than when there was no PDT (main effect PDT: $F(1, 45) = 8.364$, $p = .006$).
  - When curves were present there was no main effect of PDT.
- When after the entrance there was no interaction of Curves x PDT nor a main effect of Curves or PDT.

Taken together, this 3-way interaction indicates a lower SDL-A/D after the entrance than before. Importantly, there only were differences in SDL-A/D before the entrance, and not after the entrance. The decrease in SDL-A/D was dependent on Curves and PDT. The decrease in SDL-A/D when PDT was present and no PDT was present was similar and not dependent on the presence of curves. However, the decrease in SDL-A/D for curves and no curves did depend on the presence of PDT. That is, when no curves were present the decrease was larger when no PDT was present than when there was PDT. Although this pattern was opposite when curves were present (a larger decrease when PDT was present than when no PDT was present) there was not a significant differences between these two decreases.

Table 15 SDL-A/D for interaction Curves x PDT x Entrance (n = 46) (zone 20 & zone 21-22)

Curves	PDT	Entrance	Mean	SE
No	No	Before	.387	.050
		After	.149	.013
	Yes	Before	.256	.038
		After	.155	.015
Yes	No	Before	.322	.056
		After	.169	.017
	Yes	Before	.366	.054
		After	.155	.015

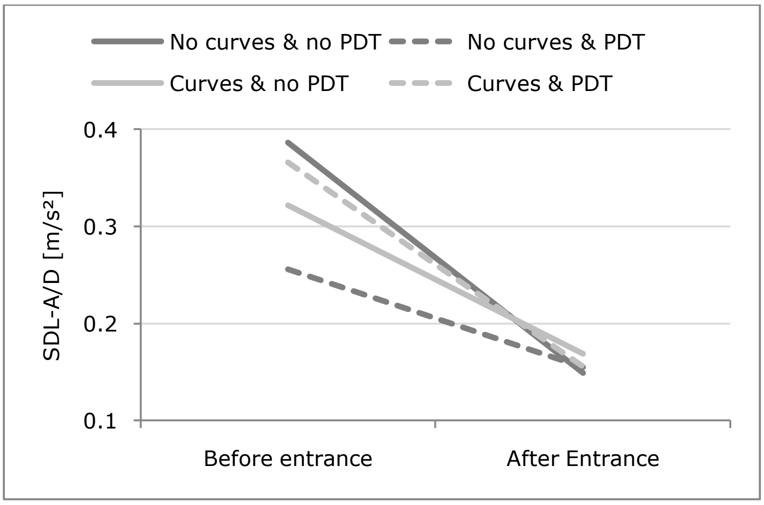

Figure 33 SDL-A/D for interaction Curves x PDT x Entrance (n = 46) (zone 20 & zone 21-22)

7.2.4 Influence of continued driving in a thoroughfare

SDL-A/D was lower when there were no curves than when there were curves (main effect Curves: $F(1, 45) = 13.974$, $p = .001$), lower when no gates were present than when there were gates (main effect Gates: $F(1, 45) = 12.948$, $p = .001$) and lower after the middle than before the middle (main effect Middle: $F(1, 45) = 69.386$, $p < .0005$).

Table 16 SDL-A/D for Curves, Gates and Middle (n = 46) (zone 21-26 & zone 27-32)

Curves	**Mean**	**SE**
No	.079	.006
Yes	.093	.006
Gates	**Mean**	**SE**
No	.079	.006
Yes	.093	.006
Middle	**Mean**	**SE**
Before	.106	.007
After	.067	.006

There was an interaction of *Gates x Middle* ($F(1, 45) = 28.780$, $p < .0005$), indicating a larger decrease in SDL-A/D when there were gates than when no gates were present (see Figure 34). When this interaction was further examined SDL-A/D was lower before the middle when no gates present than when there were gates ($t(45) = -4.797$, $p < .0005$) and SDL-A/D decreased more between before the middle and after the middle when gates were present ($t(45) = 10.134$, $p = .0005$) than when there were no gates present (t(45) = 4.204, p < .0005). After the middle there was no effect of Gates (t(45) = .323, p = .748).

Table 17 SDL-A/D for interaction Gates x Entrance (n = 46) (zone 21-26 & zone 27-32)

Gates	Middle	Mean	SE
No	Before	.091	.007
	After	.067	.006
Yes	Before	.120	.008
	After	.066	.006

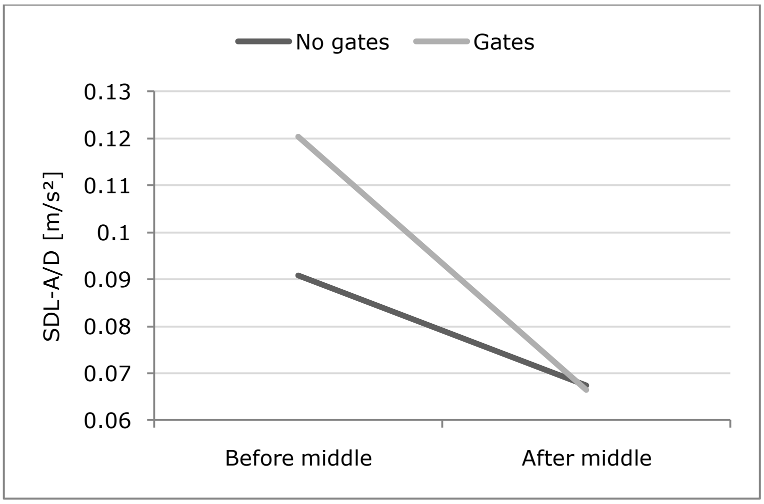

Figure 34 SDL-A/D for interaction Gates x Middle (n = 46) (zone 21-26 & zone 27-32)

7.2.5 Conclusion

A comparison of the whole thoroughfare showed that SDL-A/D was larger inside the built-up area than outside. Furthermore, this increase was larger when curves were present than when no curves were present. Around the entrance of the thoroughfare, however, SDL-A/D was lower after than before the entrance. This decrease was dependent on Gates and on the interaction of Curves x PDT.

SDL-A/D was lower when no gates were present than when there were gates, before and after the entrance and SDL-A/D decreased more across the entrance when gates were present. The higher SDL-A/D when gates had been present was maintained before the middle of the entrance but decreased to the level of SDL-A/D when no gates were present after the middle. Because SDL-A/D decreased throughout the thoroughfare, the decrease of SDL-A/D when gates were present was larger than when gates were present.

SDL-A/D decreased between before and after the entrance but this decrease was dependent on Curves and PDT. When no curves were present the decrease across the entrance was larger when no PDT was present than when there was PDT. When curves were present the decrease across the entrance was independent of PDT. In addition, when PDT was present there was a larger decrease when curves were present than when there were no curves. When no PDT was present, the decrease across the entrance was not influenced by Curves. After the entrance there was no effect of Curves or PDT any more. Both before and after the middle of the thoroughfare SDL-A/D was lower when no curves were present.

7.3 Standard deviation lateral position

7.3.1 Overview of SD LP in zones of 97 meter

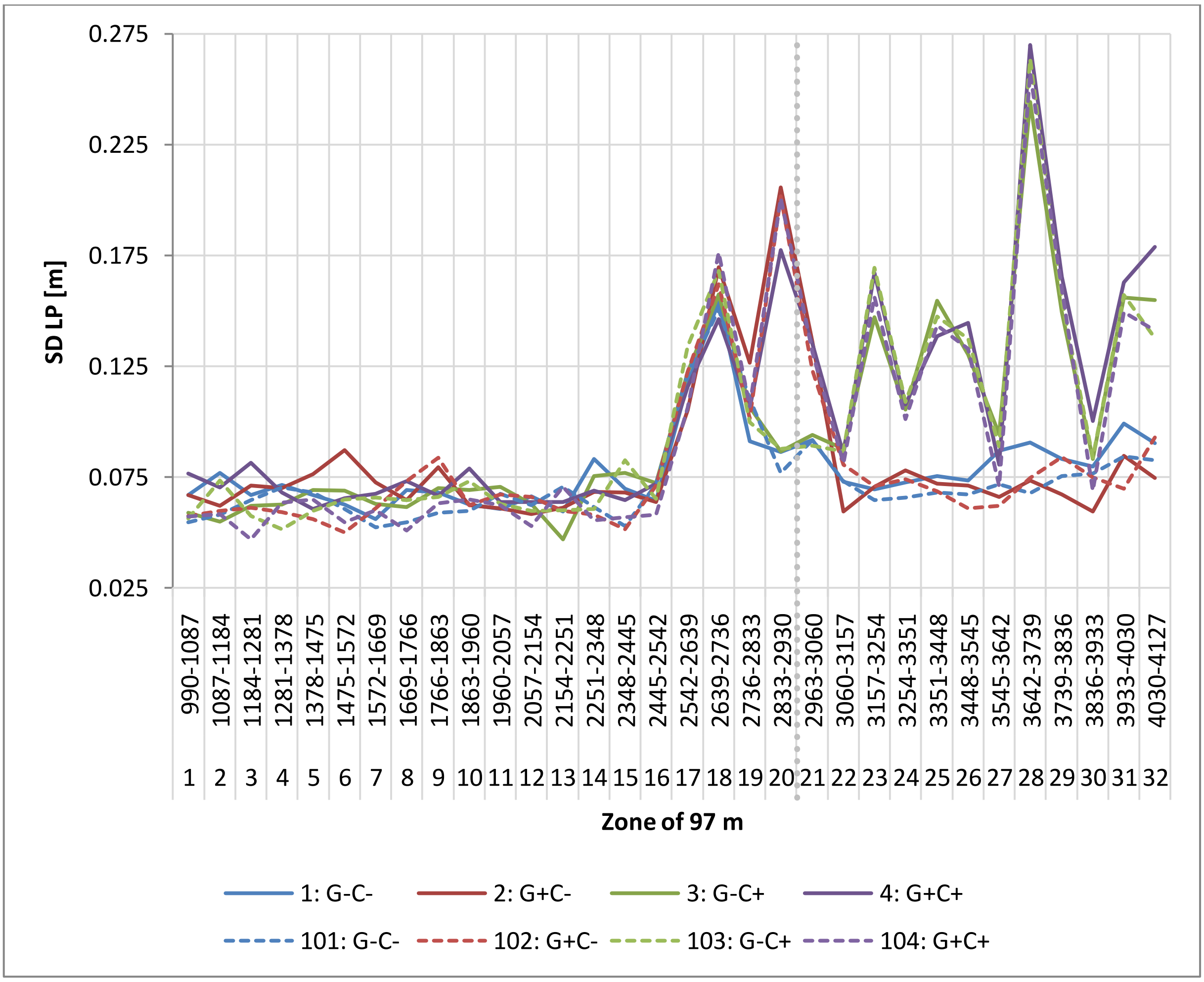

Figure 35 SD LP per zone of 97 m (n = 46)

On the straight monotonous road section outside the built-up area standard deviation of lateral position (SD LP) fluctuates around the same low value for each thoroughfare configuration. SD LP reaches a first peak at 250 m before the built-up area (zone nr 18) because of the curve lying over there. The raise of the SD LP starts at 200 m before this curves (zone nr 16). After the curve SD LP decreases again and the first differences between the different thoroughfare configuration are visible at about 200 m before the built-up area (zone 19) where SD LP raises again when gates are present and decreases further on when no gates are present. About 200 m after the entrance (zone nr 22) SD LP is broadly the same in each thoroughfare configuration.

Throughout the thoroughfare SD LP remains in general the same when no curves were present. In a curved thoroughfare large fluctuations in SD LP were measured. In each of the four curves located in a curved thoroughfare SD LP raises significantly. The third curve (zone nr 28) towers above all the others despite the fact that the second curve has the same layout. Between the second and the third curve and between the third and the fourth curve SD LP decreases to the level when no curves were present. SD LP between the first and the second curve remains higher than the level when no curves were present. Only small differences occur between mean speed with PDT and without PDT.

7.3.2 Influence of the curviness of a thoroughfare and the presence or absence of gate constructions in the whole thoroughfare

Standard deviation of lateral position (SD LP) was lower when no curves were present than when there were curves (main effect Curves: $F(1, 45) = 103.039$, $p < .0005$), lower when no gates were present than when there were gates (main effect Gates: $F(1, 45) = 10.271$, $p = .002$), lower when PDT present than when there was no PDT (main effect PDT: $F(1, 45) = 7.837$, $p = .008$) and lower outside the built-up area than inside (main effect Built-up area: $F(1, 45) = 181.096$, $p < .0005$).

Table 18 SD LP for Curves, Gates, PDT and Built-up area (n = 46) (zone 1-20 & zone 21-32)

Curves	**Mean**	**SE**
No	.078	.002
Yes	.107	.004
Gates	**Mean**	**SE**
No	.091	.003
Yes	.094	.003
PDT	**Mean**	**SE**
No	.095	.003
Yes	.091	.002
Built-up area	**Mean**	**SE**
Outside	.078	.002
Inside	.107	.003

There was a four-way interaction of *Curves x Gates x PDT x Built-up area* ($F(1, 45) = 5.119$, $p = .029$).

- Separate tests for each level of PDT showed that
    - When no PDT was present there was an interaction of *Curves x Gates x Built-up area* ($F(1, 45) = 8.809$, $p = .005$).

Separate tests for each level of Curves showed that

- When no curves were present there was an interaction of *Gates x Built-up area* ($F(1, 45) = 8.340$, $p = .006$) (see Figure 36).

  Separate tests for each level of Built-up area showed that

  - When outside the built-up area SD LP was lower when no gates were present than when there were gates (main effect Gates: $F(1, 45) = 7.436$, $p = .009$).
  - When inside the built-up area there was no main effect of Gates.

  Separate tests for each level of Gates showed that

  - When no gates were present there was no main effect of Built-up area.
  - When gates were present SD LP was lower inside the built-up area then outside (main effect Built-up area: $F(1, 45) = 4.815$, $p = .033$).

- When curves were present there was no interaction of *Gates x Built-up area*, but SD LP was lower when no gates were present than when there were gates (main effect Gates: $F(1, 45) = 9.934$, $p = .003$) and lower when outside the built-up area than inside (main effect Built-up area: $F(1, 45) = 155.614$, $p < .0005$) (see Figure 36).

Separate tests for each level of Gates showed that

- When no gates were present there was an interaction of *Curves x Built-up area* ($F(1, 45) = 76.920$, $p < .0005$) (see Figure 36).

  Separate tests for each level of Built-up area showed that

  - When outside the built-up area there was no main effect of Curves.
  - When inside the built-up area SD LP was lower when no curves were present than when there were curves (main effect Curves: $F(1, 45) = 73.180$, $p < .0005$).

- When gates were present there was an interaction of *Curves x Built-up area* ($F(1, 45) = 79.530$, $p < .0005$) (see Figure 36).

  Separate tests for each level of Built-up area showed that

  - When outside the built-up area there was no main effect of Curves.

- When inside the built-up area SD LP was lower when no curves were present than when there were curves (main effect Curves: F(1, 45) = 103.127, p < .0005).

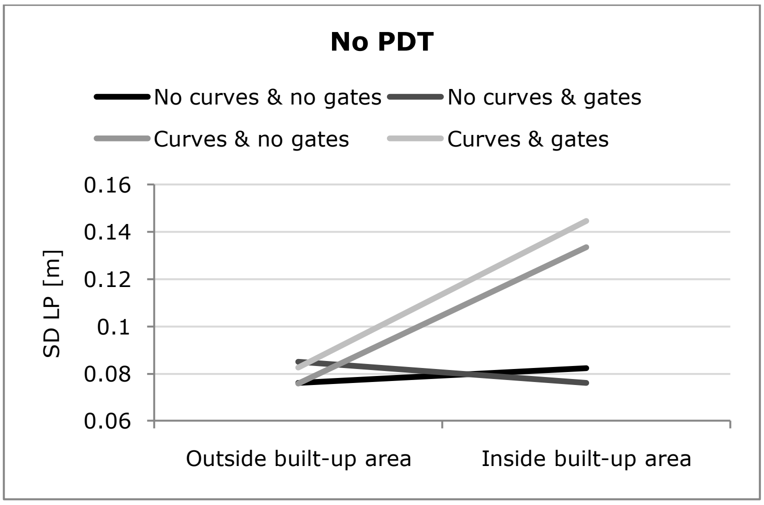

Figure 36 SD LP for interaction Curves x Gates x PDT x Built-up area where no (n = 46) (zone 1-20 & zone 21-32)

The interaction of Curves x Gates x Built-up when no PDT was present indicated that when curves were present SD LP was higher inside the built-up area than outside. This increase was independent of Gates, but SD LP was lower when no gates were present than when there were gates, both outside and inside the built-up area. Outside the built-up area SD LP was lower when no gates were present than when there were gates, both when curves were present or not. When no curves were present SD LP was decreased across the built-up area when gates were present to an equal level for gates and no gates inside the built-up area. Inside the built-up area SD LP was lower when no curves were present than when there were curves, this relation is not influenced by Gates.

- When PDT was present there was an interaction of *Curves x Built-up area* (F(1, 45) = 136.372, p < .0005) (see Figure 37).

  Separate tests for each level of Built-up area showed that

  - When outside the built-up area there was no main effect of Curves.
  - When inside the built-up area SD LP was lower when no curves were present than when there were curves (F(1, 45) = 123.805, p < .0005).

Separate tests for each level of Curves showed that

- When no curves were present there was no main effect of Built-up area.
- When curves were present SD LP was lower outside the built-up area than inside (main effect Built-up area: $F(1, 45) = 211.776$, $p < .0005$).

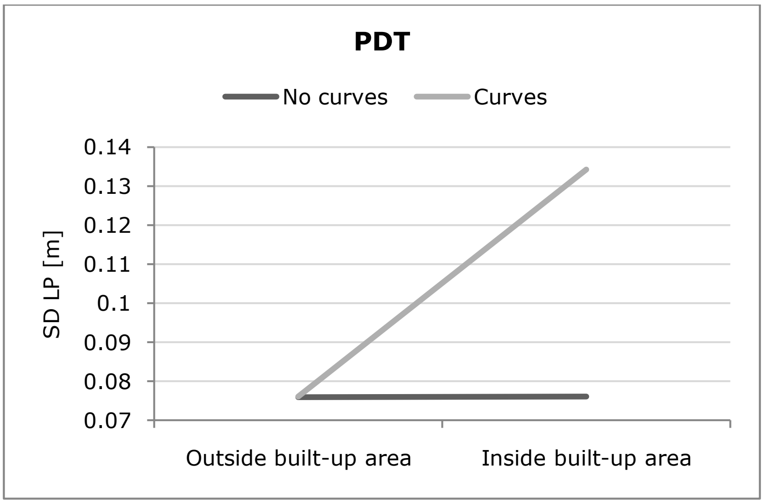

Figure 37 SD LP for interaction Curves x Gates x PDT x Built-up area where PDT (n = 46) (zone 1-20 & zone 21-32)

When PDT was present SD LP was higher inside than outside the built-up area when curves were present whereas SD LP did not change between outside and inside when no curves were present. Outside the built-up area SD LP was independent of the level of Curves.

Table 19 SD LP for interaction Curves x Gates x PDT x Built-up area (n = 46) (zone 1-20 & zone 21-32)

Curves	Gates	PDT	Built-up area	Mean	SE
No	No	No	Outside	.076	.004
			Inside	.082	.004
		Yes	Outside	.072	.003
			Inside	.074	.003
	Yes	No	Outside	.085	.003
			Inside	.076	.003
		Yes	Outside	.079	.003
			Inside	.078	.003
Yes	No	No	Outside	.076	.003
			Inside	.133	.005
		Yes	Outside	.076	.003
			Inside	.135	.005
	Yes	No	Outside	.083	.004
			Inside	.145	.006
		Yes	Outside	.077	.004
			Inside	.133	.006

7.3.3 Influence of the curviness of a thoroughfare and the presence or absence of gate constructions at the entrance of a thoroughfare

SD LP was lower when no gates were present than when there were gates (main effect Gates: $F(1, 45) = 144.110$, $p < .0005$) and lower after the entrance than before the entrance (main effect Entrance: $F(1, 45) = 123.757$, $p < .0005$). There was an interaction of *Gates x Entrance* ($F(1, 45) = 94.543$, $p < .0005$) (see Figure 38). When this interaction was further examined SD LP was lower when no gates were present than when there were gates, before the entrance ($t(45) = -12.513$, $p < .0005$) and after the entrance ($t(45) = -3.607$, $p = .001$). When gates were present SD LP was lower after the entrance than before the entrance ($t(45) = 12.572$, $p < .0005$). There was no effect of Entrance on SD LP when no gates were present.

Table 20 SD LP for interaction Gates x Entrance (n = 46) (zone 20 & zone 21-22)

Gates	Entrance	Mean	SE
No	Before	.084	.004
	After	.086	.004
Yes	Before	.196	.007
	After	.104	.003

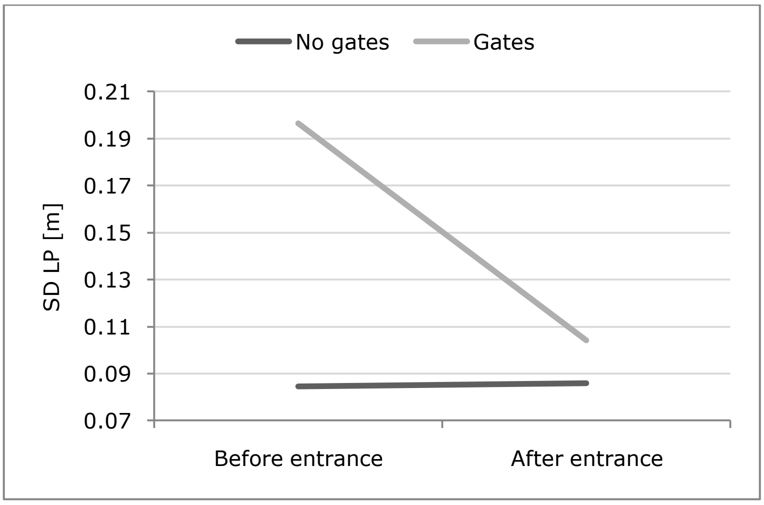

Figure 38 SD LP for interaction Gates x Entrance (n = 46) (zone 20 & zone 21-22)

7.3.4 Influence of continued driving in a thoroughfare

SD LP is lower when no curves are present than when there are curves (main effect Curves: $F(1, 45) = 132.008$, $p < .000$), lower when PDT were present than when there were no PDT (main effect PDT: $F(1, 45) = 4.460$, $p = .040$) and lower before the middle than after the middle (main effect Middle: $F(1, 45) = 23.366$, $p < .0005$).

Table 21 SD LP for Curves, PDT and Middle (n = 46) (zone 21-26 & zone 27-32)

Curves	**Mean**	**SE**
No	.078	.003
Yes	.137	.005
PDT	**Mean**	**SE**
No	.109	.004
Yes	.105	.003
Middle	**Mean**	**SE**
Before	.101	.003
After	.113	.004

There was an interaction of *Gates x Middle* ($F(1, 45) = 4.986$, $p = .031$) (see Figure 39). Separate tests showed that SD LP was lower before the middle than after the middle, when no gates were present ($t(45) = -4.746$, $p < .0005$) and when gates were present ($t(45) = -2.822$, $p = .007$). Before the middle SD LP was lower when no gates were present than when there were gates ($t(45) = -2.453$, $p = .018$). There was no effect of Gates on SD LP when after the middle.

Table 22 SD LP for interaction Gates x Middle (n = 46) (zone 21-26 & zone 27-32)

Gates	Middle	Mean	SE
No	Before	.098	.003
	After	.115	.004
Yes	Before	.104	.003
	After	.112	.004

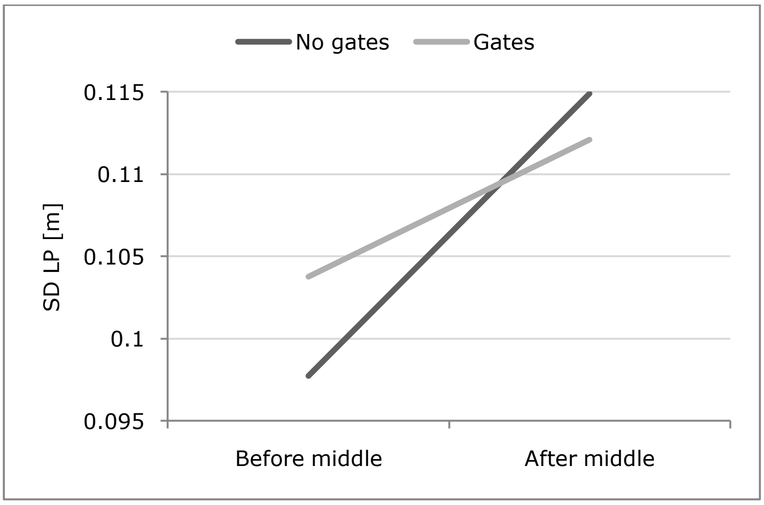

Figure 39 SD LP for interaction Gates x Middle (n = 46) (zone 21-26 & zone 27-32)

There was an interaction of *Curves x Middle* (F(1, 45) = 23.977, p < .0005) (see Figure 40). When this interaction was further examined SD LP was lower when no curves were present than when there were curves, before the middle (t(45) = -12.194, p < .0005) and after the middle (t(45) = -10.068, p < .0005). When curves were present SD LP was lower before the middle than after the middle (t(45) = -5.945, p < .0005). There was no effect of Middle on SD LP when no curves were present.

Table 23 SD LP for interaction Curves x Middle (n = 46) (zone 21-26 & zone 27-32)

Curves	Middle	Mean	SE
No	Before	.077	.003
	After	.078	.003
Yes	Before	.124	.004
	After	.149	.007

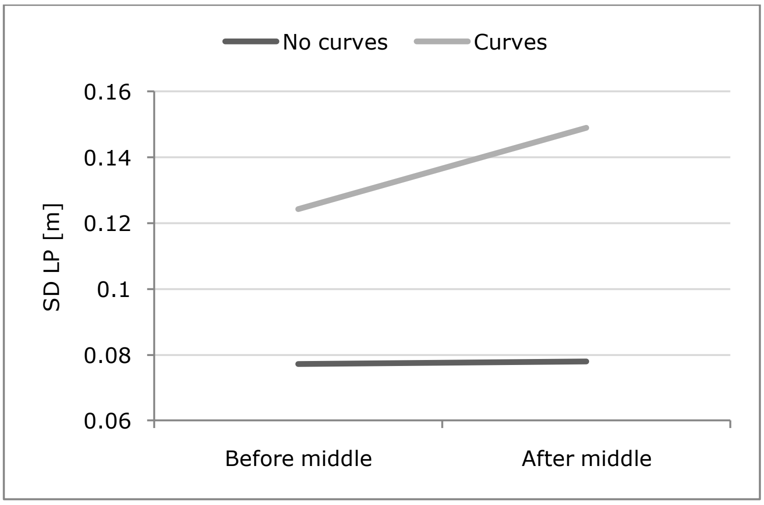

Figure 40 SD LP for interaction Curves x Middle (n = 46) (zone 21-26 & zone 27-32)

There was a three-way interaction of *Curves x Gates x PDT* ($F(1, 45) = 10.962$, $p = .002$) (see Figure 41).

- Separate tests for each level of PDT showed that
    - When no PDT was present there was an interaction of *Curves x Gates* ($F(1, 45) = 9.990$, $p = .003$).

      Separate tests for each level of Gates showed that
        - When no gates were present SD LP was lower when no curves were present than when there were curves (main effect Curves: $F(1, 45) = 73.180$, $p < .0005$).
        - When gates were present SD LP was lower when no curves were present than when there were curves (main effect Curves: $F(1, 45) = 103.127$, $p < .0005$).

      Separate tests for each level of Curves showed that
        - When no curves were present there was no main effect of Gates.
        - When curves were present SD LP was lower when no gates were present than when there were gates (main effect Gates: $F(1, 45) = 9.204$, $p = .004$).
    - When PDT was present there was no interaction of *Curves x Gates* but SD LP was lower when no curves were present than when there were curves (main effect Curves: $F(1, 45) = 123.805$, $p < .0005$).
- Separate tests for each level of Curves area showed that
    - When no curves were present there was no interaction of *Gates x PDT* nor a main effect of Gates or PDT.

- When curves were present there was an interaction of *Gates x PDT* (F(1, 45) = 7.047, p = .011)
  Separate tests for each level of Gates showed that
  - When no gates were present there was no main effect of PDT.
  - When gates were present SD LP was lower when PDT was present than when there was no PDT (F(1, 45) = 7.895, p = .007).

  Separate tests for each level of PDT showed that
  - When no PDT was present SD LP was lower when no gates were present than when there were gates (main effect Gates: F(1, 45) = 9.204, p = .004).
  - When PDT was present there was no main effect of Gates.

Table 24 SD LP for interaction Curves x Gates x PDT (n = 46) (zone 21-26 & zone 27-32)

Curves	Gates	PDT	Mean	SE
No	No	No	.082	.004
		Yes	.074	.003
	Yes	No	.076	.003
		Yes	.078	.003
Yes	No	No	.133	.005
		Yes	.135	.005
	Yes	No	.145	.006
		Yes	.133	.006

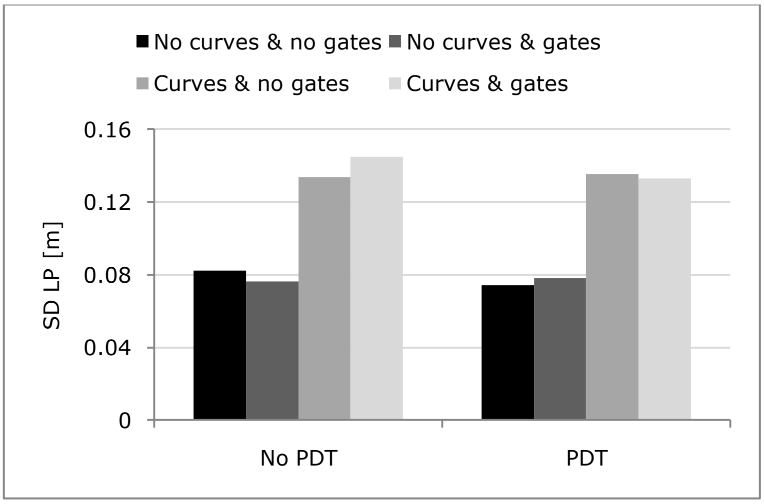

Figure 41 SD LP for interaction Curves x Gates x PDT (n = 46) (zone 21-26 & zone 27-32)

The interaction of Curves x Gates x PDT showed that SD LP was lower when no curves were present than when there were curves, when PDT was present or not. But when curves and no PDT were present SD LP was lower when no gates were present than when there were gates. When curves and gates were present SD LP was lower when PDT was present than when there was no PDT. In the other thoroughfare configurations the level of PDT had no effect on SD LP.

7.3.5 Conclusion

SD LP increased between outside and inside the built-up area when curves were present, independent of Gates and PDT. When no PDT was present, outside the built-up area SD LP was higher when there were gates than no gates, independent of curves. Inside the built-up area SD LP still was higher when there were gates than no gates, but only when there were curves, whereas there was no difference anymore between gates and no gates when there were no curves. There thus was a small decrease in SD LP when there were no curves but gates between the outside and inside of the built-up area.

At the entrance of a thoroughfare SD LP was lower when no gates were present than when there were gates before and after the entrance. Furthermore, SD LP decreased when gates were present whereas it remained equal when no gates were present.

Throughout the thoroughfare SD LP increased stronger when no gates were present than when gates were present. Whereas SD LP in the first part of the thoroughfare was lower when no gates were present, the stronger increase resulted in an equal SDLP in the second part of the thoroughfare for gates and no gates. SD LP also increased throughout the thoroughfare when there were curves, whereas it remained equal when there were no curves. Finally, an interaction of Curves x Gates x PDT throughout the thoroughfare indicated that SD LP was lower when no curves were present than when there were curves, independent of PDT, but when there were curves (similar to the effect reported before) SD LP was lower when no gates were present than when there were gates, only when no PDT was present. When PDT was present there was no difference between gates and no gates and SD LP when curves and gates were present was lower when PDT was present than when there was no PDT.

7.4 Mean SWM frequency for larger SWM

7.4.1 Overview of mean SWM FREQ in zones of 97 meter

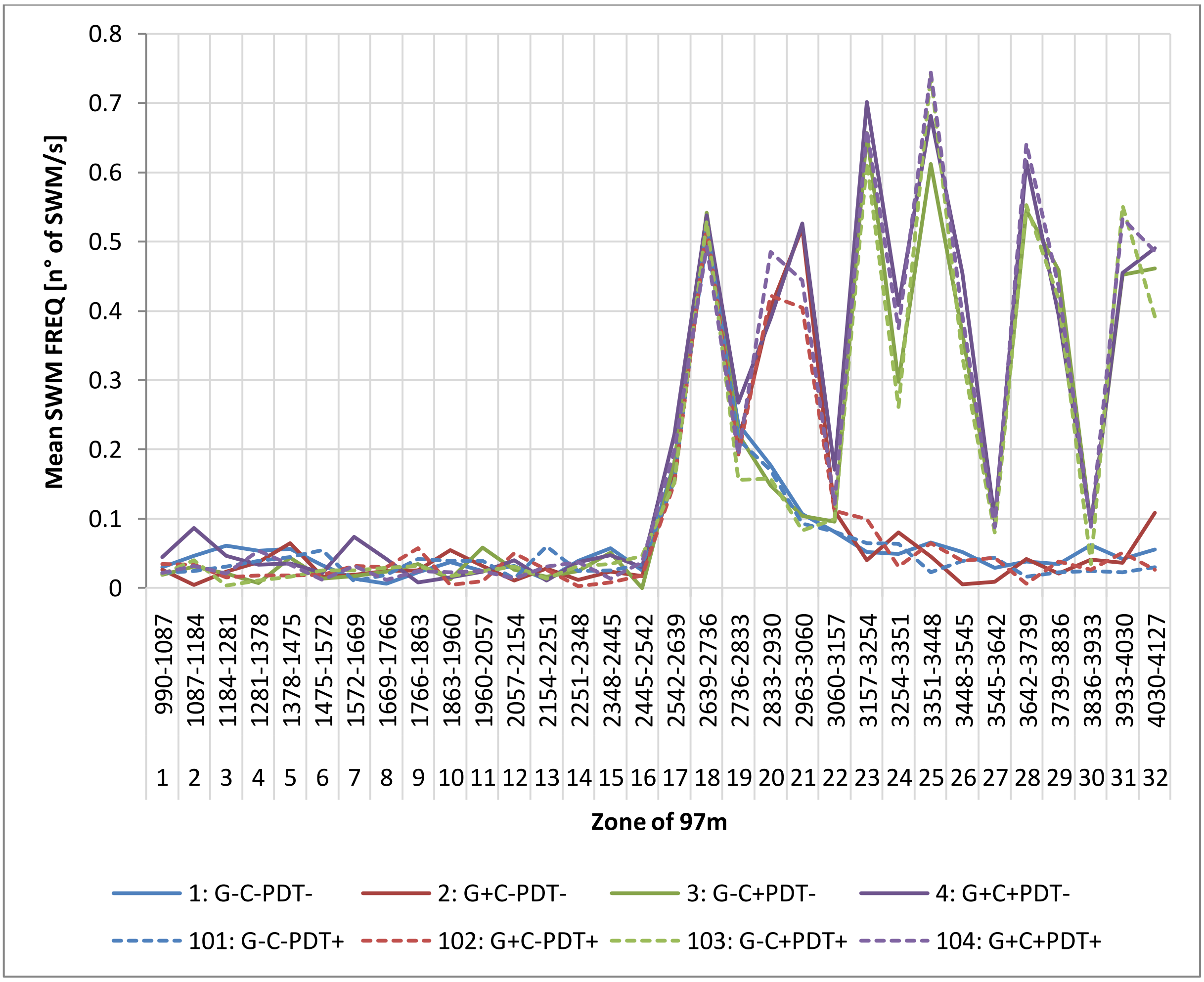

Figure 42 Mean SWM FREQ per zone of 97 m (n = 46)

On the straight monotonous road outside the built-up area mean steering wheel movement frequency (SWM FREQ) for larger SWM fluctuates around the same low value for each thoroughfare configuration. About 400 m before the built-up area mean SWM FREQ raises for each thoroughfare configuration to a peak at 250 m before the built-up area (zone nr 18) where a curve is located. After the curve mean SWM FREQ decreases again and the first differences between the different thoroughfare configuration are visible at about 200 m before the built-up area (zone 19) where mean SWM FREQ decreases further on when no gates are present and raises again when gates are present. About 200 m after the entrance (zone nr 22) mean SWM FREQ is broadly the same in each thoroughfare configuration.

In a curved thoroughfare large fluctuations in mean SWM FREQ were measured because mean SWM FREQ raises significantly in each curve. However, mean SWM FREQ decreases as more curves were passed with the lowest peak of mean SWM FREQ in the fourth curve. Between the second and the third curve mean SWM FREQ decreases more than between the first and the second curve. Throughout the thoroughfare mean SWM FREQ remains in general the same when no curves were present. Only small differences occur between mean speed with PDT and without PDT.

7.4.2 Influence of the curviness of a thoroughfare and the presence or absence of gate constructions in the whole thoroughfare

Mean steering wheel movement frequency of larger SWM (SWM FREQ) was lower when no curves were present than when there were curves (main effect Curves: $F(1, 45) = 470.148$, $p < .0005$), lower when no gates were present than when there were gates (main effect Gates: $F(1, 45) = 45.559$, $p < .0005$) and lower outside the built-up area than inside (main effect Built-up area: $F(1, 45) = 168.038$, $p < .0005$).

Table 25 Mean SWM FREQ for Curves, Gates and Built-up area (n = 46) (zone 1-20 & zone 21-32)

Curves	**Mean**	**SE**
No	.071	.005
Yes	.189	.008
Gates	**Mean**	**SE**
No	.119	.006
Yes	.141	.006
Built-up area	**Mean**	**SE**
Outside	.094	.007
Inside	.166	.007

There was an interaction of *Gates x Built-up area* ($F(1, 45) = 12.715$, $p = .001$) (see Figure 43). Separate tests showed that mean SWM FREQ was lower when outside the built-up area than inside, when no gates were present ($t(45) = -11.750$, $p < .0005$) and when gates were present ($t(45) = -11.663$, $p < .0005$). Mean SWM FREQ was lower when no gates were present, outside the built-up area ($t(45) = -3.560$, $p = .001$) and inside the built-up area ($t(45) = -6.471$, $p < .0005$).

Table 26 Mean SWM FREQ for interaction Gates x Built-up area (n = 46) (zone 1-20 & zone 21-32)

Gates	Built-up area	Mean	SE
No	Outside	.088	.007
	Inside	.150	.007
Yes	Outside	.100	.007
	Inside	.182	.008

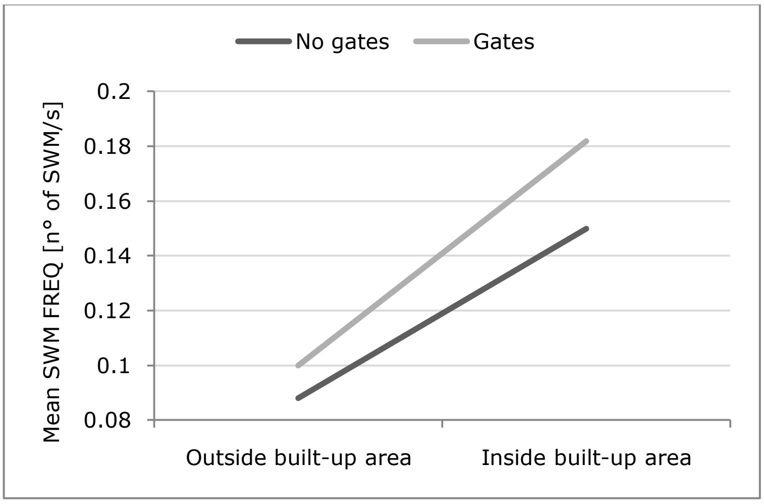

Figure 43 Mean SWM FREQ for interaction Gates x Built-up area (n = 46) (zone 1-20 & zone 21-32)

There was an interaction of *Curves x Built-up area* (F(1, 45) = 572.552, p < .0005) (see Figure 44). When this interaction was further examined mean SWM FREQ was lower inside the built-up area than outside, when no curves were present (t(45) = 7.664, p < .0005). The opposite is true when curves were present: mean SWM FREQ was lower outside the built-up area than inside (t(45) = -21.889, p < .0005). Inside the built-up area mean SWM FREQ was lower when curves were present than when there were no curves (t(45) = -24.262, p < .0005). There was no effect of Curves on mean SWM FREQ when outside the built-up area.

Table 27 Mean SWM FREQ for interaction Curves x Built-up area (n = 46) (zone 1-20 & zone 21-32)

Curves	Built-up area	Mean	SE
No	Outside	.093	.007
	Inside	.048	.004
Yes	Outside	.095	.006
	Inside	.283	.011

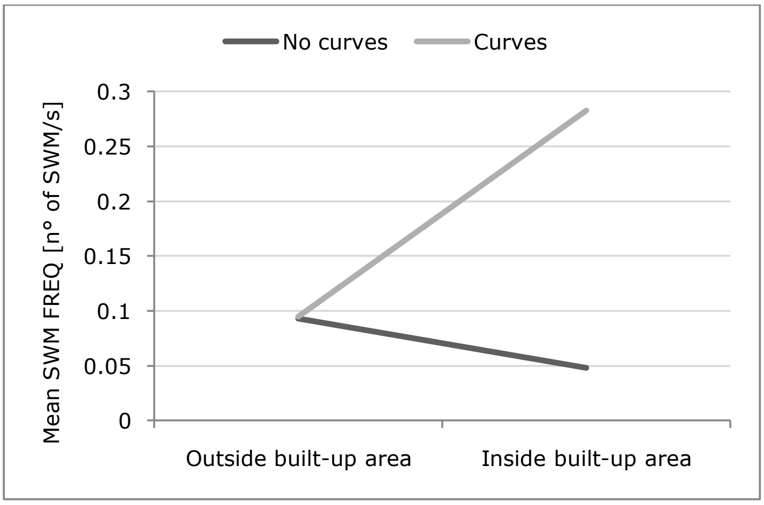

Figure 44 Mean SWM FREQ for interaction Curves x Built-up area (n = 46) (zone 1-20 & zone 21-32)

7.4.3 Influence of the curviness of a thoroughfare and the presence or absence of gate constructions at the entrance of a thoroughfare

Mean SWM FREQ was lower when no gates were present than when there were gates (main effect Gates: $F(1, 45) = 101.570$, $p < .0005$).

Table 28 Mean SWM FREQ for Gates (n = 46) (zone 20 & zone 21-22)

Gates	Mean	SE
No	.091	.014
Yes	.270	.018

There was an interaction of *PDT x Entrance* ($F(1, 45) = 5.952$, $p = .019$) (see Figure 45). Separate tests showed that mean SWM FREQ was lower before the entrance than after the entrance, when no PDT was present ($t(45) = -2.436$, $p = .019$). When PDT was present there was no effect of Entrance on mean SWM FREQ. Before the entrance mean SWM FREQ was lower when no PDT was present than when there was PDT ($t(45) = -3.196$, $p = .003$). After the entrance there was no effect of PDT on mean SWM FREQ.

Table 29 Mean SWM FREQ for interaction PDT x Entrance (n = 46) (zone 20 & zone 21-22)

PDT	Entrance	Mean	SE
No	Before	.141	.014
	After	.203	.023
Yes	Before	.202	.019
	After	.176	.029

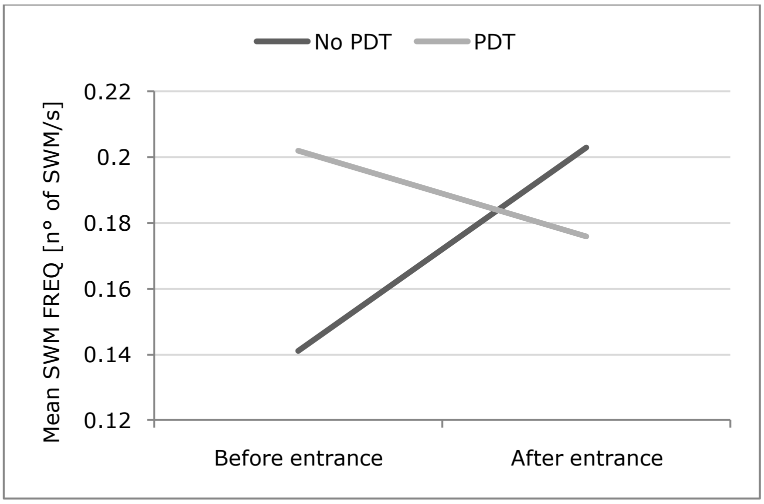

Figure 45 Mean SWM FREQ for interaction PDT x Entrance (n = 46) (zone 20 & zone 21-22)

7.4.4 Influence of continued driving in a thoroughfare

Mean SWM FREQ was lower when no curves were present than when there were curves (main effect Curves: $F(1, 45) = 601.808$, $p < .0005$), lower when no gates were present than when there were gates (main effect Gates: $F(1, 45) = 31.717$, $p < .0005$) and lower after the middle than before the middle (main effect Middle: $F(1, 45) = 40.103$, $p < .0005$).

Table 30 Mean SWM FREQ for Curves, Gates and Middle (n = 46) (zone 21-26 & zone 27-32)

Curves	**Mean**	**SE**
No	.046	.004
Yes	.281	.011
Gates	**Mean**	**SE**
No	.149	.007
Yes	.177	.007
Middle	**Mean**	**SE**
Before	.178	.008
After	.148	.006

There was an interaction of *Gates x Middle* ($F(1, 45) = 35.485$, $p < .0005$) (see Figure 46). Separate tests showed that mean SWM FREQ was lower when no gates were present than when there were gates, when before the middle ($t(45) = -6.755$, $p < .0005$). When gates were present mean SWM FREQ was lower after the middle than before the middle (t(45) = 7.448, p < .0005). There was no effect of Middle when no gates were present nor an effect of Gates after the middle.

Table 31 Mean SWM FREQ for interaction Gates x Middle (n = 46) (zone 21-26 & zone 27-32)

Gates	Middle	Mean	SE
No	Before	.153	.007
	After	.146	.007
Yes	Before	.204	.010
	After	.150	.006

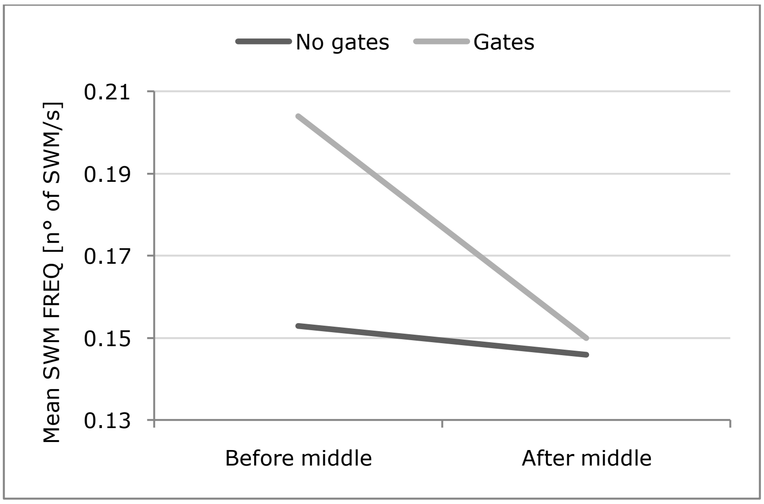

Figure 46 Mean SWM FREQ for interaction Gates x Middle (n = 46) (zone 21-26 & zone 27-32)

7.4.5 Conclusion

Mean SWM FREQ was lower outside the built-up area than inside when gates were present and when there were no gates, but the increase of the mean SWM FREQ between outside and inside the built-up area was stronger when gates were present. SWM FREQ increased between outside and inside the built-up area when curves were present whereas it decreased when there were no curves.

Before and after the entrance of a thoroughfare mean SWM FREQ was lower when no gates were present. Mean SWM FREQ increased across the entrance when no PDT was present and before the entrance it was lower than when there PDT was present.

Throughout the thoroughfare mean SWM FREQ was higher when curves were present than when there were no curves and higher before the middle than after the middle. SWM FREQ was higher when there were gates than when no gates were present only before the middle, whereas it was lowered to a level similar to when no gates were present after the middle. There was thus no effect of Gates after the middle.

7.5 Mean response time

7.5.1 Influence of the curviness of a thoroughfare and the presence or absence of gate constructions in the whole thoroughfare

Mean response time (RT) was lower outside the built-up area than inside the built-up area (main effect Built-up area: $F(1, 45) = 33.006$, $p < .0005$).

Table 32 Mean RT for Built-up area (n = 46) (stimuli 1-18 & stimuli 19-36)

Built-up area	Mean	SE
Outside	639.649	14.310
Inside	687.382	14.161

7.5.2 Influence of continued driving in a thoroughfare

There was an interaction of *Curves x Middle* ($F(1, 45) = 12.759$, $p = .001$) for mean RT (see Figure 47). When this interaction was further examined mean RT was lower after the middle than before the middle, when no curves were present ($t(45) = 2.723$, $p = .009$). The opposite was true when curves were present as mean RT was then marginally lower before the middle than after the middle ($t(45) = -1.955$, $p = .057$). After the middle mean RT was lower when no curves were present than when there were curves ($t(45) = -3.811$, $p < .0005$). There was no effect of Curves on mean RT before the middle.

Table 33 Mean RT for interaction Curves x Middle (n = 46) (stimuli 19-27 & stimuli 28-36)

Curves	Middle	Mean	SE
No	Before	699.261	17.554
	After	660.962	15.615
Yes	Before	682.798	17.642
	After	708.817	15.857

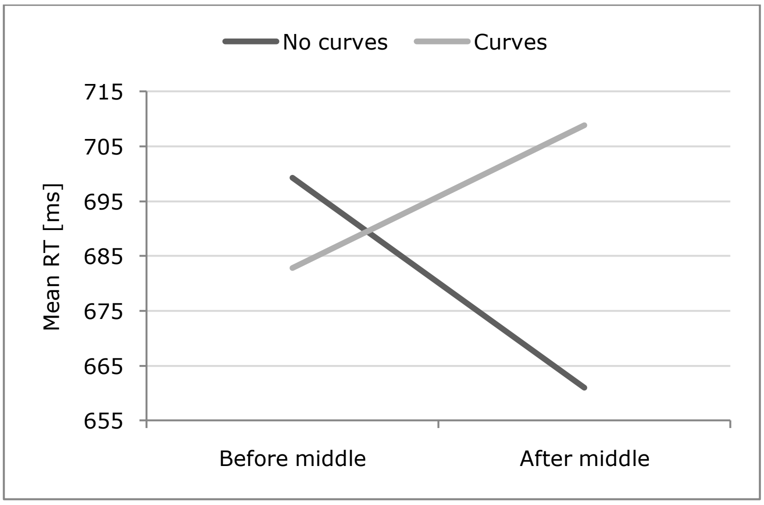

Figure 47 Mean RT for interaction Curves x Middle (n = 46) (stimuli 19-27 & stimuli 28-36)

7.5.3 Conclusion

Mean RT increased between outside and inside the built-up area. Throughout the thoroughfare mean RT increased when curves where present and decreased when no curves were present. There was no effect of Gates on mean RT.

7.6 Mean hit rate

7.6.1 Influence of the curviness of a thoroughfare and the presence or absence of gate constructions in the whole thoroughfare

Mean hit rate was lower inside the built-up area than outside the built-up area (main effect Built-up area: $F(1, 45) = 11.531$, $p = .001$).

Table 34 Mean hit rate for Built-up area (n = 46) (stimuli 1-18 & stimuli 19-36)

Built-up area	Mean	SE
Outside	98.460	.284
Inside	97.192	.417

7.6.2 Influence of continued driving in a thoroughfare

Mean hit rate was not influenced by any of the factors.

7.6.3 Conclusion

Mean hit rate decreased between outside and inside the built-up area and remained the same throughout a thoroughfare. Moreover, mean hit rate was never influenced by Curves or Gates.

Chapter 8 DISCUSSION

This driving simulator study confronted the driver with four different thoroughfare configuration (curviness: straight, curved & gate construction: present, absent) which were presented twice: once with and once without PDT. Before discussing the influence of the curviness and the absence or presence of gate construction on the speed and the attention level, it is important to know whether the assumptions were confirmed by the results.

8.1 Evaluation of the assumptions

8.1.1 Assumption about the contrast between the monotonous road environment outside the built-up area and the complex environment in the thoroughfare

The first assumption deals with the contrast between the low workload and the high speed in the monotonous road environment outside the built-up area and the high workload and the low speed in the complex environment in the thoroughfare (see paragraph 4.4.2). This assumption is evaluated on the basis of the results of analysis 1 for the different parameters. It is important to note that the road section 'outside the built-up area' in this analysis ends just before the entrance of the thoroughfare. Therefore, this road section contains not only the straight monotonous road outside the built-up area but also the curve before the ribbon building, the ribbon building and a view on the approaching thoroughfare. The graphs for each parameter per zone of 97 m (see Figure 27, Figure 30, Figure 35 and Figure 42) show a large deviation of the parameter values in the last 400 m before the built-up area. This resulted for some parameters in a significant effect of Curves or Gates outside the built-up area despite no curves and no gates were located outside the built-up area. For the evaluation of this assumption the differences between outside and inside the built-up area will be examined, indicated by a main effect of Built-up area. Furthermore, the more complex environment before the built-up area diminishes the contrast between the straight monotonous road outside the built-up area (before the curve) and the complex thoroughfare.

The results for analysis 1 showed that mean speed was lower inside the built-up area than outside. This is a logical result of the different speed limits inside and outside the built-up area. Drivers complied very well with the speed limit of 50 kph inside the built-up area (CI [43.845; 46.759]), whereas the speed limit outside the built-up area was very slightly, but significant, exceeded (CI [67.527; 70.189]). This difference of drivers not reaching the speed limit inside the built-up area while exceeding it outside the built-up area indicates that workload was lower outside the built-up area than inside the built-up area. Although there were some differences between curves/no curves and gates/no gates, SDL-A/D was always lower outside the built-up area than inside. This indicates decreased driving performance inside the built-up area which resulting from an increased workload in the complex thoroughfare. According to the SD LP the workload inside the built-up area was always higher than or equal to the workload outside the built-up area with the exception of a straight thoroughfare with gate constructions when no PDT was present. The results of the mean SWM FREQ confirm the assumption that workload is lower outside the built-up area than inside with the exception of a straight thoroughfare. In these exceptions SD LP and mean SWM FREQ was lower inside the built-up area than outside which indicates a lower workload inside the built-up area. Figure 35 and Figure 42 show that these exceptions are the result of an increased SD LP and mean SWM FREQ outside the built-up area caused by the curve before the ribbon building. The performance measures of the PDT (mean RT and mean hit rate) show a lower workload level for the secondary PDT inside the built-up area than outside which indicates that drivers experience a thoroughfare as more complex than the road outside the built-up area.

In conclusion it can be said that speed was lower and workload was higher inside the built-up area than outside the built-up area. This confirms the assumption that drivers experience the road segment outside the built-up area as monotonous and the thoroughfare as complex.

8.1.2 Assumption about PDT-instructions

The assessment of the drivers' workload level via the PDT rest on the instruction which is imposed on the drivers (see paragraph 5.3.1B). It is assumed that drivers obey the PDT-instruction through which their driving performance level is not influenced by the presence or absence of the PDT. When drivers disobey the PDT-instruction, it is expected that when PDT is present driving performance measures are influenced in the same direction as when workload increases (see paragraph 5.3.1B).

The various analyses showed that PDT influenced the driving performance measures only under certain condition and moreover often in an unexpected direction. The marginally lower mean speed in a thoroughfare when PDT was present indicates that drivers disobeyed the PDT-instruction with regard to their speeding behavior. SD LP on the other hand was influenced by PDT in an unexpected direction: in a curved thoroughfare with gate constructions SD LP was lower when PDT was present than when there was no PDT. This indicates that workload is lower when PDT was present.

Despite the fact that the driving performance measures are only (marginally) influenced by the PDT in certain specific situation (often outside the built-up area) the mean RT and the mean hit rate as performance measures of the PDT are still used to assess the drivers' workload. Furthermore, Patten et al. (2006; 2004) and Jahn et al. (2005) also used the PDT as assessment for the workload of the driving task by applying the same PDT-instruction but they did not examine the influence of the PDT on the driving performance. The six driving performance measures are used in the discussion but when an analysis showed an interaction with PDT only the results when no PDT was present will be used in the discussion.

8.2 Influence of the curviness of a thoroughfare on traffic safety and workload

8.2.1 Speed differences between straight and curved thoroughfare

Drivers approached the entrance of a thoroughfare with a higher mean speed when no curves were present than when there were curves. This speed difference between a straight and a curved thoroughfare was still present after the entrance and was continued during the whole thoroughfare. The extent to which the mean speed decreased at the entrance was not influenced by the curviness of the thoroughfare.

The lower mean speed in a curved thoroughfare was however associated with a higher SDL-A/D in that thoroughfare. This indicates that the traffic flow was more homogenous in a straight thoroughfare and that drivers made more accelerating and decelerating maneuvers throughout the whole thoroughfare when curves were present. This is the direct result from the fact that driver decrease their speed before entering a curve and accelerate again after the curve. These speed fluctuations lead automatically to a higher SDL-A/D when curves are present than when there are no curves.

Speed variations around curves have been investigated in many studies. Taragin (1954) (in Felipe, 1996) suggested that drivers adjust their speed before entering a curve and keep it constant in a curve. Mintsis (1988) (in Felipe, 1996) on the other hand found that minimum speeds were measured in the middle of the curve. The back-and-forth visual pattern, which was explored by Shinar et al. (1977) (in Shinar, 2007) (see paragraph 3.1.3A) and Tsimhoni and Green (1999) (in Dewar & Olson, 2001), showed that driver need more visual information on a curved road: visual demand began to increase about 100 m before the curve, reached a peak after the beginning and diminished throughout the curve. The demanded attention at the entry of the curve did not mirror the demanded attention at the exit. In addition, amongst others Laya (1992) (in Dewar & Olson, 2001), found that the pattern of eye fixations varies throughout the curve sequence (approach and entry, in curve and exit). McDonald and Ellis (in Dewar & Olson, 2001) found that a curved road required more allocated attention than a straight road. In addition, several studies mentioned in Dewar and Olson (2001) found that curves increased workload which was highly dependent on the curve geometric characteristics (curve radius and deflection angle as a measure of curve length).

The lower mean speed before and after the entrance when curves were present was caused by the fact that drivers see the upcoming curve[7] and as response lower their speed to cope with the higher environmental demanded attention in that curve[8]. Although curves have a speed reducing effect before and after the entrance, SDL-A/D was not influenced by curves around the entrance of the thoroughfare[9]. The difference of SDL-A/D between a straight and a curved thoroughfare was thus not yet present after the entrance. Two possible explanations are provided here. First, drivers may have decreased their speed after the entrance of the thoroughfare to such an extent that an

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[7] The second analysis zone of analysis 2 (zone 21-22) ends 3 m before the beginning of the first curve.

[8] An additional analysis in which zone 20 (97 m before the entrance) versus zone 21 (97 m after the entrance and thus 100 m before the first curve) was analyzed showed only a marginal main effect of Curves ($F(1, 45) = 3.575$, $p = .065$). Mean speed was marginally lower when curves were present than when there were no curves, before and after the entrance. The effect of Curves on mean speed occurs thus mainly in zone 22 which ends 3 m before the first curve.

[9] However, when PDT was present, the speed reduction effect of curves before the entrance was accompanied by a higher SDL-A/D when gates were present.

additional deceleration before the first curve was not necessary to experience a safe drive. The absence of that additional decelerating maneuver can explain the absence of an effect of Curves on SDL-A/D after the entrance. An accelerating maneuver after the first curve and a decelerating and accelerating maneuver around the second curve can explain the higher SDL-A/D when curves were present than when there were no curves before the middle. Second, drivers did not reduce their speed enough to drive safely through the first curve and therefore had to decelerate before they entered the curve. The absence of an effect of Curves on SDL-A/D in the road section between 197 m and 3 m (zone nr 21-22) before the curve indicates that drivers decreased their speed suddenly just before they entered the first curve. The first explanation better fits with our data because no sudden speed decrease was established in zone nr 23 where the first curve was located whereas speed variations around the following three curves were present. These results suggest that the first curve in a thoroughfare did not come as a surprise, as hypothesized in paragraph 4.4.2.

These results confirm the hypothesis that drivers try to cope with the unexpected situations of a curve by reducing their speed and that this lower speed is maintained throughout the whole thoroughfare. In addition, the lower speed before and after the entrance when curves were present than when there were no curves indicates that speed adaptation is opposed by the curves in a thoroughfare. The resulting speed fluctuations in a curved thoroughfare have a negative impact on the homogeneity of the traffic flow and can endanger road safety before and after a curve, for example by an increased number of rear-end collisions. In conclusion, curves have a positive impact on traffic safety, because mean speed is reduced but at the same time the homogeneity of the traffic flow is diminished by the increased SDL-A/D which can have a negative impact on traffic safety.

8.2.2 Workload differences between straight and curved thoroughfares

The continued lower mean speed in a curved thoroughfare than in a straight one indicates that driver’s workload was higher when curves were present. Furthermore, higher SD LP and higher mean SWM FREQ in the whole curved thoroughfares also indicated increased workload when curves were present. Finally, mean RT of the PDT was higher when curves were present than when there were no curves, but only after the middle of the thoroughfare. This result indicates that drivers experience a higher workload when driving in a curved thoroughfare.

Looking at Figure 35 and Figure 42, the use of SD LP and mean SWM FREQ as measures of workload can be criticized because these measures clearly fluctuate with the location of curves. The higher mean SWM FREQ is the logical result of the fact that drivers have to make (more) SWM to follow the curved road. The increased SD LP on the other hand is the result of the corner cut which drivers make during their drive through a curve and the adjustments of the steering angle throughout the curve. Despite the fact that mean SD LP and mean SWM FREQ depend highly on the curviness of the road, the high values in a curved thoroughfare can have a negative impact on traffic safety.

An additional analysis wherein the SD LP and mean SWM FREQ are compared for the four curves in the thoroughfare can increase the insight in drivers' workload levels in different curves. Despite the fact that the curve number 1 and 4 and curve number 2 and 3 had the same design Figure 35 and Figure 42 showed differences between these curves. Different levels of workload and driving performance in different curves is the result of the different perception of curve geometric characteristics which was explained in paragraph 8.2.1.

In conclusion, the lower mean speed, the higher SD LP and the higher mean SWM FREQ in a curved thoroughfare confirm the hypotheses that curves increase workload. Although the reduced mean speed in curved thoroughfares should improve traffic safety, the higher SD LP and the higher mean SWM FREQ can have a negative impact on traffic safety because of the increased risk to collide with other road users (e.g. driving in the opposite driving direction), road furniture or parked vehicles.

8.3 Influence of the absence or presence of gate constructions on traffic safety and workload

8.3.1 Speed differences between gates and no gates

Gate constructions have only an effect on the mean speed around the entrance of the thoroughfare. Mean speed was lower when gates were present than when there were no gates, both before and after the entrance, but larger speed decreases between before and after the entrance were measured when no gates were present. The fact that mean speed outside the built-up area is not influenced by the absence or presence of gate constructions indicates that the interaction of Gates and Entrance began when mean speed decreased more during the approaching of the thoroughfare with gate constructions. The moment when this larger speed decrease takes place is not analyzed but Figure 27 suggests that the decrease begins about 200 m before the entrance gate (zone nr 19).

The fact that mean speed before the middle of the thoroughfare is not influenced by the presence or absence of gate constructions indicates that the lower mean speed after an entrance gate is only maintained very locally. The exact distance that this lower speed is maintained is not analyzed, but Charlton and O'Brien (2002) found that the speed reduction caused by a gate construction disappears after 250 m. In addition, they noted the presence of a habituation effect of gates which will diminish the local speed reduction effects with repeated exposure.

The analyses of the SDL-A/D showed that accelerating and decelerating maneuvers were brusquer when gates are present. This effect was not only present before and after the entrance gate but also before the middle of the thoroughfare. The SDL-A/D after the middle of the thoroughfare is not influenced anymore by the presence or absence of gate constructions. In addition, SDL-A/D decreased throughout the thoroughfare whether gate constructions were present or not which results in a more homogenous traffic flow after the middle of the thoroughfare.

The combination of a smaller deceleration between before and after the entrance of a thoroughfare when gates were present than when there were no gate and the higher SDL-A/D both before and after an entrance gate indicates that the deceleration at an entrance with gates expired brusquer than when no gates were present. The larger speed decrease at the entrance when no gates were present is thus the result of a little by little deceleration. The fact that the lower mean speed after an entrance gate is not maintained throughout the thoroughfare and even disappeared before the middle of the thoroughfare indicates that drivers accelerated more after the entrance of the thoroughfare when gates were present than when there were no gates. This strong accelerating maneuver is also shown in Figure 27 and the results of SDL-A/D indicated that it was very brusque (see Figure 30). Although the local speed reduction effect of gates improve traffic safety, the increased SDL-A/D interrupts the homogeneity of the traffic flow seriously which has in turn a negative impact on traffic safety.

These results confirm partially the stated hypotheses. Gate constructions reduced mean speed significantly at the entrance of the thoroughfare but this speed reduction is only very local maintained. The involved accelerating and decelerating maneuvers before and after the entrance gate and before the middle of the thoroughfare were brusquer than when no gates were present. In addition, the local speed reduction and the stronger decelerating maneuvers may be an indication of the interruption of the speed adaptation which was formed during the monotonous drive outside the built-up area. While the brusque accelerating maneuvers after the entrance gate and the absence of a speed difference before the middle of the thoroughfare between gates and no gates reject the hypothesis that gate constructions interrupt speed adaptation. In general, gates interrupt speed adaptation only very local. Gate constructions have thus only a local speed reduction effect and interrupt the homogeneity of the traffic flow. The desired traffic safety improvement provoked by gate construction can therefore be questioned thoroughly.

8.3.2 Workload differences between gates and no gates

The lower mean speed before and after the entrance gate than when no gates were present indicates that drivers' workload was higher when gates were present. The result of SD LP and mean SWM FREQ confirm this result: the higher SD LP and the higher mean SWM FREQ before and after the entrance when gates were present indicate a higher workload when gates were present. Whereas mean speed, mean RT and mean hit rate did not differ between gates/no gates before and after the middle of the thoroughfare, SD LP and mean SWM FREQ was higher when gates were present than there were no gates before the middle. After the middle there was no effect of Gates on SD LP or mean SWM FREQ. The absence of an effect of Gates on mean speed, mean RT and mean hit rate indicate that workload was not higher when gates were present. According to the results of SD LP and mean SWM FREQ workload was higher when gates were present, but only before the middle of the thoroughfare. The dissociation between these different measures for workload may indicate that not all these measures are sensitive to workload in the same area of performance (see paragraph 3.2.5). In general, gates have only a local workload increasing effect which is maybe prolonged till the middle of the thoroughfare.

The decrease of mean speed at the entrance of the thoroughfare, when gates were present or not, indicate an increase of the workload between before and after the entrance. However, SD LP showed an opposite relation. When gates were present SD LP was higher before the entrance than after which indicates a decrease of the workload between before and after the entrance. There was no difference of workload between before and after the entrance when no gates were present. Despite that mean SWM FREQ was higher when gates were present than there were no gates, before and after the entrance, there was no difference of the workload level between before and after the entrance, when gates were present or not. It is worth noting that the increased SD LP and mean SWF FREQ were not the result of the steering maneuvers itself in the gate because the road segments between F1 and the end of the entrance gate were excluded from the analysis zones (see paragraph 6.2.1).

As with the effect of Gates before the middle, the workload differences between before and after the middle are subject to dissociation. Nevertheless, the opposite relation between mean speed and SD LP may arise from the increased visual demand before the entrance gate. The gate construction in this study with non-parallel axis displacement and central reservation (see paragraph 5.3.2) increase visual demand as with curves. When gates provoke the same behavioral adaptations as curves do (see paragraph 8.2.1) it can be supposed that:

- Gates cause a speed reduction before entering the gate (Taragin, 1954) (in Dewar & Olson, 2001). Figure 27 showed that mean speed decreased seriously in the 97 m before the entrance gate (zone nr 19). This was also confirmed in analysis 2 where mean speed was lower when gates were present than when there were no gates. In addition, SDL-A/D was higher before the entrance when gates were present than there were no gates. Figure 30 showed that SDL-A/D peaked more when gates were present than when there were no gates at the same location. When mean speed is, as with curves (Mintsis, 1988) (in Felipe, 1996), minimized in the gate it is not uncommon that mean speed is lower after the gate. This could explain the speed reduction between before and after the entrance gate. Additional analyses are needed to determine the exact distance at which gates begin to have a speed reduction effect.
- Gates increase visual demand about 100 m before the gate. The higher workload when gates were present as a result of this increased demanded attention was shown for mean speed, SD LP and mean SWM FREQ. The decrease of the workload between before and after the entrance gate as indicated by SD LP can be caused by the fact that high demanded attention at the entry of the gate

(before entrance) did not mirror the demanded attention at the exit (after entrance).

- The geometric characteristics of gates influence the workload before, in and after these gates. This way of thinking can however not be proved in this driving simulator study because only one type of gate construction was used.

In conclusion, the lower mean speed, the higher SD LP and the higher mean SWM FREQ before and after the entrance gate indicate that gates increase workload before and after the entrance. According to SD LP and mean SWM FREQ this higher workload is prolonged till the middle of the thoroughfare whereas mean speed showed only a local workload increase around the entrance gate. The workload differences between before and after the entrance show at first sight some dissociation but a parallel way of thinking between behavioral adaptations in curves and gates can clarify this dissociation. It is supposed that mean speed is decreased before entering the gate and minimized in the gate. These speed reductions can lead to a lower mean speed after the entrance gates than before which result in a higher workload after the entrance gate than before. The dissimilarity between the high demanded attention at the entry of the gate and the demanded attention at the exit is shown by the decrease of SD LP between before and after the entrance gate and indicate a decrease of the workload. In general, the local reduced mean speed when gates were present can improve traffic safety, though the impact would be very local. The higher SD LP and the higher mean SWM FREQ when gates are present can have a negative impact on traffic safety because of the increased risk to collide with other road users (e.g. driving in the opposite driving direction), road furniture or parked vehicles. These potentially negative impacts would however be disappeared after the middle of the thoroughfare.

8.4 Speed and workload differences with prolonged driving throughout thoroughfares

For each level of Curves and Gates mean speed increased between before the middle and after the middle of the thoroughfare. This speed increase is accompanied with a decreased workload throughout the thoroughfare which was also indicated by the decreased mean SWM FREQ. The lower workload level after prolonged driving was also established by Campagne, Pebayle and Muzet (2005), Rogé et al. (2005), Thiffault and Bergeron (2003) and Matthews and Desmond (2002). Those authors hypothesized that when the duration of the driving task increased attention level and driving performance decreased. However they used different measurement for attention and driving performance, they all established that an attention or driving performance decreased and/or drowsiness increased after prolonged driving in a monotonous environment.

Campagnes (BRON) found that the reduction in blinking and ocular activity, as a measure for attention, was smaller for less significant events. They concluded that attention and driving performance decreased with increased duration of driving (two hours of driving). Rogé et al. (BRON) established a link between the duration of monotonous driving in traffic and general inference and tunnel vision. When time-of-task increased (total two hours of driving) driver's longitudinal stability and detection of central signal decreased. Both studies found that increased age had more negative effects on attention and driving performance after prolonged driving. Matthews and Desmond (BRON) found also decreased signal detection as driving time increased. Thiffault and Bergeron (BRON) found that when driving in a more monotonous environment mean SWM FREQ of larger SWM[10] increased as time-on-task increased, which implied that fatigue en vigilance increased.

A similar parallel connection can be making with this driving simulator study where mean speed increased as driving time increased between before and after the middle of the thoroughfare. The increased mean speed and the decreased mean SWM FREQ indicate a lower workload after the middle but this decreased workload level was not measured in terms of SD LP and indicate a dissociation between the different workload measures. It is however not clear which effect age plays in these results but the equal division of participant of the different age categories would facilitate additional investigations. Finally, it is worth nothing that the mean speed increase between before and after middle only was 2 kph which could questioning the above way of thinking.

In conclusion it can be said that drivers practice a negative behavioral adaption throughout the thoroughfare by increasing their mean speed and at the same time increasing their SD LP under the influence of a decreasing workload. These behavioral adaptations can result in a negative impact on traffic safety. It is however a good option to implement curves in a thoroughfare because mean speed was lower in a curved thoroughfare than in a straight one, before and after the middle.

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[10] Larger SWM were defined as SWM with an angle between 6 and 10°.

Chapter 9 CONCLUSION

This driving simulator study investigated the effect of the curviness of thoroughfare configurations and the absence and presence of gate constructions on traffic safety and workload. Traffic safety was not only approached from difference in mean speed between different thoroughfare configuration but other driving performance measures were used to evaluate the effect of curviness and gate constructions on traffic safety.

The results showed that curves have a speed reduction effect which was maintained throughout the whole thoroughfare, but this lower mean speed was accompanied by a higher SDL-A/D in a curved thoroughfare. The lower mean speed, the higher SD LP and the higher mean SWM FREQ in a curved thoroughfare confirm the hypotheses that curves increase workload. Although the reduced mean speed in curved thoroughfares should improve traffic safety, the higher SDL-A/D, the higher SD LP and the higher mean SWM FREQ can have a negative impact on traffic safety because of the diminishing of the homogeneity of the traffic flow and the increased risk to collide with other road users, road furniture or parked vehicles.

Gates have only a local speed reduction effect before and after the entrance of the thoroughfare. The higher SDL-A/D around the entrance gate and before the middle of the thoroughfare indicates that the local lower speed around gates was achieved by a brusquer decelerating maneuver before the entrance gate and a brusquer accelerating maneuver after the gate to reach the same speed level as when no gates were present. The lower mean speed, the higher SD LP and the higher mean SWM FREQ before and after the entrance gate indicate that gates increase workload before and after the entrance. In general, the local reduced mean speed when gates were present can improve traffic safety, though the impact would be very local. The higher SDL-A/D, the higher SD LP and the higher mean SWM FREQ when gates are present can have a negative impact on traffic safety because of the diminishing of the homogeneity in the traffic flow and an increased risk to collide with other road users, road furniture or parked vehicles. The desired traffic safety improvement provoked by gate construction can therefore be questioned thoroughly.

In conclusion, curves have more potential to improve traffic safety in thoroughfare whereas gates may only have a positive impact on traffic on a very local scale. It is however important to design the infrastructural characteristics of curves and gates in a way that all determinants of traffic safety are considered.

Chapter 10 RECOMMENDATIONS

In the last phase in this study (*advice*) recommendations are formulated which can be useful to take into account in future thoroughfare reconstructions.

Based on the results it is recommended to implement curved thoroughfares because of their speed reduction effect. The potential negative compensational behavioral adaptations by means of higher SDL-A/D, SD LP and mean SWM FREQ should be minimized by the development of forgiving roads (Odgen, 1996). As was discussed in paragraph 8.2.1 the curve geometric characteristics have a significant impact on driving performance before, in and after a curve. An optimal curve radii, which is correctly estimated by drivers, is thus recommended to minimize SDL-A/D, SD LP and mean SWM FREQ in a curved thoroughfare. Wider traffic lanes and recovery areas next to the traffic lane should set off collisions with other road users (e.g. driving in the opposite driving direction), road furniture or parked vehicles when SD LP and mean SWM FREQ increase.

Gate constructions on the other hand are only recommended in certain circumstances. The implementation of gate constructions should depend on the traffic function in thoroughfares and the residential function around the entrance of thoroughfares. That is, in thoroughfares that mainly have a traffic function and an important traffic flow the implementation of gate constructions will not improve traffic safety, and may even decline traffic safety because of interruption of the homogeneity of the traffic flow at these gate constructions. In that case, the local speed reduction effect does not outweigh this negative impact. However, in thoroughfares that have an important residential function which generates a large number of vulnerable road users (such as a school, a hospital or a shopping centre), the speed reduction effect will outweigh the interruption of the homogeneity of the traffic flow. The design of these gate constructions should also be based on the principles of forgiving roads. Because of the similarity between the behavioral adaptations caused by curves and gates (see paragraph 8.3.2) it is recommended to use optimal radii in the gate construction, to increase traffic lane width before, in and after the gate construction and to construct recovery areas next to the traffic lanes. These forgiving road design elements should minimize negative impact of higher SDL-A/D, SD LP and mean SWM FREQ. It is however recommended to examine the effect of different gate construction designs on traffic safety.

Finally, it is recommended to do some additional analyses which zoom in on road segments of interest. These analyses could provide additional detailed information about how and when drivers adapt their behavior. Examples of additional analyses are the examination of the decelerating and accelerating behavior before and after gate construction, the examination of the driving behavior at the exit of a thoroughfare and the comparison of the driving behavior in the four curves of a curved thoroughfare.

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ANNEX

Annex 1 Angular velocity

The differences in the rate of change of the visual angle to elements in the driver's visual field can explain the differences in speed estimations between the peripheral and foveal vision. The visual angle from a driver's view towards the focus of expansion increases as the driver moves continues forward towards the focus of expansion. The further the element is from the driver's forward central line of sight, the greater the extent the visual angle increases. This is shown in the figure below where the angle θ_x for car x has a larger rate of change than the angle θ_y does for car y because the environmental element of car x is further away from the observer's point of view (Godley, 1999).

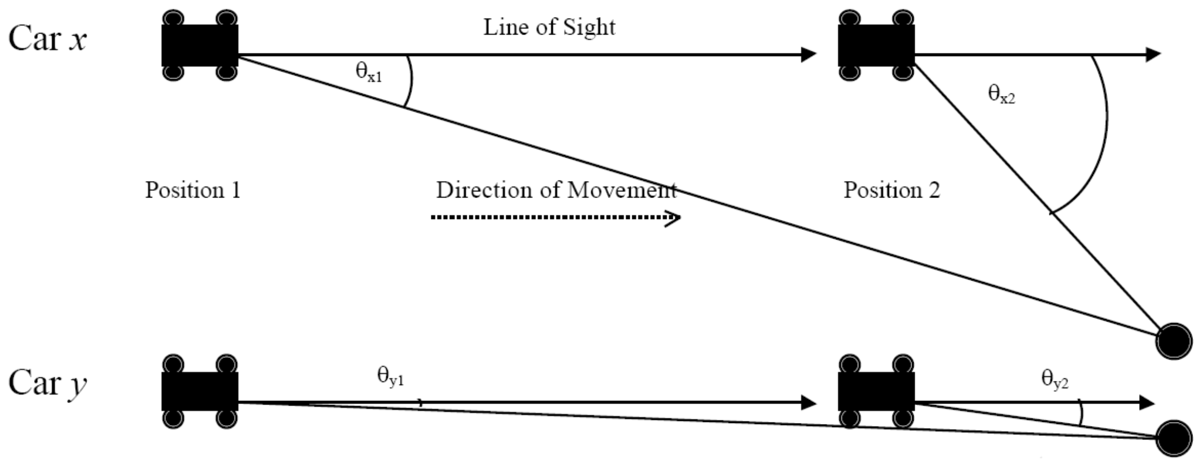


Figure 48 Angular velocity for peripheral (car x) and central (car y) vision
Source Godley (1999)

Annex 2 Environmental demands exceed driver performance

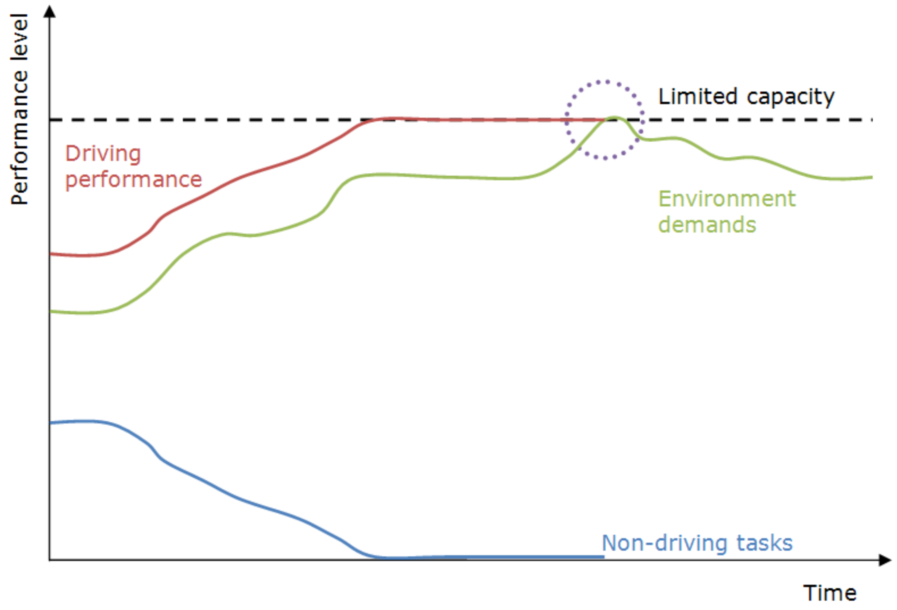


Figure 49 Environment demands exceed driver performance because of insufficient capacity

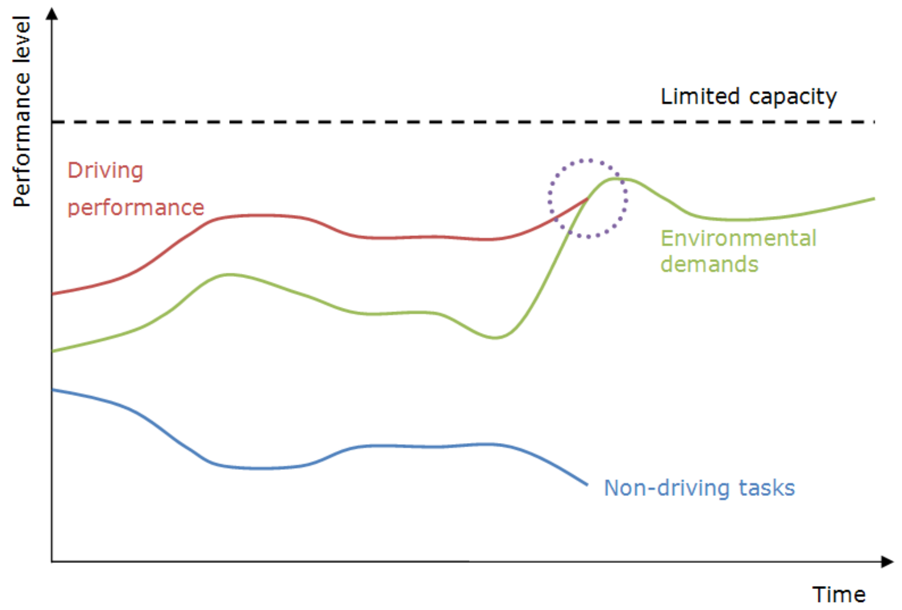


Figure 50 Environment demands exceed driver performance because of insufficient time

Annex 3 Wilde's risk model

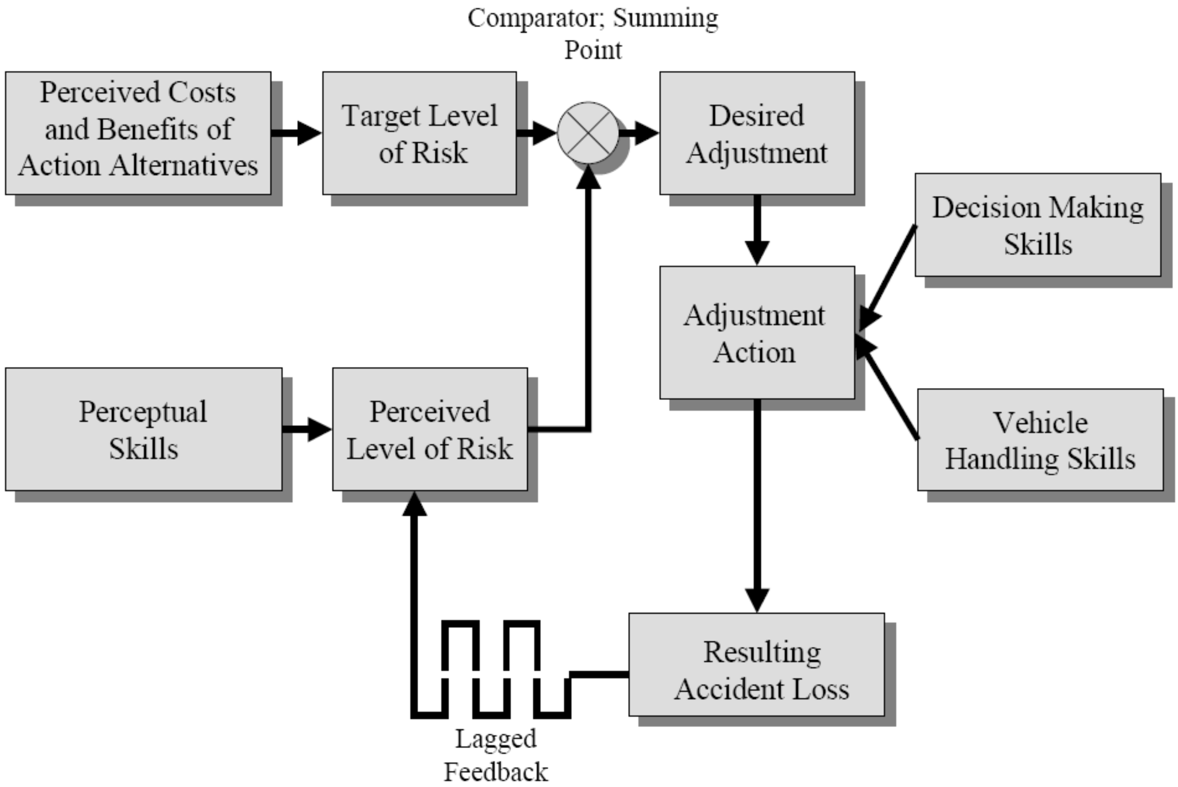


Figure 51 Wilde's risk model
Source Wilde (1994) (in Weller et al., 2006)

Annex 4 Effectiveness of gate constructions

Table 35 Effectiveness of gate constructions

Gates without other traffic calming devices in the built-up area			
Speed reduction (V_{85})		*Crash reduction*	
10 km/h	VISP (1994) (in Lamberti et al., 2009)	10% slightly injured 43% seriously injured and fatalities	Taylor and Wheeler (2000)
At the gates: 5 to 24 km/h In the built-up area: 5 to 22 km/h	Taylor and Wheeler (2000)		
Very little impact to 11 km/h dependent on the traffic calming strategy	Hallmark et al. (2007)		

Gates with other traffic calming devices in the built-up area			
Speed reduction (V_{85})		*Crash reduction*	
15 km/h	VISP (1994) (in Lamberti et al., 2009)	37% slightly injured 70% seriously injured and fatalities	Taylor and Wheeler (2000)
25 km/h	DETR (2005) (in Lamberti et al., 2009)		

Source See table

Annex 5 Descriptive statistics of participants

Table 36 General statistical descriptives

	N	Minimum	Maximum	Mean	SD
Age	46	20.0	75.0	45.3	16.1
Travelled distance per year as driver	46	3 000	55 000	16 163.0	11 448.9

Table 37 Descriptive statistics of the age for the different age categories

		N	Minimum	Maximum	Mean	SD
20-29	Man	5	22.0	28.0	24.4	2.608
	Woman	5	20.0	26.0	23.0	2.237
30-39	Man	5	34.0	39.0	37.4	2.074
	Woman	4	30.0	39.0	34.3	4.425
40-49	Man	5	41.0	49.0	45.8	3.564
	Woman	3	40.0	48.0	43.7	4.041
50-59	Man	4	52.0	59.0	55.0	2.944
	Woman	5	51.0	57.0	53.6	2.191
60 and older	Man	5	64.0	75.0	69.6	4.615
	Woman	5	61.0	75.0	65.4	6.107

Table 38 Descriptive statistics of the travel distance per year as driver for the different age categories

		N	Minimum	Maximum	Mean	SD
20-29	Man	5	7 500.0	35 000.0	15 200.0	11 261.661
	Woman	5	5 000.0	30 000.0	11 800.0	10 353.743
30-39	Man	5	15 000.0	50 000.0	26 600.0	13 612.494
	Woman	4	9 000.0	35 000.0	21 000.0	11 430.952
40-49	Man	5	5 000.0	55 000.0	22 000.0	19 248.377
	Woman	3	6 000.0	30 000.0	15 333.3	12 858.201
50-59	Man	4	15 000.0	24 000.0	17 250.0	4 500.000
	Woman	5	5 000.0	10 000.0	6 900.0	2 133.073
60 and older	Man	5	9 000.0	25 000.0	13 200.0	6 685.806
	Woman	5	3 000.0	25 000.0	13 200.0	9 038.805

Annex 6 Consent form

Driving simulator study

Dear participant

Thanks again for participating in this driving simulator study as part of my Master Thesis Transport Studies at the University of Hasselt.

Before the examination starts in the driving simulator, it is intended that you wait HERE till the researcher calls for you. While you wait here, you may take a drink and a titbit. To reduce the time in the stimulator room it is asked to go through this sheaf quietly and attentive and to fill it in.

First, some general information about the driving simulator study is given after which you are asked to sign this document that you provide your consent for this experiment. Finally, some participants data is collected by answering several questions.

Thanks very much!

Caroline Ariën

Consent form

This driving simulator study is part of the Master Thesis of Caroline Ariën (Traffic Engineering student at the University of Hasselt). The overall goal of this study is to improve road safety. The specific aim of this study should not be disclosed in advance because drivers can adapt their driving accordingly resulting in biased results. When all drivers participated in the experiment, you will be informed about the purpose of this driving simulator study.

As driver you will make few drives in the driving simulator and each trip is alternated with a break. It is expected that you behave as a driver as you normally would behave in traffic. During some drives it is asked to perform some additional tasks. This will be discussed further in the driving simulator room. Data about your driving behavior will be collected during the drives. These data will be kept, analysed and reported in scientific research completely anonymous.

Finally, there is a chance that you face driving simulator sickness. Some symptoms are dizziness, headache and a thin feeling. If you recognizes symptoms of simulator sickness, you are requested to inform the researched immediately. Besides, you are always free to terminate the experiment.

I, the undersigned participant, grant my permission to participate in the Master Thesis of Caroline Ariën.

I certify that I voluntarily participate in this study, the right at any time preserving my participation in the investigation to stop, pass any information to other people and i will behave as I normally behave in traffic.

This is to certify that I will participate voluntarily in this experiment, that I have the right to terminate the experiment at any time, that I pass no information to other persons and that I will behave myself as I normally should do in traffic.

Date:

Name and signature of the participant:

Signature of the researcher:

Participants details

These data will be kept, analysed and reported in scientific research completely anonymous.

Date of birth: ____ / ____ / ________

Sex: M / W

Are you left- or right-handed: L / R

Do you wear glasses or contact lenses: Yes / No

Since when do you have a driver's license in your possession? ____ / ____ / ________

Estimated travel distance per year as driver: _____________ km

How often are you as a driver involved in an accident?

- Never
- _____ time with only material damage
- _____ time with slightly injured
- _____ time with seriously injured
- _____ time with fatalities

Annex 7 Computation steering wheel movement parameters

Steering wheel movement frequency = amount of steering wheel movements (SWM) per second

Step 1: Prepare basic data

Access

1. Make a query which gets the following columns from the Stisim style table (PersonID, zone, 1, 6, 11). Each thoroughfare configuration is divided into 32 zones of 97m. The number 1, 6 and 11 reflect the parameter number of Stisim and thus represent:

   1) Elapsed time since the beginning of the run (seconds)

   6) Total longitudinal distance that the driver has travelled since the beginning of the run (meters)

   11) Steering wheel angle input (degrees)

   ```
   SELECT [Stisim style].PersonID, [Stisim style].Zone, [Stisim style].[1], [Stisim style].[6], [Stisim style].[11]
   FROM [Stisim style]
   WHERE ((([Stisim style].Zone)>0));
   ```

2. Save query as **Steering frequency basic data query**.

SPSS

3. Run the query **Steering frequency basic data query**.
   File_Open database_New query
4. Save data as **1 Basic data**

   ```
   SAVE OUTFILE='E:\Allemaal\Caroline\Data-
   analyse\Bewerkingen\Berekening steering frequency\1 '+
     'Basic data.sav'
    /COMPRESSED.
   ```

5. Define the analysis zones. There are three analysis each comparing two analysis zones for each of the eight thoroughfare configurations.
   a. Analysis zones for the analysis of the built-up area as a whole

      ```
      IF  (Zone < 20 or (Zone > 100 and Zone < 121))
      analysiszone_builtup=11.
      EXECUTE.
      IF  (Zone > 120 and Zone < 133) analysiszone_builtup=12.
      EXECUTE.
      ```

```
IF ((Zone > 20 and Zone < 30) or (Zone > 200 and Zone < 221))
analysiszone_builtup=21.
EXECUTE.
IF (Zone > 220 and Zone < 233) analysiszone_builtup=22.
EXECUTE.
IF ((Zone > 30 and Zone < 40) or (Zone > 300 and Zone < 321))
analysiszone_builtup=31.
EXECUTE.
IF (Zone > 320 and Zone < 333) analysiszone_builtup=32.
EXECUTE.
IF ((Zone > 40 and Zone < 50) or (Zone > 400 and Zone < 421))
analysiszone_builtup=41.
EXECUTE.
IF (Zone > 420 and Zone < 433) analysiszone_builtup=42.
EXECUTE.
IF ((Zone > 1010 and Zone < 1020) or (Zone > 10100 and Zone <
10121)) analysiszone_builtup=1011.
EXECUTE.
IF (Zone > 10120 and Zone < 10133) analysiszone_builtup=1012.
EXECUTE.
IF ((Zone > 1020 and Zone < 1030) or (Zone > 10200 and Zone <
10221)) analysiszone_builtup=1021.
EXECUTE.
IF (Zone > 10220 and Zone < 10233) analysiszone_builtup=1022.
EXECUTE.
IF ((Zone > 1030 and Zone < 1040) or (Zone > 10300 and Zone <
10321)) analysiszone_builtup=1031.
EXECUTE.
IF (Zone > 10320 and Zone < 10333) analysiszone_builtup=1032.
EXECUTE.
IF ((Zone > 1040 and Zone < 1050) or (Zone > 10400 and Zone <
10421)) analysiszone_builtup=1041.
EXECUTE.
IF (Zone > 10420 and Zone < 10433) analysiszone_builtup=1042.
EXECUTE.
```

b. The same can be done for the analyses at the entrance (*analysiszone_entrance*) and in the middle of the thoroughfare (*analysiszone_middle*).

Step 2: Trace SWM with rotation velocity ≥ 1°/sec

Trace the rows at which a steering wheel movement (SWM) or steering reversals takes place. A movement or reversal is defined as a change in magnitude from a clockwise movement to a counterclockwise movement (or vice versa) for which the absolute rotation velocity exceeds or equals 1° per second (Verwey & H. A. Veltman, 1996). It is also possible to ignore this last condition.

Step 2.1: Trace SWM independent on their rotation velocity

*SPSS: Use dataset **1 Basic data***

Compute the difference between the present angle and the previous angle. This difference gives information about the magnitude in which the driver is rotating the steering wheel. For example, when the driver is turning to the right from 0° (= previous angle) to 3° (= present angle), the difference will be positive. Afterwards the driver is immediately rotating the steering wheel to the left from 3° to 1°. This time, the difference between the present angle (1°) and the previous angle (3°) will be negative. The adjustment from a positive to a negative angle difference indicates thus a movement. The start angle and the end angle are needed to compute the angle size of the SWM. In Table 39 an example about the tracing of movements independent on their rotation velocity is given.

1. Before starting, it is necessary to sort the column *PersonID* ascending and afterwards do the same with the column *@1*. This ensures that the previous angle is followed by the present angle.

```
SORT CASES BY PersonID(A) @1(A).
```

2. Put column *@11* one row lower and call it *prev_11*

```
COMPUTE prev_11=lag(@11).
EXECUTE.
```

3. Compute the difference between the present angle and the previous one and call this column *diff*.

   But before doing so, it has to be sure that the previous and the present angle are logged for the same subject in the same analysis zone.

   a. Put columns *PersonID*, *analysiszone_builtup*, *analysiszone_entrance* and *@1* one row lower and call them *prev_personid*, *prev_analysiszone_builtup*, *prev_analysiszone_entrance* and *prev_1*

```
COMPUTE prev_personid=lag(PersonID).
EXECUTE.
COMPUTE prev_analysiszone_builtup=lag(analysiszone_builtup).
```

```
EXECUTE.
COMPUTE prev_analysiszone_entrance=lag(analysiszone_entrance).
EXECUTE.
COMPUTE prev_1=lag(@1).
EXECUTE.
```

b. Compute *diff* in the case that *prev_personid = PersonID* and *prev_analysiszone_builtup = analysiszone_builtup.* Because the *analysiszone_entrance* has the same boundary as the *analysiszone_builtup* it is sufficient to set the condition about the *analysiszone_builtup*.

```
IF  ((prev_personid = PersonID) and (prev_analysiszone_builtup =
analysiszone_builtup)) diff=@11 -
   prev_11.
EXECUTE.
```

4. Put column *diff* one row lower and call it *prev_diff*. This column can also be obtained by putting the row *prev_11* one row lower (= *prev_prev_11*) and compute the difference between *prev_11* and *prev_prev_11*. Because *prev_diff* goes two rows back, it is necessary to be sure that the *PersonID*, *analysiszone_builtup* and *analysiszone_entrance* of two rows ago are the same as the *PersonID*, *analysiszone_builtup* and *analysiszone_entrance* of the present row.

   a. Put columns *prev_personis*, *prev_analysiszone_builtup* and *prev_analysiszone_entrance* one row lower and call them *prev_prev_personid*, *prev_prev_analysiszone_builtup* and *prev_prev_analysiszone_entrance*

```
COMPUTE prev_prev_personid=lag(prev_personid).
EXECUTE.
COMPUTE
prev_prev_analysiszone_builtup=lag(prev_analysiszone_builtup).
EXECUTE.
COMPUTE
prev_prev_analysiszone_entrance=lag(prev_analysiszone_entrance).
EXECUTE.
```

   b. Compute *prev_diff* in the case that *prev_prev_personid = PersonID* and *prev_analysiszone_builtup = analysiszone_builtup.* Because the *analysiszone_entrance* has the same boundary as the *analysiszone_builtup* it is sufficient to set the condition about the *analysiszone_builtup*.

```
IF  ((prev_prev_personid = PersonID) and
(prev_prev_analysiszone_builtup = analysiszone_builtup))
   prev_diff=lag(diff).
EXECUTE.
```

5. Create a new column *movement* which receives the previous angle if the following statements are fulfilled.
    a. If diff > 0 and prev_diff < 0
    b. If diff < 0 and prev_diff > 0
    c. If diff > 0 and prev_diff = 0
    d. If diff < 0 and prev_diff = 0
    e. If diff = 0 and prev_diff > 0
    f. If diff = 0 and prev_diff < 0

```
IF  ((diff > 0 and prev_diff = 0) or (diff <
    0 and prev_diff = 0) or (diff = 0 and
    prev_diff > 0) or (diff = 0 and prev_diff <
    0) or (diff > 0 and prev_diff < 0) or (diff <
    0 and prev_diff > 0)) movement=prev_11.
EXECUTE.
```

    In other cases the column movement receives the value 1000000. This is done to simplify the following steps.

```
IF  ((diff > 0 and prev_diff > 0) or (diff <
    0 and prev_diff < 0) or (diff = 0 and prev_diff = 0))
movement=1000000.
EXECUTE.
```

6. Export data to Access and save it as **Movements independent on rotation velocity**

Access

7. Compress the table by selecting only the movements smaller than 1000000. Remember these where the rows where the start and end angles of a movement are stored. Save query as **Movements < 1000000 query**.

```
SELECT [Movements independent on rotation velocity].*
FROM [Movements independent on rotation velocity]
WHERE ((([Movements independent on rotation
velocity].movement)<1000000));
```

SPSS

8. Run the query **Movements < 1000000 query**.
    File_Open database_New query
9. Save data as **2 Movements**

```
SAVE OUTFILE='E:\Allemaal\Caroline\Data-
analyse\Bewerkingen\Berekening steering frequency\2 '+
    'Movements.sav'
  /COMPRESSED.
```

Table 39 Example of the tracing of movements independent on their rotation velocity

PersonID	Zone	prev_zone	@1	@6	@11	prev_11	diff	prev_diff	movement
1	11		85,02	1344,99	0				
1	11	11	85,05	1345,63	0	0	0		
1	11	11	85,08	1346,27	0	0	0	0	1000000
1	11	11	85,12	1346,91	0,02	0	0,02	0	0
1	11	11	85,15	1347,55	0,06	0,02	0,04	0,02	1000000
1	11	11	85,18	1348,13	0,08	0,06	0,02	0,04	1000000
1	11	11	85,22	1348,83	0,08	0,08	0	0,02	0,08
1	11	11	85,25	1349,47	0,08	0,08	0	0	1000000
1	11	11	85,28	1350,11	0,08	0,08	0	0	1000000
1	12	11	85,32	1350,75	0,07	0,08	-0,01	0	0,08
1	12	12	85,35	1351,39	0,07	0,07	0	-0,01	0,07
1	12	12	85,38	1352,03	0,08	0,07	0,01	0	0,07
1	12	12	85,42	1352,67	0,07	0,08	-0,01	0,01	0,08
1	12	12	85,45	1353,30	0,06	0,08	-0,02	-0,01	1000000
1	12	12	85,48	1353,94	0,05	0,06	-0,01	-0,02	1000000
1	13	12	85,52	1354,58	0,03	0,05	-0,02	-0,01	1000000
1	13	13	85,55	1355,22	0,02	0,03	-0,01	-0,02	1000000
1	13	13	85,58	1355,86	0,01	0,02	-0,01	-0,01	1000000
1	13	13	85,62	1356,49	0	0,01	-0,01	-0,01	1000000
1	13	13	85,65	1357,13	0	0	0	-0,01	0
1	13	13	85,68	1357,77	0	0	0	0	1000000
		13				0		0	

Step 2.2: Trace SWM with rotation velocity ≥ 1°/sec

Rauch, Kaussner, Krüger, Boverie and Flemisch (n.d) give the start to compute the rotation velocity.

*SPSS: Use dataset **2 Movements***

1. Define start angle and end angle. If the present angle differs from the previous angle the start angle is defined as the previous angle. If the present angle differs from the previous angle the end angle is defined as the present angle.
   a. Put colulmn *movement* one row lower and call it *prev_movement*
      ```
      COMPUTE prev_movement=lag(movement).
      EXECUTE.
      ```
   b. Define *start_angle*
      ```
      IF  (movement ~= prev_movement) start_angle=prev_movement.
      EXECUTE.
      ```
   c. Define *end_angle*
      ```
      IF  (movement ~= prev_movement) end_angle=movement.
      EXECUTE.
      ```
2. Define the absolute size of the angle of the movement (*size_angle*) by diminishing the end angle from the start angle
   ```
   COMPUTE size_angle=abs(start_angle-end_angle).
   EXECUTE.
   ```
3. Define start time and end time. Pay attention: the corresponding time of the angle in the column *movement* cannot be found in the column *@1* but in the column *prev_1*. If the present angle differs from the previous angle the start time is defined as the previous time. If the present angle differs from the previous angle the end time is defined as the present time.
   a. Put column *prev_1* one row lower and call it *prev_prev_1*
      ```
      COMPUTE prev_prev_1=lag(prev_1).
      EXECUTE.
      ```
   b. Define *start_time*
      ```
      IF  (movement ~= prev_movement) start_time=prev_1_1.
      EXECUTE.
      ```
   c. Define *end_time*
      ```
      IF  (movement ~= prev_movement) end_time=prev_1.
      EXECUTE.
      ```

4. Define the time difference of the movement (*time_diff*) by diminishing the end time from the start time

```
COMPUTE time_diff=end_time - start_time.
EXECUTE.
```

5. Compute rotation velocity by dividing the *size_ange* by the *time_diff* and call it *swm_velocity*

```
COMPUTE swm_velocity=size_angle / time_diff.
EXECUTE.
```

6. Export data to Access and save it as **Movements with rotation velocity**

Access

7. Compress the table by selecting only the movements with a rotation velocity greater than or equal to 1°/sec. Save query as **Movements with rotation velocity >= 1°/sec query**.

```
SELECT [Movements with rotation velocity].*
FROM [Movements with rotation velocity]
WHERE ((([Movements with rotation velocity].swm_velocity)>=1));
```

SPSS

8. Run the query **Movements with rotation velocity >= 1°/sec query**. *File_Open database_New query*
9. Save data as **3 Movements with rotation velocity equal or exceed 1 degree per second**

```
SAVE OUTFILE='E:\Allemaal\Caroline\Data-
analyse\Bewerkingen\Berekening steering frequency\3 '+
   'Movements with rotation velocity equal or exceed 1 degree per
second.sav'
  /COMPRESSED.
```

Step 3: Compute SWM frequency

Define the total amount of SWM in an analysis zone of which their angle size match with the conditions.

Step 3.1: Divide the SWM in categories

*SPSS: Use dataset **3 Movements with rotation velocity equal or exceed 1 degree per second***

Matthews and Desmond (2002) divide the SWM in three categories according to the size of the angle.

1. Fine: < 2°

2. Medium: >= 2° and < 10°
3. Coarse: >= 10°

Thiffault and Bergeron (2003) on the other hand make the following three categories:

1. Small: 1-5°
2. Large: 6-10°
3. Extreme: >10°

Because the scenario of this study contains a lot of straight road segments, this categorization of Matthews and Desmond (2002) is used.

If *size_angle* match this condition the colums *movement_...* gets the value 1.

```
IF  (size_angle < 2) movement_fine_smaler_than_2=1.
EXECUTE.
IF  (size_angle  >= 2 and  size_angle < 10)
movement_medium_between_2_and_10=1.
EXECUTE.
IF  (size_angle >= 10) movement_coarse_larger_than_10=1.
EXECUTE.
```

Step 3.2: Aggregate to analysis

SPSS: Use dataset ***3 Movements with rotation velocity equal or exceed 1 degree per second***

Aggregate to analysis zone and sum the columns *movement_...* By summing these columns the columns in the aggregated file contain the total amount of SWM in a analysis zone of which their angle size match with the conditions.

The example of the analysis zone built-up is given. To compute the SWM frequency for the analysis zone gates, the steps 3.2, 3.3 and 3.4 have to be executed.

For example: Analysis zone built-up: **4 SWM according to angle size analysis zone builtup**.

```
AGGREGATE
  /OUTFILE='E:\Allemaal\Caroline\Data-analyse\Bewerkingen\Berekening steering
frequency\4 SWM '+
    'according to angle size analysis zone builtup.sav'
  /BREAK=prev_personid prev_analysiszone_builtup
  /movement_fine_smaler_than_2_sum=SUM(movement_fine_smaler_than_2)
```

```
/movement_medium_between_2_and_10_sum=SUM(movement_medium_betwee
n_2_and_10)

/movement_coarse_larger_than_10_sum=SUM(movement_coarse_larger_than_1
0).
```

Step 3.3: Compute SWM frequency according to angle size

1. Open dataset **1 Basic data**
2. Aggregate with *PersonID* and *analysis_zone_builtup* as braking values and give the corresponding minimum and maximum time (*@1*). Save it as **5 Time analysis zone builtup**

```
AGGREGATE
  /OUTFILE='E:\Allemaal\Caroline\Data-analyse\Bewerkingen\Berekening
steering frequency\5 Time '+
    'analysis zone builtup.sav'
  /BREAK=PersonID analysiszone_builtup
  /@1_min=MIN(@1)
  /@1_max=MAX(@1).
```

3. Open dataset **4 SWM according to angle size analysis zone builtup**
4. Merge datasets **4 SWM according to angle size analysis zone builtup** with **1 Basic data** and save it as **6 Frequency according to angle size analysis zone builtup**

```
SAVE OUTFILE='E:\Allemaal\Caroline\Data-
analyse\Bewerkingen\Berekening steering frequency\6 '+
    'Frequency according to angle size analysis zone builtup.sav'
  /COMPRESSED.
```

This dataset contains the columns *PersonID*, *prev_personid*, *analysis_zone_builtup* and *prev_analysis_zone_builtup*. Because the conditions in step 2.1.4b are fulfilled, these columns contain the same values.

*SPSS: Use dataset **6 Frequency according to angle size analysis zone builtup***

5. Compute time difference between the beginning of the analysis zone till the end

```
COMPUTE time_diff_analysis_zone_builtup=@1_max - @1_min.
EXECUTE.
```

6. Compute SWM frequency for each angle size category by dividing the columns *movement_...* by the column *time_diff_analysis_zone_builtup.* The new columns get the names *freq_fine*, *freq_medium* and *freq_coarse*.

```
COMPUTE freq_fine=movement_fine_smaler_than_2_sum /
time_diff_analysis_zone_builtup.
```

```
EXECUTE.
COMPUTE freq_medium=movement_medium_between_2_and_10_sum /
time_diff_analysis_zone_builtup.
EXECUTE.
COMPUTE freq_coarse=movement_coarse_larger_than_10_sum /
time_diff_analysis_zone_builtup.
EXECUTE.
```

Step 3.4: Compute SWM frequency of one angle size category per analysis zone for each person

1. Prepare dataset **6 Frequency according to angle size analysis zone builtup** to get a dataset with the SWM frequency of one angle size category per analysis zone for each *PersonID*.

```
IF  (prev_analysiszone_builtup = 11) freq_fine_11_120=freq_fine.
EXECUTE.
IF  (prev_analysiszone_builtup = 12) freq_fine_121_132=freq_fine.
EXECUTE.
IF  (prev_analysiszone_builtup = 21) freq_fine_21_220=freq_fine.
EXECUTE.
IF  (prev_analysiszone_builtup = 22) freq_fine_221_232=freq_fine.
EXECUTE.
IF  (prev_analysiszone_builtup = 31) freq_fine_31_320=freq_fine.
EXECUTE.
IF  (prev_analysiszone_builtup = 32) freq_fine_321_332=freq_fine.
EXECUTE.
IF  (prev_analysiszone_builtup = 41) freq_fine_41_420=freq_fine.
EXECUTE.
IF  (prev_analysiszone_builtup = 42) freq_fine_421_432=freq_fine.
EXECUTE.
IF  (prev_analysiszone_builtup = 1011) freq_fine_1011_10120=freq_fine.
EXECUTE.
IF  (prev_analysiszone_builtup = 1012) freq_fine_10121_10132=freq_fine.
EXECUTE.
IF  (prev_analysiszone_builtup = 1021) freq_fine_1021_1020=freq_fine.
EXECUTE.
IF  (prev_analysiszone_builtup = 1022) freq_fine_10221_10232=freq_fine.
EXECUTE.
IF  (prev_analysiszone_builtup = 1031) freq_fine_1031_10320=freq_fine.
EXECUTE.
IF  (prev_analysiszone_builtup = 1032) freq_fine_10321_10332=freq_fine.
EXECUTE.
IF  (prev_analysiszone_builtup = 1041) freq_fine_1041_10420=freq_fine.
EXECUTE.
IF  (prev_analysiszone_builtup = 1042) freq_fine_10421_10432=freq_fine.
```

```
EXECUTE.
```

Do the same for the categories medium and coarse

2. Aggregate with *PersonID* as braking value and give the corresponding mean SWM frequency (*freq_fine*). Save it as **7 Frequency fine analysis zone builtup**.

```
AGGREGATE
  /OUTFILE='E:\Allemaal\Caroline\Data-analyse\Bewerkingen\Berekening
steering frequency\7 '+
    'Frequency fine analysis zone builtup.sav'
  /BREAK=prev_personid
  /mean_11_120=MEAN(freq_fine_11_120)
  /mean_121_132=MEAN(freq_fine_121_132)
  /mean_21_220=MEAN(freq_fine_21_220)
  /mean_221_232=MEAN(freq_fine_221_232)
  /mean_31_320=MEAN(freq_fine_31_320)
  /mean_321_332=MEAN(freq_fine_321_332)
  /mean_41_420=MEAN(freq_fine_41_420)
  /mean_421_432=MEAN(freq_fine_421_432)
  /mean_1011_10120=MEAN(freq_fine_1011_10120)
  /mean_10121_10132=MEAN(freq_fine_10121_10132)
  /mean_1021_1020=MEAN(freq_fine_1021_1020)
  /mean_10221_10232=MEAN(freq_fine_10221_10232)
  /mean_1031_10320=MEAN(freq_fine_1031_10320)
  /mean_10321_10332=MEAN(freq_fine_10321_10332)
  /mean_1041_10420=MEAN(freq_fine_1041_10420)
  /mean_10421_10432=MEAN(freq_fine_10421_10432).
```

Do the same for the categories medium and coarse. This gives the datasets **8 Frequency medium analysis zone builtup** and **9 Frequency coarse analysis zone builtup**

Repeat steps 3.2, 3.3 and 3.4 for analysis zone gates. This gives the datasets

4 SWM according to angle size analysis zone gates

5 Time analysis zone gates

6 Frequency according to angle size analysis zone builtup

7 Frequency fine analysis zone gates

8 Frequency medium analysis zone gates

9 Frequency coarse analysis zone gates

Step 4: Merge datasets

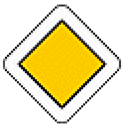
Merge the datasets with the corresponding angle size category. This results in three datasets with the steering wheel movement frequency per second in each analysis zone for each *PersonID.*

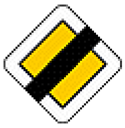
7 Frequency fine analysis zone builtup & **7 Frequency fine analysis zone gates ➔ <u>7 Frequency fine</u>**

8 Frequency medium analysis zone builtup & **8 Frequency medium analysis zone gates ➔ <u>8 Frequency medium</u>**

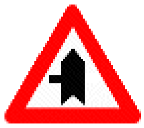
9 Frequency coarse analysis zone builtup & **9 Frequency coarse analysis zone gates ➔ <u>9 Frequency coarse</u>**

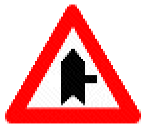
Annex 8 Road signs


B9


B11


B15a


B15c


B15f

C43


D7

F1

F3

Figure 52 Used road signs
Source Verkeersweb.be (n.d.)

Annex 9 Detailed scenario

Table 40 Detailed description of a curved thoroughfare with gate constructions

<table>
<tr><th>Distance [m]</th><th colspan="2">Description</th></tr>
<tr><td>0</td><td colspan="2">End of the previous thoroughfare / end of a 400 m long starting segment
Start of the ribbon building of previous thoroughfare</td></tr>
<tr><td>30</td><td colspan="2">Sign C43</td></tr>
<tr><td>200</td><td>End of the ribbon building of previous thoroughfare</td><td rowspan="5">After the 400 m long starting segment: straight road without ribbon building</td></tr>
<tr><td>225</td><td>Start entrance of curve of 20° to the right</td></tr>
<tr><td>250</td><td>End entrance of curve & start middle of curve</td></tr>
<tr><td>325</td><td>End middle of curve & start exit of curve</td></tr>
<tr><td>350</td><td>End exit curve</td></tr>
<tr><td>973</td><td colspan="2">Last stimulus which will not be used in the analyses</td></tr>
<tr><td>990</td><td colspan="2">Start analysis zone outside built-up area</td></tr>
<tr><td>1052</td><td colspan="2">First stimulus which will be used in the analyses</td></tr>
<tr><td>2610</td><td colspan="2">Start entrance of curve of 20° to the left</td></tr>
<tr><td>2635</td><td colspan="2">End entrance of curve & start middle of curve</td></tr>
<tr><td>2685</td><td colspan="2">End middle of curve & start exit of curve</td></tr>
<tr><td>2710</td><td colspan="2">End exit curve</td></tr>
<tr><td>2730</td><td colspan="2">Start of the ribbon building of approaching thoroughfare</td></tr>
<tr><td>2833</td><td colspan="2">Start analysis zone before the entrance of the thoroughfare</td></tr>
<tr><td>2930</td><td colspan="2">End of the ribbon building of approaching thoroughfare
End analysis zone outside built-up area
End analysis zone before the entrance of the thoroughfare
Sign F1
Sign B11
Start entrance gate with sign D7</td></tr>
<tr><td>2963</td><td colspan="2">End entrance gate
Start analysis zone inside built-up area
Start analysis zone after the entrance of the thoroughfare
Start analysis zone before the middle of the thoroughfare</td></tr>
<tr><td>3010</td><td colspan="2">Sign B15a</td></tr>
<tr><td>3050</td><td colspan="2">Zebra crossing 1a</td></tr>
<tr><td>3060</td><td colspan="2">Intersection 1 with two side streets</td></tr>
<tr><td>3066</td><td colspan="2">Zebra crossing 1b</td></tr>
<tr><td>3157</td><td colspan="2">End analysis zone after the entrance of the thoroughfare</td></tr>
<tr><td>3160</td><td colspan="2">Start entrance of curve 1 (30° to the right)</td></tr>
</table>

3185	End entrance of curve 1 Start middle of curve 1
3235	End middle of curve 1 Start exit of curve 1
3260	End exit curve 1
3310	Sign B15f
3350	Zebra crossing 2a
3360	Intersection 2 with one side streets on the left side Start entrance of curve 2 (40° to the left)
3366	Towers & zebra crossing 2b
3385	End entrance of curve 2 Start middle of curve 2
3435	End middle of curve 2 Start exit of curve 2
3460	End exit curve 2
3545	**End analysis zone before the middle of the thoroughfare** **Start analysis zone after the middle of the thoroughfare**
3560	Zebra crossing 3
3660	Start entrance of curve 3 (40° to the left)
3685	End entrance of curve 3 Start middle of curve 3
3710	Sign B15c
3735	End middle of curve 3 Start exit of curve 3
3750	Zebra crossing 4a
3760	End exit curve 4 Intersection 4
3766	Zebra crossing 4b
3960	Start entrance of curve 4 (30° to the right)
3985	End entrance of curve 4 Start middle of curve 4
4010	Sign B15a
4035	End middle of curve 4 Start exit of curve 4
4050	Zebra crossing 5a
4060	End exit curve 5 Intersection 5
4066	Zebra crossing 5b

4127	Start exit gate with sign D7 **End analysis zone inside built-up area** **End analysis zone after the middle of the thoroughfare**
4160	End exit gate
4200	Sign F3 Sign B9 Start of the ribbon building Start next monotonous road segment

Annex 10 Amount of asterisks in box plots

Fout! Verwijzingsbron niet gevonden. shows the amount of asterisks per subject in the box plots per driving performance measure. The subjects which have two or less asterisk are not included in this table. In the box plots of the sd of the lateral position, the mean SWM angle, the sd SWM angle and the mean SWM velocity no subjects are found with more than 2 asterisks. Based on the threshold of 6 or more asterisk in 16 boxplots, subjects 9, 44 and 55 are labeled as outliers.

Table 41 Amount of asterisk in box plots per driving performance measure

	Mean speed			**SDL-A/D**			**Mean SWM FREQ (large SWM)**		
Analysis	**G**	**T**	**M**	**G**	**T**	**M**	**G**	**T**	**M**
9*						**9**			
8*						**44** **50**			
7*					**9**				
5*				33	**44**			16	
4*		10		**50**	**50**				
3*				2 3 22 **44**					

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Driving simulator study on the effectiveness of different thoroughfare configurations

Richting: **master in de verkeerskunde-verkeersveiligheid**
Jaar: **2010**

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Arien, Caroline

Datum: **28/05/2010**