PEEK traffic solutions

UNIVERSITY OF TWENTE.

Individual users' perception of signalised intersections

Master Thesis

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Colophon

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ABSTRACT

Knowledge of the users' perception of signalised intersections is important to increase the acceptance of a system. A good traffic light controller not only optimizes its control to the objectives of the road authorities, but also takes the user acceptance into account. A low acceptance might result in red light or speed violations and route alterations.

The perceived waiting time (PWT) is an indicator for the users' perception. The PWT is a measurement of how long car drivers experience their waiting time at a traffic light. Besides the actual waiting time, other factors (e.g. the number of stops or green waves) influence the PWT. Knowing the PWT in the design process is necessary to increase the user acceptance of the final system. Therefore it is necessary to evaluate the PWT a priori of implementing a system. This evaluation can be performed using simulation studies.

The main objective of this study is to find a model that describes the PWT of car drivers. A literature review resulted in ten factors with various levels of influence on the waiting time perception at signalised intersections. The most important factors are the actual waiting time, the number of stops in the queue, the unused green time of conflicting traffic and green waves between adjacent intersections.

An online video survey among 159 respondents is conducted to retrieve the influence of each factor on the PWT. Respondents were shown a number of movies filmed from the drivers' perspective of a vehicle passing a signalised intersection in Den Bosch or Helmond, and after each movie the respondents were asked to estimate their waiting times. In total 44 movies were analyzed by the respondents, resulting in the following model for the perceived waiting time:

$$PWT = \beta_0 + \beta_1 \cdot RW + (\beta_2 + \beta_3 \cdot Stops + \beta_4 \cdot RW) \cdot WT + \beta_5 \cdot WT^2$$

Where:

PWT = Expected perceived waiting time

WT = Actual waiting time

$Stops$ = Number of stops in the queue

RW = Red wave, 1 if there is a red wave (else 0)

The figure 1 shows the outcomes of the model in all possible situations. The dots represent the main perceived waiting time measured in the survey. The model predicts the measured perceived waiting times good: the $R^2 = 0.907$.

Respondents were also asked if their perceived waiting time is acceptable or not. Based on this question, the following model for the user acceptance (UA) is retrieved. According to this model, a PWT up to 66 seconds is acceptable.

$$\text{UA} = \frac{1}{1+e^{-3.650+0.055 \cdot PWT}}$$

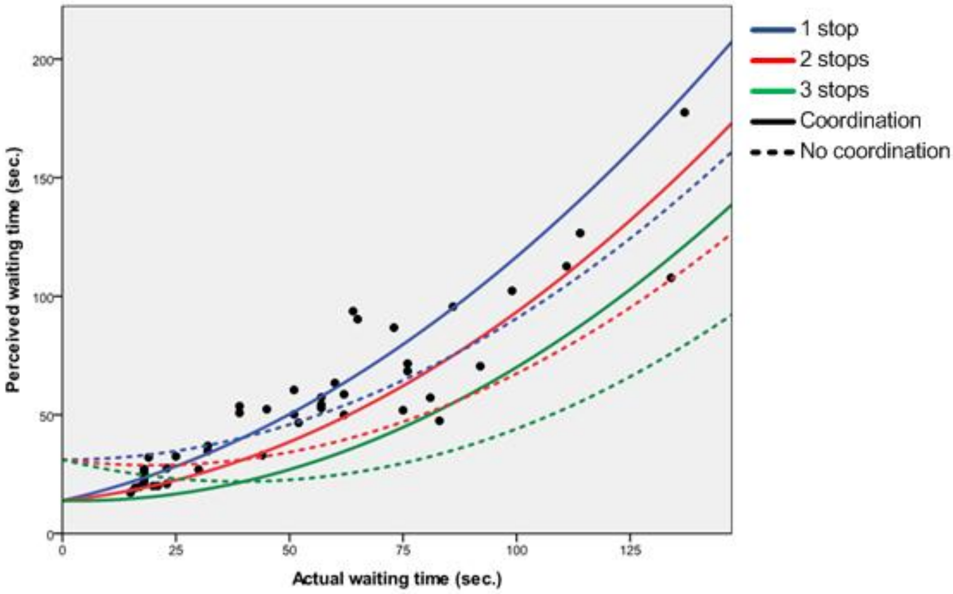

Figure 1: the various outcome of the perceived waiting time model.

Both models are validated with a real-world experiment. Both in Den Bosch and Helmond, two car drivers were asked for their PWT and UA while they were driving a route over a number of signalised intersections. Together the subjects analyzed 37 situations, resulting in a positive validation of both models. Although the models are retrieved from an online video survey, they are a good prediction of the real-world PWT and UA.

A second objective was to evaluate the perceived waiting time in the traffic simulator Vissim. Using the COM-Interface, an external application is used to retrieve vehicle data from Vissim, calculate the PWT and UA for each vehicle and visualize the PWT by colouring the vehicles in the simulation. Figure 2 illustrates the application and its output in Vissim. The more red a vehicle is, the higher its perceived waiting time is.

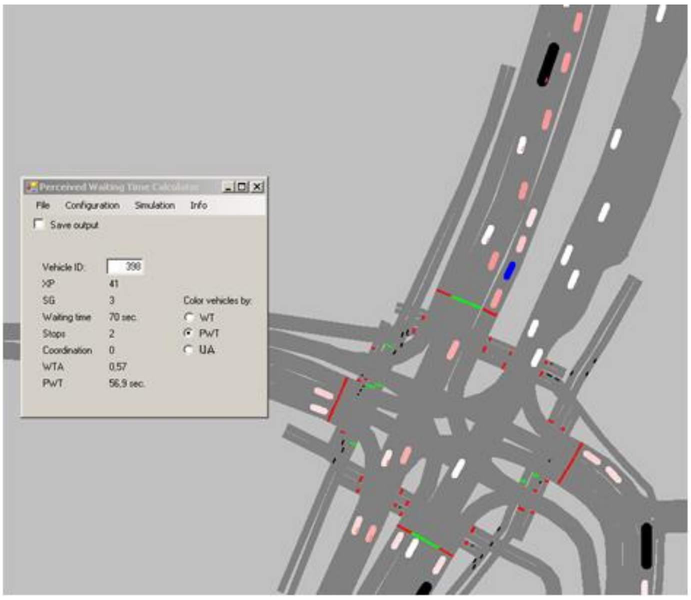

Figure 2: Visualization of the developed application

The third objective of this study was to evaluate the differences in the users' perception of different traffic light control systems and configurations. In simulation the network controller Utopia is compared the solitaire controlled intersections, and different configurations of Utopia are compared with each other.

In the solitaire controlled scenario, the user acceptance is higher compared to the Utopia-scenario. Due to the network optimization of Utopia, left turning vehicles and vehicles on the side roads have to wait longer, resulting in more unacceptable perceived waiting times. Alternative configurations of Utopia also have some influence of the user acceptance. More coordination on the main road, for example, results in a higher acceptance of the main road and a lower acceptance on the side roads.

In conclusion, the perceived waiting time is a good indicator for the users' perception of signalised intersections. A lower average PWT results in a higher user acceptance of a traffic light control system. According the model, the following requirements can be set to increase the users' perception of a system:

- Prevent short and long waiting times. Due to the quadratic nature of the model, both short and long waiting times are overestimated while average waiting times are perceived as they are.
- Multiple stops in the queue result in lower perceived waiting times, which impacts the user acceptance of traffic lights.
- If there is a red wave between two adjacent intersections, a short stop at the second results in an increase of the PWT, while a long stop decreases the perceived PWT.

CONTENTS

1 RESEARCH SCOPE

1.1 Background

In the Netherlands, local road authorities are responsible for the operation of transport systems. According the *Nota Mobiliteit* (Ministerie van Verkeer en Waterstaat, 2004), the road authorities aim to decrease the overall travel times and to improve the reliability of these travel times.

When focusing on urban networks, one of the most powerful measurements of road authorities to manage traffic are traffic light controllers (TLC) at intersections. With different TLC-systems, the traffic can be controlled by other objectives. Examples of such objectives are short waiting times at intersections and a decrease of emissions. Depending on the situation and the preferences of the responsible road authority, the best TLC-system is implemented.

Local road authorities and private companies use several measures of performances (MOPs) to assess the operation of a TLC-system. Peek Traffic, for instance, uses the following MOPs to assess the operation of TLC-systems (Hermkes, 2007, 2009; Holwerda, 2009):

- Travel time, delay time and number of stops on the main roads;
- Travel time, delay time and number of stops in the entire network;
- Cycle time per intersection.

Lee, Kim and Pietrucha (2007) state that most of the current MOPs have been created exclusively for evaluating the transport system without focusing on the user aspects. These MOPs can be used to assess a TLC-system from the local road authorities' point of view, like Peek Traffic does.

Knowing the users' perception of a TLC-system is important to improve the user acceptance of that system. A low acceptance may, for example, result in red light violation or speeding. Road users have other priorities then the local authorities, and therefore perceive certain measures differently. Knowledge of the users' perception a priori of implementing a TLC-system increases the user acceptance of the system.

In the last years, different indictors of the users' perception have been studied. Most of these indicators, for example the perceived Level-of-Service (Lee et al., 2007), focus on the average perception of signalised intersections. However, different road users may perceive the same intersection differently, for example drivers on the main road experience crossing an intersection differently then drivers on a side road. Although the individual perception of signalised intersections seems crucial to estimate the users' perception, only once this individual perception has been studied before. Wu, Levinson and Liu (2009) proposed a simple indicator, depending on the waiting time only while other factors (e.g. the number of stops and coordination) influence the users' perception as well.

1.2 Objective

Knowing a priori of implementing a TLC-system the individual users' perception is necessary to adopt the system to the needs of the road users, and therefore increase user acceptance of the system. Therefore the main objective of this study is:

> ***Objective***
> *Define an indicator of the individual users' perception of signalized intersections, and determine a method to evaluate a priori of implementing a TLC-system the user acceptance.*

1.3 Research questions and model

In this study the next four questions are answered. These questions provide insight in the individual users' perception of signalised intersections and how these perceptions can be evaluated.

1. What is a good indicator of the individual users' perception of signalised intersections?
2. On what characteristics of a TLC-system depends this indicator?
3. How can the individual users' perception of several TLC-systems be evaluated a priori?

Figure 1.1 illustrates the research model related to the questions. This model describes the different steps needed to fulfil the objective and answer the questions. The study itself follows the structure of the model.

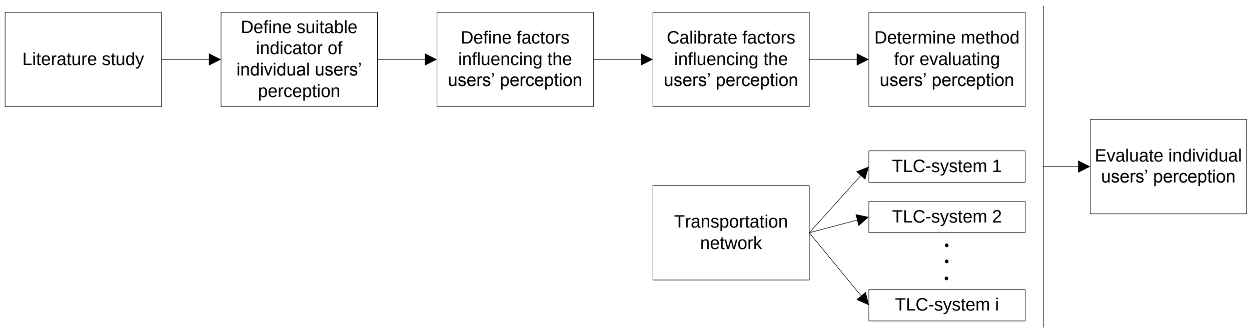

Figure 1.1: Research model

2 INDIVIDUAL USERS' PERCEPTION OF TRAFFIC LIGHTS

2.1 Introduction

As discussed in section 1.1, local road authorities are mainly interested in the MOPs of TLC-systems. Examples of such MOPs are a minimization of travel times or the number of stops. Some recent studies state that users' perception of the TLC-system is important as well: a low acceptance may result in red light negation or speeding.

In this chapter existing indicators of the users' perception of traffic lights are discussed. Based on this discussion, the perceived waiting time (PWT) is chosen as indicator in this study. Finally a description is provided how the PWT can be calibrated and a priori evaluated for TLC-systems.

2.2 Existing indicators

Two indicators of the users' perception of TLC-systems have been studied before: the perceived Level-of-Service (LOS) and the perceived waiting time. Both indicators are reviewed in this paragraph.

2.2.1 The perceived Level-of-Service

Fang, Elefteriadou, Pécheux and Pietrucha (2003), Lee et al. (2007), Pécheux (2000), Pécheux, Pietrucha and Jovanis (2000) and Zhang (2004) studied the perceived LOS of signalized intersections. This indicator of the users' perception results in an average score per intersection, which depends on the following characteristics:

- *Intersection characteristics* are indicators of the lay-out of an intersection;
- *Signal scheme characteristics* are indicators of the traffic light control program;
- *Traffic characteristics* are indicators of the traffic situation while a vehicle is waiting before an intersection;
- *Personal characteristics* are indicators of the car drivers.

Stated preference surveys are performed to determine which characteristics are of importance for the perceived LOS. For the different studies, these characteristics are presented in Appendix A.

The advantage of the perceived LOS is that many factors influencing the users' perception are included. The downside of this indicator is that the model is calibrated by asking questions to respondents; answering questions about a situation is different than experiencing a certain situation. Secondly, the perceived LOS evaluates the users' perception of signalised intersections as an average score per intersection.

2.2.2 The perceived waiting time

Wu et al. (2009) studied the PWT of car drivers at signalised intersections. The PWT is defined as how long car drivers perceive their waiting time at a traffic light, and depends on the actual waiting time and some personal characteristics of the car drivers:

- The actual waiting time knows a quadratic relationship with the PWT;
- The personal characteristics have a significant but limited influence on the PWT.

The model of Wu et al. is calibrated by presenting respondents a 3D-movie on a computer screen. This movie, recorded from the traffic simulator Aimsun (figure 2.1), shows a vehicle passing a number of intersections. After the movie, the respondents were asked how long they think they waited for each intersection.

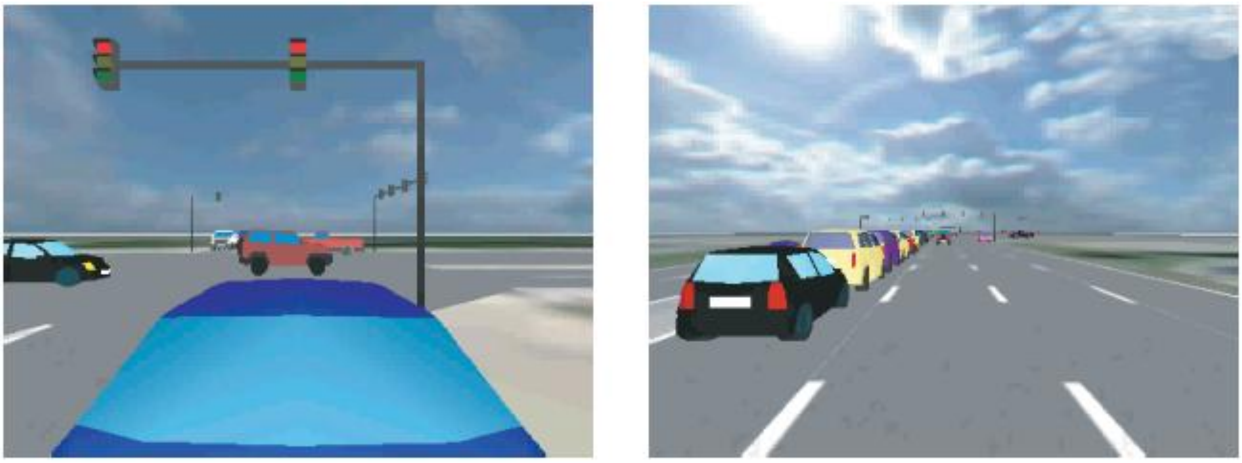

Figure 2.1: Visualization of the movies used to calibrate the PWT (Wu et al., 2009)

The advantage of the PWT is that it evaluates the individual users' perception of signalised intersection. However, many characteristics, like the number of stops and coordination, of the situation are excluded. Also the realism of the movies is discussable, because they are not recorded from a real vehicle.

2.3 Selection of the indicator

In the previous section two existing indicators of the users' perception of TLC-systems are discussed. The perceived LOS evaluates many characteristics and results in an average perception per intersection, while the PWT depends only on the actual waiting time and some personal characteristics and results in an individual users' perception. The realism of both indicators is discussable, because they are either obtained from a stated preference survey (perceived LOS) or from a non-realistic movie (perceived waiting time).

Although the PWT defined by Wu et al. (2009) has some downsides, this seems to be the most promising indicator for further research in this study. The influence of factors of the perceived LOS will be determined to improve the model of the PWT.

The perceived waiting time, as presented in this study, is a combination of both existing indicators. The individual approach of the PWT proposed by Wu et al. (2009) is combined with the factors included in the perceived LOS.

2.3.1 Modelling of perceived waiting time

Besides the actual waiting time, many factors may influence the perceived waiting time of individual car drivers. Therefore the relationships between those factors and the PWT are studied in this research. First a literature study is performed to select the most dominant factors influencing the PWT (see chapter 3), secondly a survey is conducted to model the PWT (chapters 4 and 5). The results of the survey are used to model the relation between the PWT and the factors discussed in chapter 3.

2.3.2 Evaluating the perceived waiting time

The main objective of this study is to define an indicator to evaluate a priori the users' perception of a TLC-system. The best method for a priori evaluation is a simulation study of the TLC-system. In a simulation environment the operation of the system is assessed, and it is possible to adjust the system before it is implemented on the streets.

Vissim is a simulation environment used by Peek Traffic. Using the COM-Interface it is possible to evaluate additional indicators, like the individual users' perception of the traffic lights. Therefore, the PWT has to be calibrated that it is capable of being used in combination with Vissim. This means that personal characteristics cannot be a part of the a priori evaluation as Vissim does not distinguish different personalities among road users. Therefore, the personal characteristics are given less attention in this study.

2.4 Summary

A priori evaluating the individual users' perception of TLC-systems is the main objective of this study. In literature, two indicators of the users' perception are described: the perceived Level-of-Service and the perceived waiting time.

The perceived LOS evaluates the average users' perception of a signalised intersection. Many characteristics of the situation are included in the model, but it is not possible to determine the individual users' perception. On the other hand, the PWT estimates the individual perception but it only includes some personal characteristics and the observed waiting time. Other factors are not included in this indicator.

In this study, the earlier mentioned PWT will be expanded with the factors of the perceived LOS. The new PWT is a combination of both existing indicators, resulting in an individual indication of the users' perception with respect to the characteristics of a situation on a signalised intersection.

Because the users' perception of a TLC-system has to be evaluated a priori of implanting the system, the PWT of individual car drivers has to be estimate in the simulation environment Vissim. As Vissim does not distinguish different personalities between drivers, less attention to the personal characteristics is given in this study.

3 FACTORS INFLUENCING THE PWT

3.1 Introduction

The perceived waiting time (PWT) is an indication of the users' perception of signalised intersections. For each individual road user the PWT depends on the traffic situation occurred during the waiting time, and expresses how the user perceived his waiting time before the traffic light.

In this chapter, ten factors with various levels of influence on the PWT are discussed. These factors are retrieved from the studies about the perceived Level-of-Service (section 2.2.1). From these studies the most promising factors are selected and a literature study is conducted to provide more details of the factors.

3.2 Description of the factors

Based on the factors presented in Appendix A, ten factors are chosen for further research. These factors are expected to have the greatest influence on the PWT. In this paragraph the factors are described in detail and the expected influence on the PWT is determined. The information presented in this paragraph is based on the available literature.

Figure 3.1 shows the ten factors which are discussed in this section. As described in section 2.2.1, these factors can be subdivided into four categories. Personal characteristics are not included in this study, because according to Wu et al. (2009) the influence on the PWT is minimal.

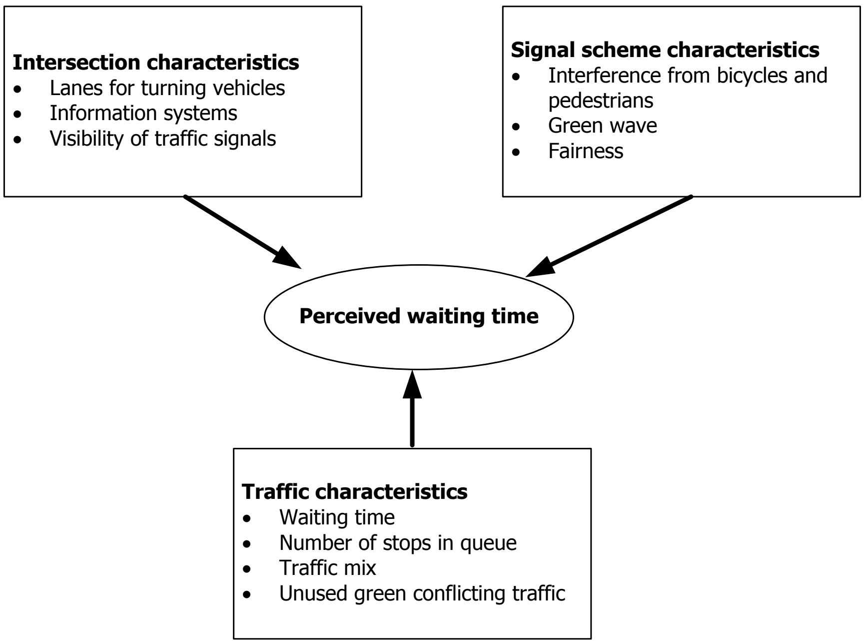

Figure 3.1: Overview of the studied factors in this research

In this section, two surveys are often referred to. The ANWB (2008) asked readers of their monthly magazine (Kampioen) about their experiences and complaints of traffic lights. Respondents were asked to describe the signalised intersection they are most annoyed by. The presented results in this chapter apply only for these intersections.

In his dissertation, Zhang (2004) studied how respondents rate a signalised intersection. Respondents were asked for their perceived importance of several factors. They could rate each factor as not, a little, moderately, very and extremely important.

3.2.1 Actual waiting time

The actual waiting time is the time spend by a vehicle in the queue before the intersection. The influence of the actual waiting time on the PWT seems rather obvious. This is confirmed by Pécheux (2000) and Wu et al. (2009) who studied the relationship between the actual and perceived waiting time at signalised intersections. They both concluded that this relationship is influenced by several factors, but the actual waiting time is the most important one.

In their model to determine the PWT, Wu et al (2009) found a quadratic relationship between the actual and perceived waiting time. Unfortunately, the validity of this model can be discussed since they did not include other factors than some personal characteristics. However, the model demonstrates the importance of the actual waiting time in the relationship.

Also Lee et al. (2007) found that the waiting time at traffic lights is one of the two most important factors (together with the unused green time of conflicting traffic) in the perceived Level-of-Service (LOS) of signalised intersections. Chen, Li, Ma and Shao (2009) agree with this finding, they state that the users' LOS ratings depend strongly on the actual waiting time.

In the survey conducted by the ANWB (2008), 62% of the respondents complain about long waiting times at their chosen intersection. According to Zhang (2004), 65% of the subjects state that the actual waiting time is very or extremely important in their assessment of an intersection.

3.2.2 Number of stops in the queue

The number of stops is a commonly used Measure of Performance (MOP) to assess the operation of a TLC system, and describes the number of times a vehicle has to stop in the queue at an intersection. The number of stops is not only an indication of the fuel consumption of a vehicle (Kang, 2000), but also a measurement of the efficiency and complexity of the movements at an intersection (Chen et al., 2009)

Zhang (2004) found that 79% of the respondents participated in his dissertation rated the ability to go through an intersection within one cycle of light changes as very or extremely important. This indicates that drivers accept only one stop in the queue at an intersection. A second stop could therefore increase the PWT.

According to the ANWB (2008), 35% of the respondents complain about too short green times at their chosen intersection. They are forced to make multiple stops in the queue before crossing the intersection. In combination with the results from Zhang (2004), it is likely that there is a major influence of the number of stops in the queue on the PWT.

3.2.3 Unused green time conflicting traffic

Many complaints about signalised intersections consider the amount of unused green time for the conflicting traffic stream. Most car drivers consider it as annoying to wait for empty intersections. According to the ANWB (2008), 62% of the car drivers complain about the amount of unused green time for conflicting traffic.

Pécheux (200) and Zhang (2004) found that most drivers prefer vehicle actuated control above fixed-timed control. They reasoned that actuated controllers are more efficient, and therefore the amount of unused green time is reduced. Pécheux proved that the PWT at actuated controlled intersections is lower compared to that of fixed-timed controlled intersections.

Together with the actual delay, Lee et al. (2007) found that the unused green time of conflicting traffic is important in the perceived LOS of signalised intersections.

3.2.4 Green wave

Coordination is a mode of signal control where platoons of vehicles can drive through several signalised intersection in a row with a minimum of stops and delays (Liu, Chu and Recker, 2001). If signals are closely spaced together, coordination is necessary to avoid excessive delay and stops. In the Netherlands, CROW states that coordination is required if intersections are situated less than 150 meters from each other (Wilson, 2006). Other studies propose coordination between intersection to 500 meter (Hoogendoorn, 2007; Rouffeart et al., 2009).

Depending on the distance between intersections, coordination is more or less preferred. The effect of vehicle bunching weakens as the platoon moves downstream, since vehicles travel at various speeds (Rouphail, Tarko and Li, 2001). This platoon dispersion results in longer required green times for coordination, which decreases the capacity of a TLC-system.

Car drivers are most times unfamiliar with the existence of coordination. If there is coordination between two adjacent intersections, they experience this as a green wave. When there is no coordination between intersections, it is possible that a car driver can pass both intersections without stopping and experience a green wave.

Wu et al. (2009) concluded that drivers have an uncomfortable feeling if there is no coordination between intersections, and they have to stop at each intersection. According to the ANWB (2008), 52% of the respondents agree with this conclusion.

As proved with the mentioned studies, coordination is not only important to reduce the actual delay and number of stops, but is also important to increase the user assessment of a TLC-system. Therefore, it is likely that the coordination between intersections has a significant influence on the perceived waiting time.

3.2.5 Protected left turns

Protected left-turns are a combination of exclusive left-turn lanes and separate phase in the signal scheme for left-turns, without conflicts with other traffic.

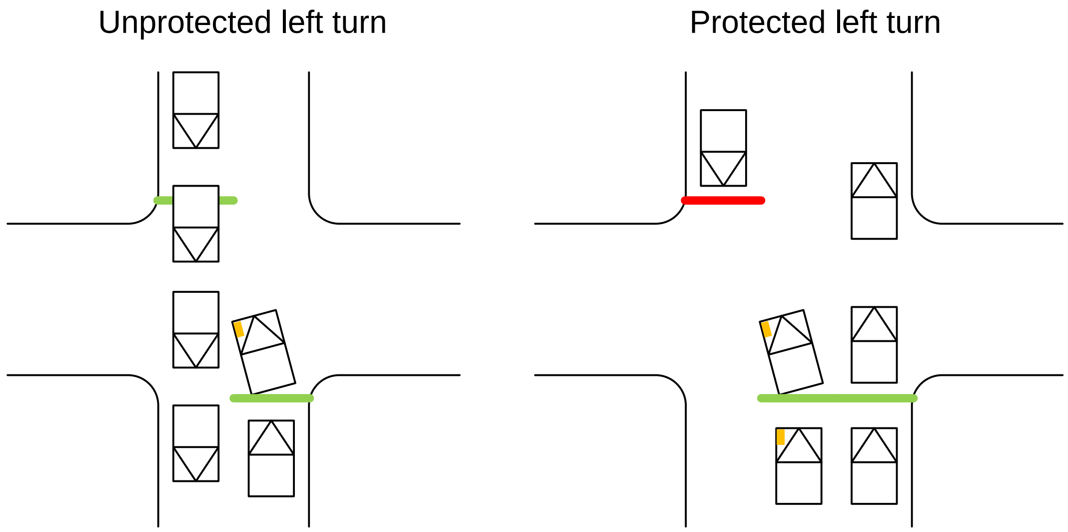

Figure 3.2: Protected and unprotected left turns

According to Zhang (2004), drivers making left turns prefer to use exclusive left-turn lanes so that they can wait safely without blocking other traffic. Around 82% of the respondent rated left-turn lanes in combination with left-turn protected signals as important. Also in the survey conducted by Pécheux (2000), respondents indicate that the presence of either a left-turn lane and/or a protected left-turn only phase influence the perceived waiting time at intersections.

75% of all car drivers consider the availability of exclusive left-turn lanes and protected left turn signals as very or extremely important (Zhang and Prevedouros, 2004). Almost all drivers feel much or extremely safer under a protected left-turn signal, and almost all driver prefer a protected left-turn.

As mentioned in the studies, exclusive left lanes and protected left turns are considered as save and are preferred by car driver. In all studies the availability of those aspects at signalised intersection is considered as important, and is included in the discussed models. Although most studies focus on the (perceived) Level-of-Service, it can be expected that the availability of protected left-turns has a significant influence on the PWT at signalised intersections.

3.2.6 Traffic mix

Heavy vehicles (e.g. trucks and busses) in a queue block the line of sight of the vehicles behind them (figure 3.3). Due to their relative slow acceleration rate, they may also cause extra delay to the vehicles behind them (Zhang, 2004). Su et al. (2009) state that drivers dislike driving behind larger vehicles, and therefore accept a larger headway when accelerating at green. This increased headway results in greater delays at the intersection, because more greentime is required to handle the same amount of traffic.

Figure 3.3: Waiting behind a heavy vehicle

According to Zhang (2004), 48% of the respondents indicate that fewer heavy vehicles waiting ahead of them as very or extreme important. However, almost 24% consider this as not or little important. Also in the survey conducted by the ANWB (2008), the mix with heavy vehicles is not mention as a complaint at the chosen intersections.

It is clear that the presence of heavy vehicles and busses increase the actual delay of vehicles behind them, but it is doubtable that the perception of this delay is significantly increased.

3.2.7 Interference from bicycles and pedestrians

Whenever the green phase of vehicles conflict with the green phase of bicycles or pedestrians, car drivers have to give right-of-way to the non-motorized traffic. This conflict of green phases result in an increased delay for vehicles: the capacity of the traffic light drops (Wilson, 2006).

According to Chen et al. (2009), drivers not only experience an increased delay but also perceive an unsafe feeling if they interfere with non-motorized traffic. This unsafe feeling affects the perceived LOS of signalised intersections.

The ANWB (2008) states that only 4% of the respondents listed interference with conflicting traffic (both other vehicles, bicycles and pedestrians) as a complaint at their chosen intersection.

It can be concluded that the effects from the interference with non-motorized traffic are notable for car-drivers: they experience an increased delay and it may be perceived as unsafe. But it is unlikely that the conflict of green phases has a significant influence on the perceived waiting time.

3.2.8 Fairness

Distributive justice is a well-known concept in economics, meaning that everyone is equal and receives a fair share of the available resources (Konow, 2003). In traffic engineering this can be translated to equal waiting times at intersections, without any favours for particular groups of vehicles. Such favours could be PT-priority, green waves or quick actuations. Liu, Oh and Recker

(2002) define fairness as the standard deviation in waiting times. A lower standard deviation results in an increased fairness among road users.

According to the ANWB (2008), 9% of the respondents mentioned PT-priority as a complaint at their chosen intersection. In other studies, fairness is not mentioned as a factor influencing the perceived waiting time of the perceived Level-of-Service.

3.2.9 Visibility of traffic signals

In many studies the signal visibility is mentioned as a factor in the perceived LOS of signalised intersections (e.g. Pécheux. 2000; Lee et al., 2007). Poorly visible signals lower the user assessment, because drivers cannot see the state of the signal and therefore do not know why they are waiting.

In the survey conducted by the ANWB (2008), only 3% of the respondents indicate the signal visibility as a problem at their chosen intersection. It is therefore unlikely that this factor has a significant influence on the PWT.

3.2.10 Waiting time information systems

Information systems, such as waiting time predictors, provide information about the time remaining until the next green phase. Van de Vrande (2009) studied the opinions of road users about recently installed waiting time predictors in Den Bosch. He found that the reaction time at the start of the green phase decreased, and therefore also the average delay of vehicles. In a conducted survey he found that almost all respondents perceived the waiting time predictor as pleasant, and experience it as an increase of the road safety.

Zhang and Levinson (2008) studied the effect of travel time information on route choice behaviour. They found that, in most cases, drivers are willing to pay for travel information, but that the task of understanding drivers' responses to information is challenging.

Based on the findings of Van de Vrande and Zhang and Levinson, it is likely that waiting time information systems have an influence on the perceived waiting time. However, it is unknown what the exact effects are.

3.3 The most dominant factors

In the previous section, ten factors which influence the PWT are discussed. Figure 3.4 shows the relationship between the factors and the PWT. Besides the relationship with the PWT, there are also some cross influences between the factors themselves.

In the figure, the thickness of the lines and the number of plusses/minuses indicate the strength between the factors. The actual waiting time, for example, is expected to have a greater influence on the PWT than fairness. A positive influence means that an increase in the factors results in a higher PWT, while a negative influence means that an increase of the factor results in a lower PWT.

The expected influences between the ten factors and the PWT are based on the literate study performed in section 3.2. The influences between the factors themselves are based on the literature and common sense.

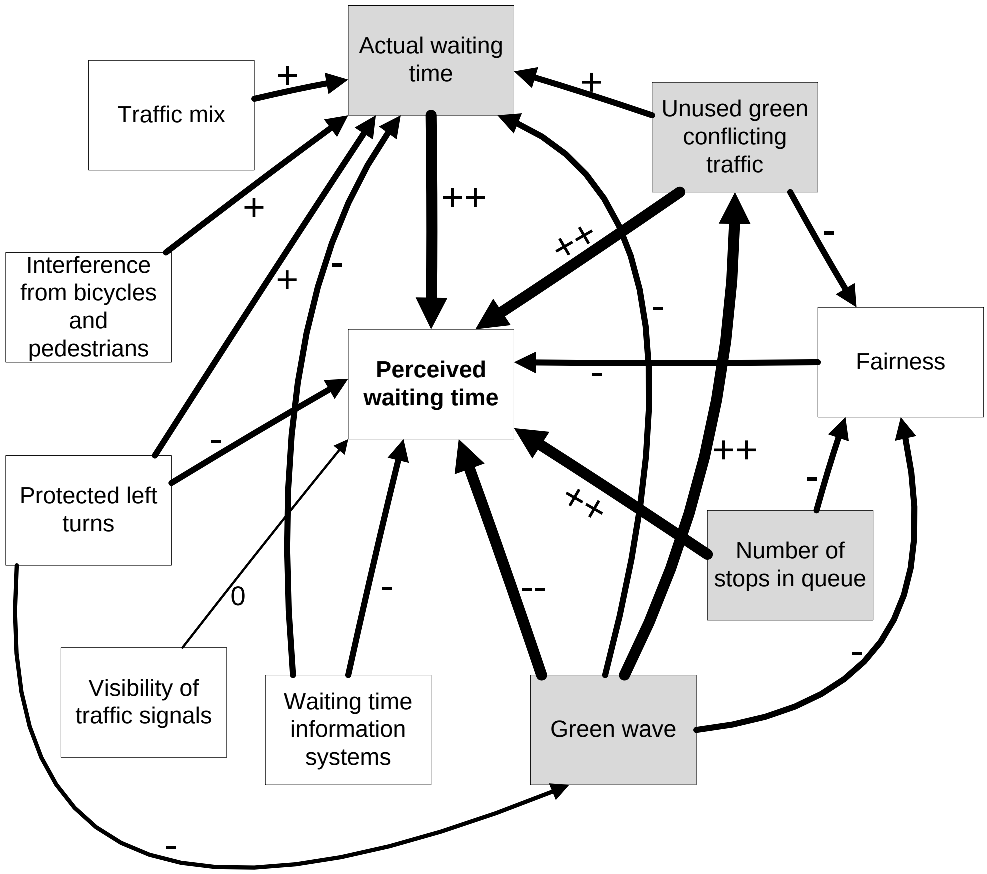

Figure 3.4: Relationships between the ten factors of section 3.2 and the PWT. The most dominant factors are coloured in this figure.

As indicated in the figure, the actual waiting time, the unused green time of conflicting traffic, the number of stops in the queue and green waves between intersections are expected to have the greatest influence on the PWT. Therefore, in this research most attention is given to those factors: in the survey and the analysis of it the focus will be on these factors. However, the influence of the other factors will also be evaluated.

3.4 Summary

The user acceptance of signalised intersections depends on a number of factors. Besides some personal characteristics, these factors can be subdivided into three categories: intersection, signal scheme and traffic characteristics. Ten of these factors, which are often mentioned in other studies regarding the user acceptance, are described in detail and the expected influence on the perceived waiting time is determined. Four factors are assumed to have the greatest influence on the PWT: the actual waiting time, the number of stops in the queue, the unused green time of conflicting traffic and green waves.

4 SURVEY

4.1 Introduction

In chapter 3 ten factors which are expected to influence the PWT are discussed. Based on the available literature, four factors are assumed to have the greatest influence on the PWT. To test these assumptions and quantify the relations between the factors and the PWT, as indicated in chapter 2, a survey is needed.

In this chapter the conducted survey is described. First some different methods of survey are discussed. The online video survey is chosen as the best alternative because a high number of respondents can participate and it has a high degree of realism.

4.2 Methods

The objective of the survey is to collect data to quantify the relations between the factors and the PWT. Also the assumption that the actual waiting time, number of stops, unused green time and green waves are the most important factors influencing the PWT needs to be tested. To fulfil these objectives, car drivers have to be confronted with a situation and indicate what their perceived waiting time is. A number of studies reviewed what kind of survey is best to determine the user perception of a transportation network.

Wu et al. (2009) state that a real-world experiment to determine the PWT is not an option, because of variable conditions and the difficulty in having to stop a driver immediately to garner perceptions. Putting a surveyor in the car with the driver would be time consuming and less realistic. A virtual experience stated preference (SP) survey, putting drivers in the driver seat of a virtual car, has advantages in this regard, as the situation can be highly controlled. However, using a driving simulator is also time consuming and expensive. Therefore, the authors choose show a movie from the driver's perspective presented on a computer screen. This movie was recorded from a 3-D simulation generated by AIMSUN.

Pécheux et al. (2000) reviewed multiple methods to observe the perceived delay estimates of subjects. For on-the-road studies, two problems were indentified. First, having subjects drive around the streets in a vehicle (even a pre-determined route) would result in a lack of control over the experimental conditions. Secondly, considering the amount of time and resources necessary for such study, running each subject individually in the field would result in a small sample size.

Controlled test-track studies are also discussed. The validity of these studies was questioned, however, due to the lack on in-context driving conditions. Even though the subjects would actually behind the wheel of a vehicle, the test track environment would not afford a real roadway network, an intersection with real traffic signals, or actual cross-street traffic.

Since video studies in laboratory situations have been used in traffic perception studies and human factors experiments for at least 40 years, it was proposed that subjects be shown videos as though they were the driver. This method would allow for multiple subjects to be run simultaneously while allowing the researchers control over the experimental conditions.

With these considerations in mind, it was agreed that video laboratory studies were a good trade-off between costs, sample size, fidelity, and other issues – the subjects would view an in-context driving situation, all subjects would experience the same conditions, and available time and monetary resources could be used efficiently to gather an adequate sample size.

Leiser and Stern (1988) used an Urban Drive Simulator (UDS) to determine the perceived travel time of a trip through a transportation network. The UDS is a collection of interactive graphic programs which run on Apple Ile microcomputers. In all of them, the subjects controls an animated moving vehicle on a road network by mean of a rotary control knob ("paddle"). The subject may have to accomplish various tasks, and the computer records a collection of performance measures.

The subject's task was to "drive" a vehicle along a route indicated on the screen. Only the direction of travel was under control of the subject, while the speed was controlled by the computer. The route is never seen in its entirety. At every point in time, the screen shows a bird's-eye view of a small segment of the road, and the moving vehicle on it. The subject's task is to keep the vehicle on the road and, at the end of the route, to estimate how long it took him or her to travel it.

Based on the described literature, five methods of survey can be distinguished. These methods are compared with each other on three properties:

- Costs: because the budget is limited in this study, the costs cannot be high;
- Number of respondents: more respondents results in more data of high quality;
- Realism: because the users' perception of a signalised intersection expresses the feeling of the users, it is important that the method meets reality.

Table 4.1 shows the properties of the five methods. The video survey is the best alternative: the number of respondents is high while the costs are low. Videos are not very realistic, but are more realistic that a stated preference survey.

Table 4.1: Overview of different methods of survey

Method	**Costs**	**Number of respondents**	**Realism**
Real-world experiment	Medium	Low	Very high
Controlled test-track experiment	High	Low	High
Driving simulator	High	Low	High
Video survey	Low	High	Medium
Stated preference survey	Low	High	Low

4.3 Prospective approach

In her dissertation, Pécheux (2000) describes the differences between prospective and retrospective time estimation. Because of the importance of these differences, the following content is adopted from her dissertation.

Prospective time estimation occurs when respondents know in advance that they will be requested to estimate time, in other words an estimation of time in passing. In this case they tend to assess time through a so-called time processor. Attention is directed in real time to information that is related to the passage of time. A positive relation is expected between attention given to the passage of time and time estimates. The more attention that is given to time, the more time units are recorded, and the longer the subjective duration.

Retrospective time estimation occurs when respondents are instructed to assess the duration of an event after the event ended. Retrospective time estimates are based on memory-related processes and require the recovery of temporal information. In this case, individuals may rely on the number of items memorized.

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One phenomenon clearly illustrates the difference between prospective and retrospective time estimation, namely non-temporal-information processing (NTIP) load. Under the retrospective paradigm, duration estimates increase with increasing NTIP, whereas under the prospective paradigm, duration estimates decrease with increasing NTIP (Zakay et al. 1996).

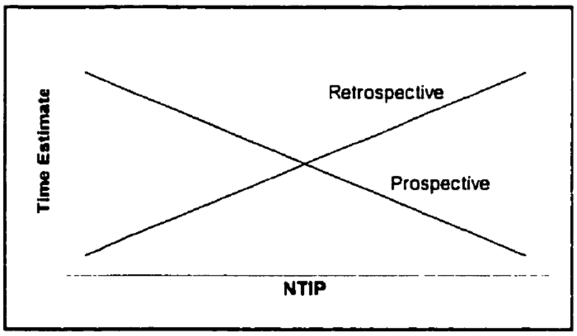


Figure 4.1: Retrospective versus prospective estimation paradigms

Meyer et al (1996), state that regarding the prospective versus retrospective paradigm of time estimation, it is not clear which one corresponds to real-life situations where people wait for the termination of a process. People may take a prospective stance at the beginning (i.e., how long will it take?), or they may take a retrospective stance (e.g., how long did that take?). It may be appropriate to consider both the information and memory processors.

Zakay (1993) states that it is not always the experimenter's instructions, but what is the subjective paradigm perceived by the respondents. For example, under time stress or an occupation with the passage of time caused by the very nature of the task itself, the respondent's attention might be attracted to the passage of time. The existence of either these two related elements in a situation induces a situation comparable to the prospective paradigm. In the same sense, if a task performed during a prospective time estimate is too difficult, the respondent will not be able to pay attention to time passage, inducing a situation comparable to the retrospective paradigm (Fraisse, 1984).

Since motorists know in advance that they will have to stop and wait when a traffic signal is red and there is no other task involved while waiting at the signal, delay estimation at traffic signals will be assumed to be under the prospective estimation paradigm.

4.4 Online video survey

As described in section 4.2, the video survey is chosen as the best method to collect the PWT of car drivers. With an online survey it is possible to invite many people to participate in the survey. Therefore the survey is distributed via the online software of NetQ[1]. People are invited with a personal email to participate in the survey, which is included in the mail as a shortcut to the website. To increase the response, people are also asked to distribute the survey in their own network.

In the online survey, movies are imbedded in the website. Unfortunately, not all respondents were able to play the movies in their web browser. Therefore, respondents could also watch the same movies on YouTube. As figure 4.2 illustrates, both techniques have a time timeline showing the elapsed time. By the imbedded movie the timeline is only an indication of the passed and remaining time, while YouTube shows the actual elapsed and total time. However, there are no significant differences in perceived waiting time between both techniques (see Appendix B).

[1] http://netq.nl/

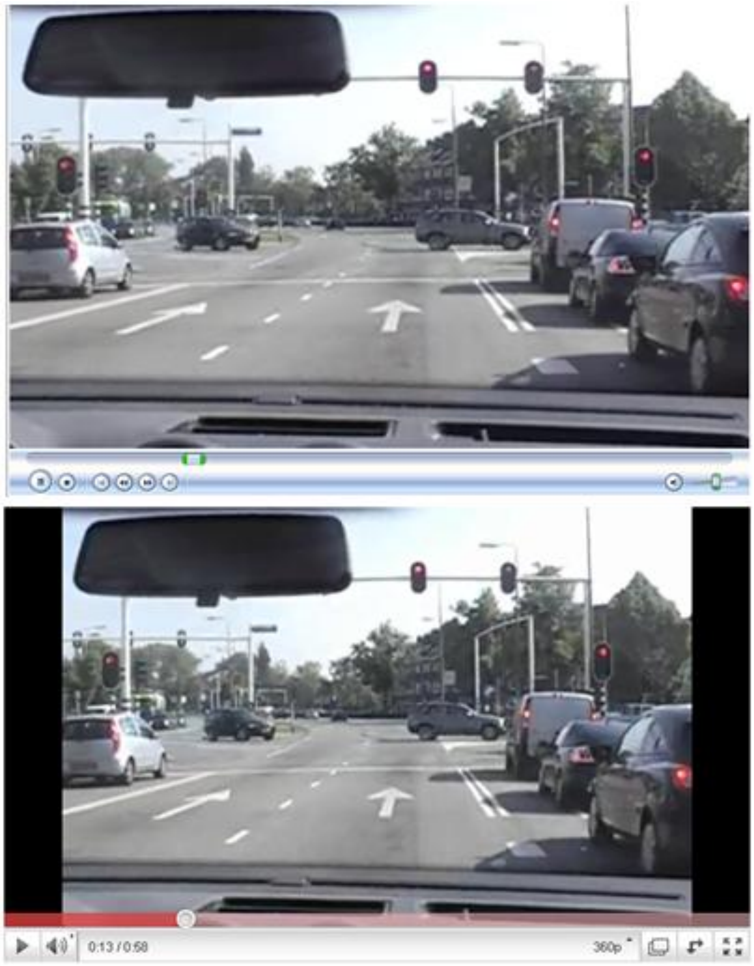


Figure 4.2: Differences between the imbedded movie (top) and the movie played in YouTube (bottom)

4.5 Movies

In the online video survey respondents are shown a number of movies. In these movies, filmed from the drivers' perspective, a vehicle approaches and waits for a red traffic light. A combination of the factors discussed in chapter 3 occurs while waiting for the traffic light.

In the first part of this section the used movies are described. Secondly attention is given to the structure of the movies in the survey.

4.5.1 Description of the movies

To increase the realism, the movies used in the survey are filmed from the drivers' perspective of a driving vehicle (figure 4.3). In each movie the vehicle approaches a signalised intersection, stops for a red traffic light, waits some time and can finally pass the intersection. To retrieve the influence of green and red waves, in some movies multiple adjacent intersections are passed. The movies are recorded on intersections controlled by Peek's Utopia in Den Bosch and Helmond, making it possible to compare the outcomes of the survey with results from a simulation study. Appendix C contains an overview of the links of the movies on YouTube, and Appendix D contains an overview of the characteristics of each movie.

Figure 4.3: Screenshot from a movie showing the driver's perspective

4.5.2 Structure of the movies

The purpose of showing the movies to the respondents is to collect their perceived waiting times in situations differently influenced by the factors discussed in chapter 3. Although the movies in the survey are primarily selected on the four most dominant factors (section 3.3), there are many combinations possible. To make a good model for the PWT, it is therefore important that many movies are watched by the respondents.

The model of the users' perception will be obtained from the average PWT per movie. Therefore, it is important that the confidence interval of the PWT of each movie is small. The confidence interval depends on the standard deviation and the number of samples. Figure 4.4 shows the relation between the 95% confidence interval, the standard deviation and the number of respondents per movie. If a movie is watched by 15 respondents, the 95%-confidence interval is half of the standard deviation.

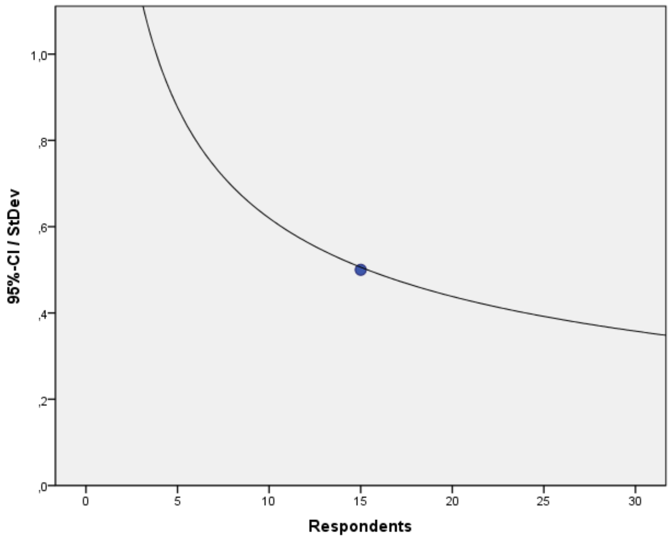


Figure 4.4: The ratio of the 95%-confidence interval (CI) and the standard deviation (StDev)

In the survey, every respondent watches 4 to 5 movies. These movies are randomly selected from 6 bins containing multiple movies (figure 4.5). During the period respondents can participate in the survey, the number of respondents and their answers are monitored. Whenever a movie is watched by 15 respondents and the confidence interval is acceptable, the movie is replaced with a new one. With this technique in total 44 movies were watched by the respondents.

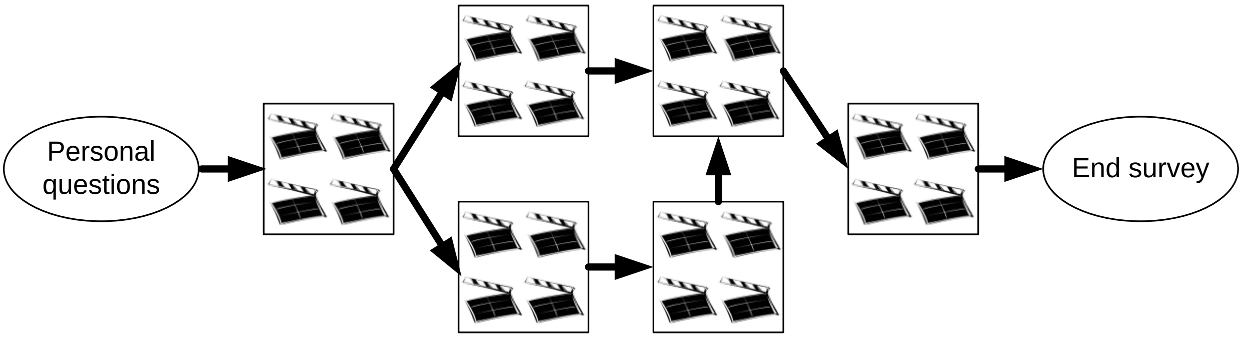


Figure 4.5: Overview of the design of the survey. First respondents are asked for their personal characteristics. Secondly 4 to 5 movies, randomly selected from 6 bins, are shown to the respondents. After each movie, some questions about the shown situation are asked.

To evaluate the relations between the factors discussed in chapter 3 and the PWT, after each movie the respondents are asked for their perceived waiting time. The following question is used for this purpose:

How long do you think you had to wait for this intersection?

Besides the question regarding the PWT, some other questions are asked as well. Although the prospective approach of the survey, these questions prevent that the respondents only focus on the waiting time and not on the other factors occurring in the movies. Therefore, these additional questions are related to the factors occurring in the movies. Examples of such questions are about the distance between two intersections or the annoyance of waiting behind a heavy vehicle.

One question is asked after almost all movies: *Do you think this waiting time is acceptable?* This question is used to analyse the user acceptance of car drivers. Unfortunately, this question is not asked after movies with a red wave between adjacent intersections.

4.6 Summary

As described in chapter 2, a survey is needed to analyse the influence of the factors discussed in chapter 3 and the perceived waiting time. In section 4.2, several methods of survey are compared on the following characteristics: costs, number of respondents and realism. An online video survey is selected as the best option. Respondents are shown a number of movies filmed from the drivers' perspective of a vehicle passing a signalised intersection, and are asked for their perceived waiting time and whether this waiting time is acceptable or not. Because it is important that many movies are analyzed by the respondents and each movie has to be analyzed 15 times, the survey is monitored and movies are replaced when they are watched 15 times.

5 RESULTS SURVEY AND MODELLING

5.1 Introduction

From the 300 respondents who participated in online video survey (as described in chapter 4), 159 completed the survey. It is possible that many respondents could not watch the imbedded movies of the survey, and therefore did not complete the survey (see section 4.3). Together the respondents watched 44 movies, which results in 730 measurements of the users' perception of signalised intersections.

In this chapter the results of the survey are analyzed. First the impacts of the factors discussed in chapter 3 are determined. Based on these impacts, in section 5.3 a model for the perceived waiting time is presented. In section 5.4 a model is presented to determine if the perceived waiting time is acceptable of not. Finally, in section 5.5 the validation of both models is discussed.

5.2 Movie characteristics

In chapter 3, ten factors which influence the users' perception of signalised intersections were discussed. These factors are also expected to have an influence on the perceived waiting time of car drivers. The most dominant factors were the actual waiting time, the number of stops in the queue unused green time of conflicting traffic and green/red waves between intersection. The relations between these four factors and the perceived waiting time are described in this section. Also the other factors presented in chapter 3 are analyzed. However, as expected in figure 3.4, these factors do not have a significant influence on the PWT, and are therefore not described in this section.

5.2.1 Actual waiting time

The PWT is an indicator of the users' perception of signalised intersections; it explains how car drivers experience their waiting time before a traffic light. Therefore, it is obvious that there is a strong relationship between the actual and perceived waiting time.

Figure 5.1 shows the mean actual and perceived waiting time of all movies. As assumed, the PWT increases with the actual waiting time. Regression analysis is performed to describe this relationship with a linear and quadratic model. The quadratic model has a slightly better fit, which also meets the conclusions from Wu et al. (2009).

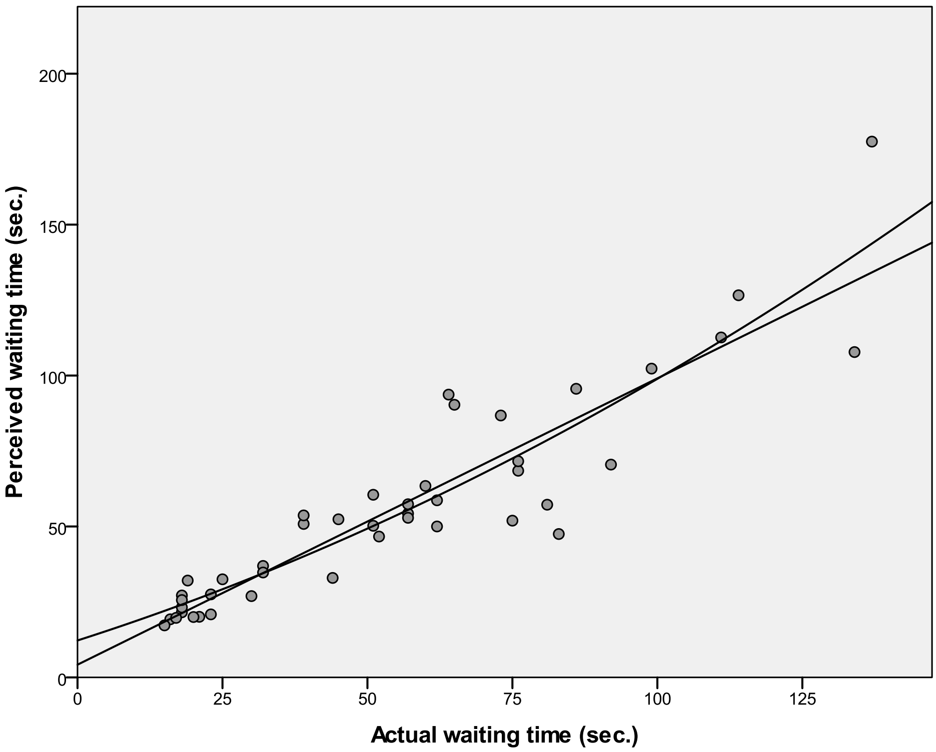


Figure 5.1: The mean actual and average perceived waiting time per movie with models: a linear model (R^2=0,833) and a quadratic model (R^2=0,842)

The quadratic relation between the actual and perceived waiting time is described with the following model:

$$PWT = \beta_0 + \beta_1 \cdot WT + \beta_2 \cdot WT^2 \qquad (5.1)$$

Where:

PWT = Predicted mean perceived waiting time per movie

WT = Actual waiting time

β = Coefficient

With regression techniques the following values for the coefficients are determined.

Table 5.1: Coefficients model 5.1

Coefficient	**Value**	**Significance**
$\boldsymbol{\beta_0}$	12.236	-
$\boldsymbol{\beta_1}$	0.616	0.01
$\boldsymbol{\beta_2}$	0.003	0.15

5.2.2 Number of stops in the queue

The number of stops in the queue is assumed to be an important factor influencing the PWT. According the figure 3.4, more stops are expected to result in a higher PWT. In the literature car drivers state that is important to pass the intersection in one cycle and it is annoying when the green phases are too short to handle all the traffic (section 3.2.2).

From the 44 movies in the survey, 6 movies show a situation where multiple stops in the queue are made. As figure 5.2 shows, the influence of multiple stops on the PWT depends on the actual waiting time. With a lower actual waiting time the expected PWT is higher than the measured PWT, while with a longer actual waiting time the expected PWT is lower.

According to this analysis, the β_0 and β_1-coefficient in model 5.1 have to be adjusted with the the number of stops. If more stops in the queue are made the expected PWT is lower, and a longer actual waiting time results in a larger reduction of the expected PWT.

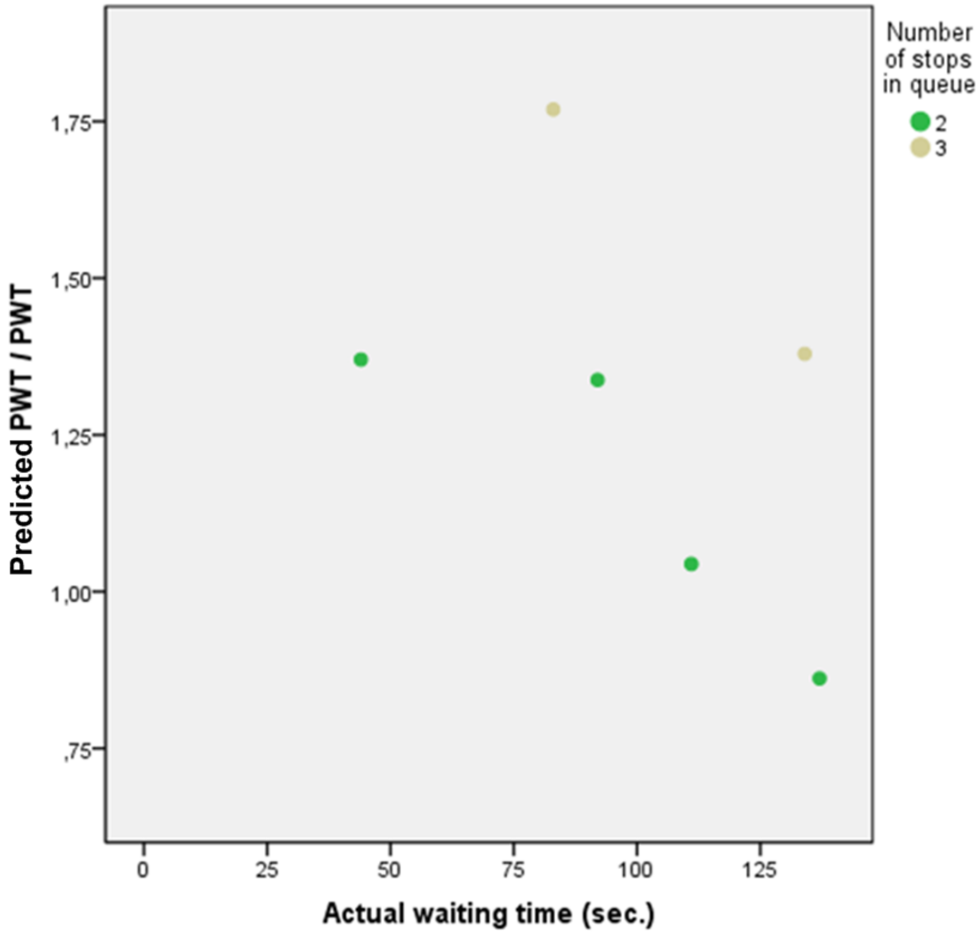


Figure 5.2: the ratio of the predicted PWT (model 5.1) and the measured PWT in relation with the number of stops and the actual waiting time.

5.2.3 Unused green time conflicting traffic

The unused green time of conflicting traffic expresses the time that a car driver is waiting for an empty intersection. According to figure 3.4, the unused green time is expected to have a positive influence on the PWT: the higher the unused green time, the higher the PWT.

Figure 5.3 shows the results of the survey regarding the unused green time. According the survey, there is no relation between the PWT and the unused green time. The ratio between the expected PWT (model 5.1) and the measured PWT is not influenced by the unused green time of conflicting traffic.

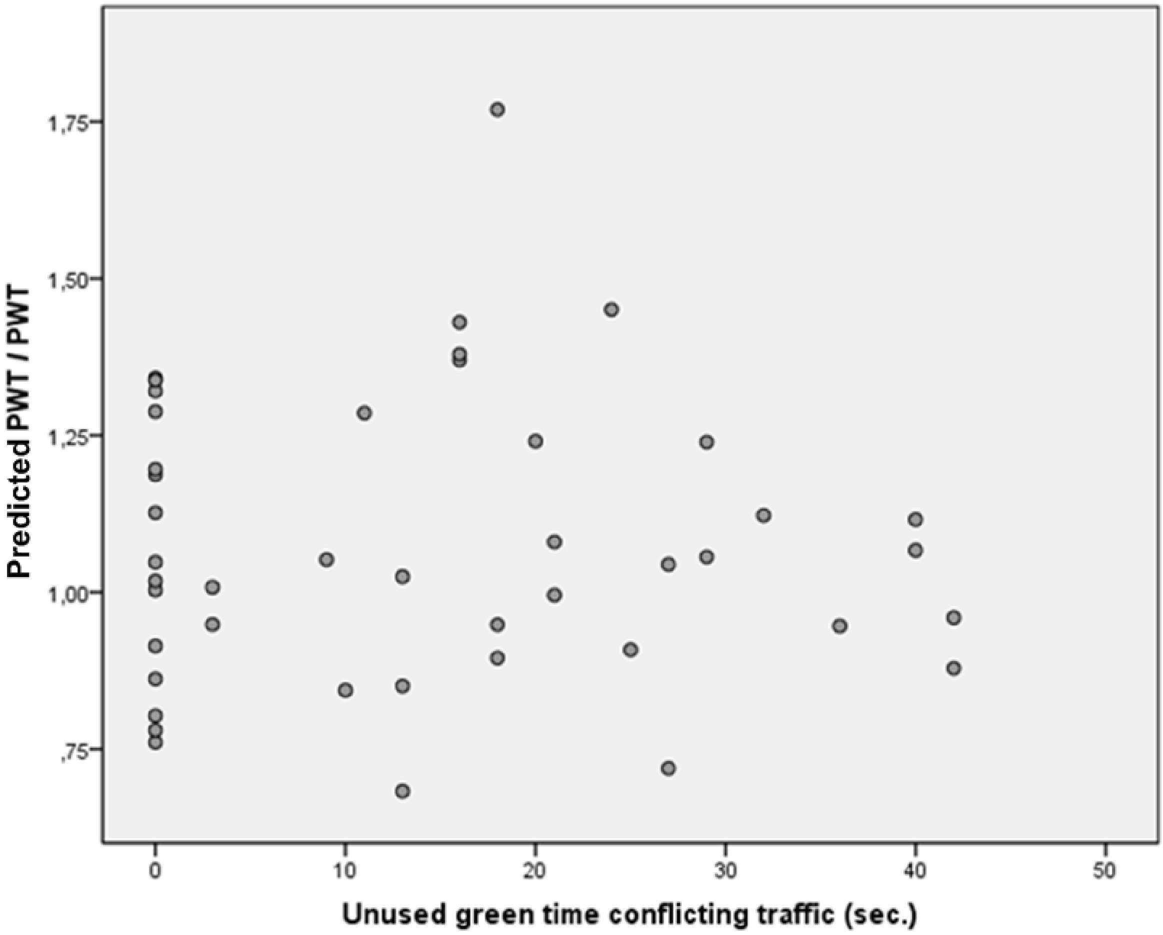


Figure 5.3: the ratio of the predicted PWT (model 5.1) and the measured PWT in relation with the unused green time of conflicting traffic.

5.2.4 Red wave

According to section 3.2.4 green waves between intersections have a positive influence on the users' perception. Therefore a red wave between intersections is expected to have a negative influence on the PWT. If a car driver has to stop at two adjacent intersections, the PWT on the second intersection is expected to be higher.

Figure 5.4 shows the outcomes of the survey regarding green and red waves. When there is a red wave and the actual waiting time is short, the measured PWT is higher than the expected PWT from model 5.1. On the other hand, when the actual waiting time is longer, the PWT is lower than the expected PWT.

According the above analysis, both the β_0 and β_1-coefficients of model 5.1 needs to adjusted to modify the model for representation red waves. If there is a red wave between two adjacent intersections, at low actual waiting times the PTW is higher while at longer actual waiting times the PWT is reduced.

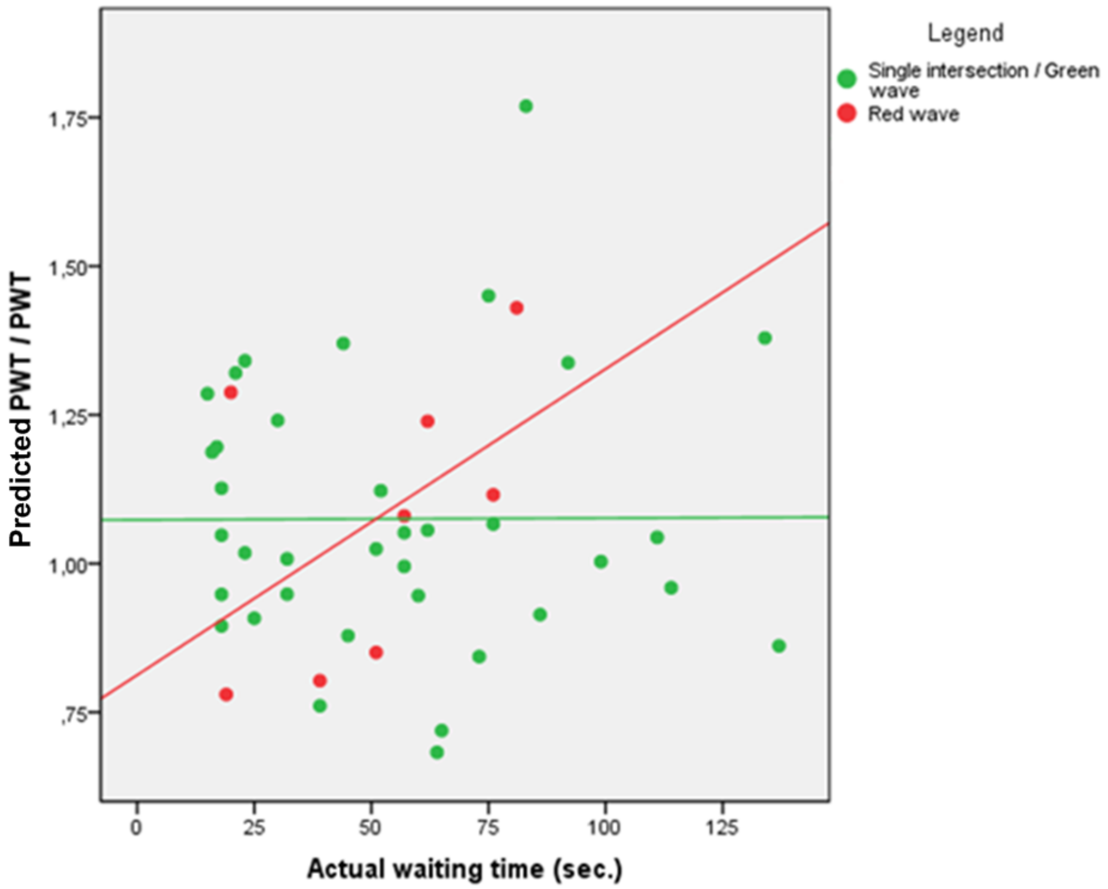


Figure 5.4: the ratio of the expected PWT (model 5.1) and the measured PWT in relation with the actual waiting time and the red/green waves

5.3 Perceived waiting time - model

In section 5.2 the influence of several factors on the PWT is discussed. Based on this discussion the following model 5.2 is retrieved. This model knows a quadratic relationship with the actual waiting time (section 5.2.1), which is similar to the model of Wu et al. (2009). The coefficients of the quadratic model are modified to implement the number of stops and the presence of a red wave (sections 5.2.2 and 5.2.4).

As can de noticed in model 5.2, de β_0 coefficient of model 5.1 is not adjusted with the number of stops. Regression analysis (also see table 5.2) showed that there is no significant relation between the number of stops ($\beta \cdot stops$) and the PWT.

$$PWT = \beta_0 + \beta_1 \cdot RW + (\beta_2 + \beta_3 \cdot Stops + \beta_4 \cdot RW) \cdot WT + \beta_5 \cdot WT^2 \quad (5.2)$$

Where:

PWT = Expected perceived waiting time

WT = Actual waiting time

$Stops$ = Number of stops in the queue

RW = Red wave, 1 if there is a red wave else 0

β = Coefficient

Regression analysis is performed to calibrate model 5.2. The coefficients have the following values.

Table 5.2: Coefficients model 5.2

Coefficient	Value	Significance
β_0	13.859	-
β_1	17.254	0.11
β_2	0.661	0.00
β_3	-0.233	0.00
β_4	-0.432	0.03
β_5	0.006	0.00

The R^2 of this model is 0.907, and all variables are significant on the 0.1-level. This model describes the PWT of car drivers good, and can therefore be used as an indicator of the users' perception of signalized intersections. Figure 5.5 shows the outcomes of model 5.2 for different situations.

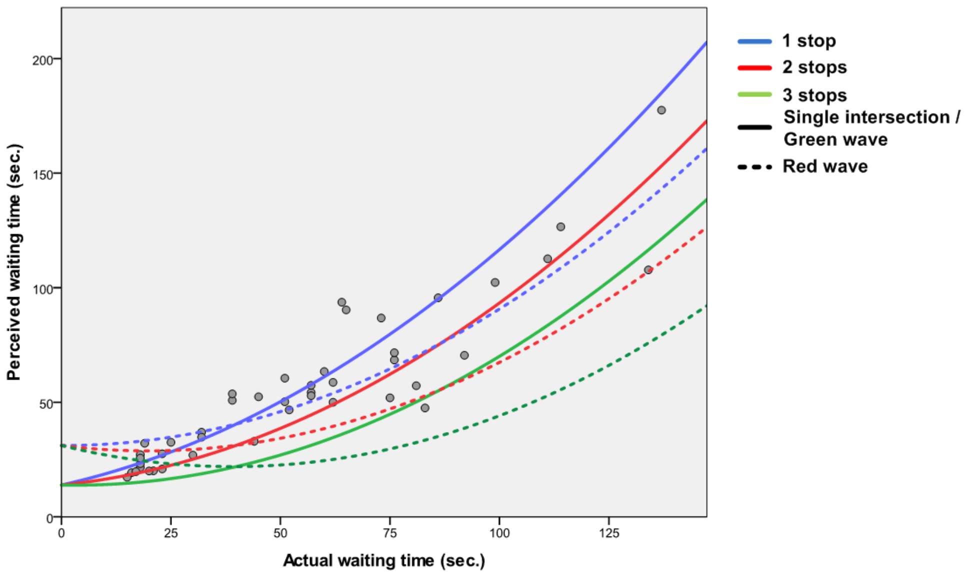


Figure 5.5: The outcomes of model 5.2 compared to the results of the survey.

5.4 User acceptance – model

As mentioned in section 4.6, after most movies the question is asked if the respondents consider their waiting time in the movie as acceptable or not. This information is used to determine if the PWT according model 5.2 is acceptable or not.

The user acceptance of car drivers is a binary measurement, the waiting time is either acceptable or not. However the mean user acceptance per movie is not binary anymore. When acceptable is equal to 1, and not acceptable 0, the user acceptance of a movie could be 0.5 when half of the respondents consider the waiting time acceptable.

To meet the binary nature of the user acceptance, a Sigmoid-function (Menon, Mehrotra, Mohan and Ranka, 1996) is used to describe the acceptance:

$$\mathrm{UA} = \frac{1}{1+e^{\beta_0+\beta_1 \cdot PWT}} \qquad (5.3)$$

Where:

UA = Estimated user acceptance

PWT = Estimated perceived waiting time

β = Coefficient

With the following values for the coefficients the R^2 is 0.85.

Table 5.3: Coefficients model 5.3

Coefficient	**Value**
$\boldsymbol{\beta_0}$	-3,650
$\boldsymbol{\beta_1}$	0,055

The outcome of the model is the probability that the car driver accepts his waiting time. Figure 5.6 shows the relation between the expected PWT and the user acceptance. If the expected perceived waiting time is higher than 65 seconds, it is more likely that the PWT is is not accepted by the car driver.

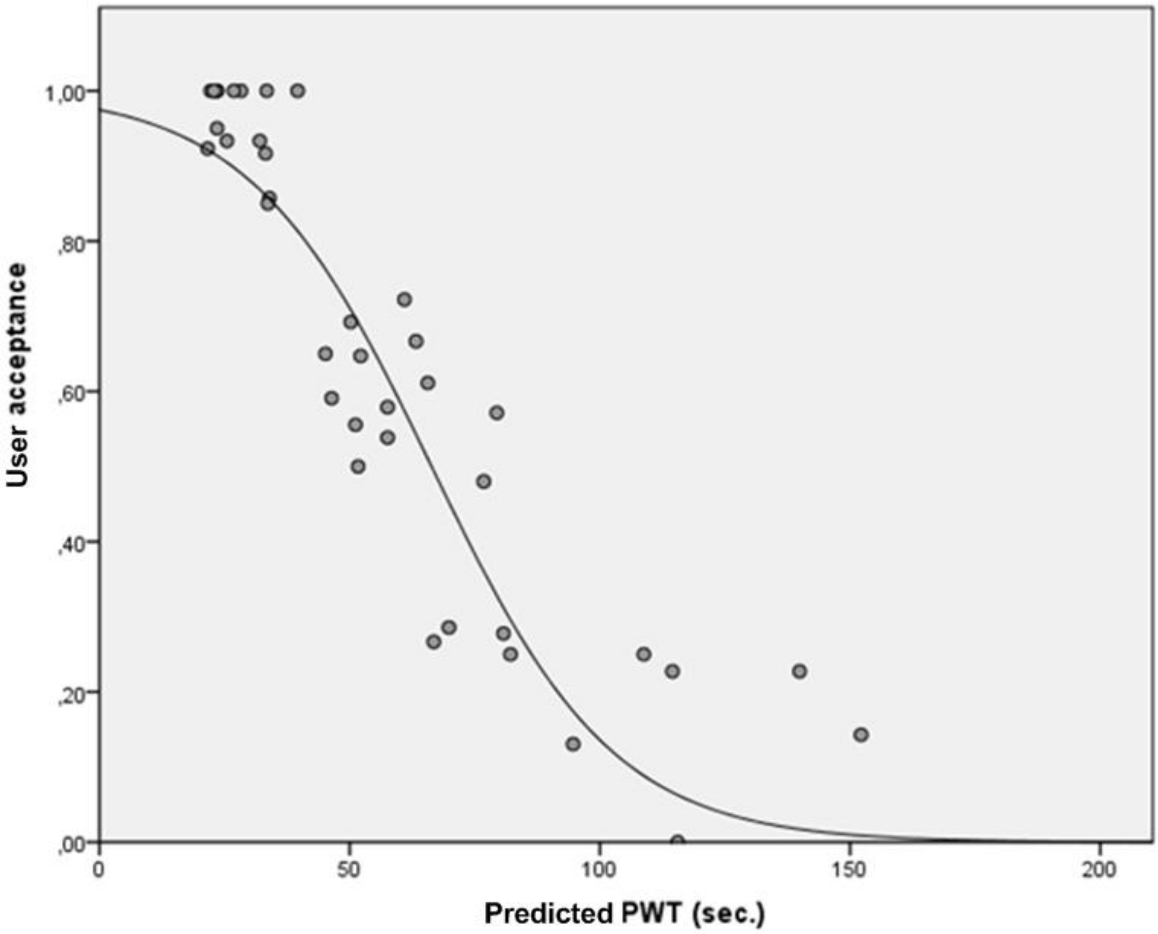


Figure 5.6: The outcomes of model 5.3 and the predicted PWT (model 5.2) per movie (1=acceptable, 0=not acceptable).

5.5 Validation

The models presented in sections 5.3 and 5.4 are based on the results of the online video survey. Both models predict the outcomes of the survey with high certainty, and are therefore considered as good models. However, it is important that the models predict the PWT and UA of real car drivers and not that of the respondents of the survey.

The local authorities of Helmond and Den Bosch were asked for an overview of complaints from car drivers in the Utopia-network in both cities. These complaints can be compared with the results of simulation-studies in both cities (see also chapter 7). If high perceived waiting times are measured in the simulations on the same spots as described in the complaints, the models can be assumed to be correct.

Unfortunately, both authorities do not register complaints of car drivers regarding long waiting times. In interviews with representatives from the authorities they admit they receive complaints regarding long waiting times. However, these complaints are not registered because the local authorities cannot solve these problems. Only complaints about solvable issues, like broken lights and not functioning induction loops, are tracked.

An alternative way to validate the models is to perform a real-world experiment (see section 4.2). Car drivers are asked to drive a predetermined route while are surveyor is sitting in the vehicle. After each signalised intersection, the car drivers report his perceived waiting time and user acceptance to the surveyor. The surveyor measures the actual waiting time, number of stops and coordination for each intersection.

Car drivers in both Helmond and Den Bosch participated in the experiment. In total 37 situations were analyzed. These situations differ on the actual waiting time, number of stops in the queue and coordination between intersections. The results are included in Appendix E.

The fitness of the model for the perceived waiting time (see section 5.3) is calculated for the results of the experiment. This fitness is expressed as a R^2 of 0.870, which means that the model is a good representation for the real-world perceived waiting time. Also in 81% of the cases the outcome of the UA-model meets the user acceptance measured in the real-world experiments.

5.6 Summary

Based on the results of the survey described in chapter 4, the influence of the factors (chapter 3) on the perceived waiting time is analyzed. First a quadratic model between the actual and perceived waiting time is calibrated. This model is used to determine how other factors influence this quadratic relation between the actual and perceived waiting time. The number of stops in the queue and a red wave between intersections have a significant influence on the perceived waiting time.

In this chapter two relations are modelled. The first model predicts the perceived waiting time out of the actual waiting time, the number of stops and the possibility of a red wave between intersections. A second model calculates the probability if a car driver considers his perceived waiting time as acceptable or not.

6 VISSIM

6.1 Introduction

In chapter 5 a model to estimate the perceived waiting time of car drivers at signalised intersections is determined based on the results of the conducted online video survey. The objective of this study is to determine a method to evaluate the PWT a priori of implementing a TLC-system. As described in section 2.3.2, this evaluation can be performed using the traffic-simulator Vissim.

This chapter describes the development of an application to evaluate the PWT in Vissim using the COM-Interface. First the basic operations of Vissim and its COM-Interface are described. Secondly the application itself is presented, and in section 6.4 the main algorithm of the application is described.

6.2 Vissim and the COM-Interface

Vissim is a stochastic microscopic simulation model capable of simulating traffic operations in urban areas with emphasis on public transport and multi-model transportation (Vélez, 2006). The main abilities of Vissim are:

- Realistic representation of traffic flow of cars, truck, buses and light rail systems
- Implementation of a psycho-physical car-following model, an thus, provides a very realistic driving behaviour
- Assessment of traffic operations along many different types of road network parameters

The simulation package of Vissim consists internally of two different parts (PTV, 2009). The traffic simulator is a microscopic traffic flow simulation model including the car following and lane change logic. The traffic light controller (TLC) is a signal control polling detector information from the traffic simulator on a discrete time step basis. It then determines the signal status for the following time step and returns this information to the traffic simulator (figure 6.1)

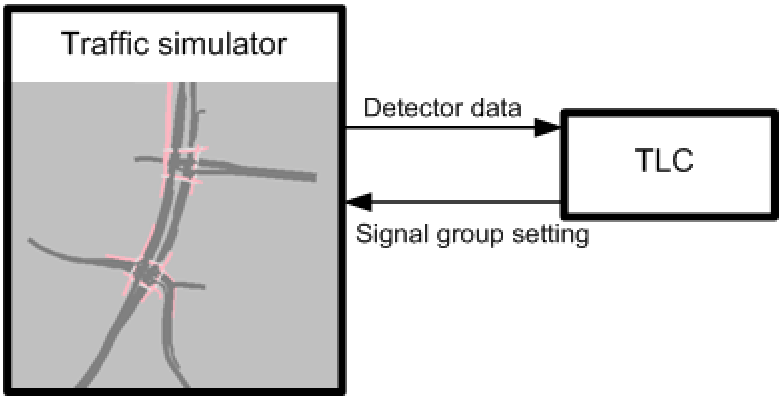


Figure 6.1: Communication between traffic simulator and signal state generator in Vissim

The COM-Interface is an additional module of Vissim to access the objects (e.g. vehicles, traffic lights) in the traffic simulator (PTV, 2010). It is possible to read the properties of the objects (e.g. speed of a vehicle) and to adjust the properties (e.g. the signal group state). Making use of the COM-Interface it is for example possible to generate extra output to apply other control algorithms. Figure 6.2 illustrates the communication model of Vissim with the COM-Interface.

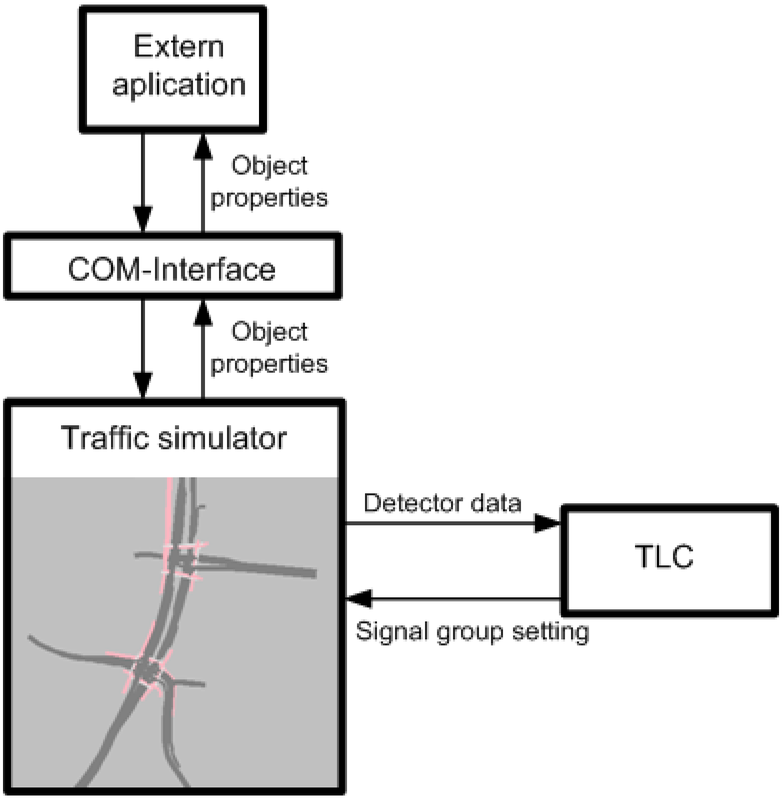


Figure 6.2: Communication model of Vissim with the COM-Interface

6.3 The perceived waiting time in Vissim

An external application is developed to measure the perceived waiting time (PWT) and user acceptance (UA) in Vissim. This Visual Basic application communicates with Vissim using the COM-Interface (see section 6.2).

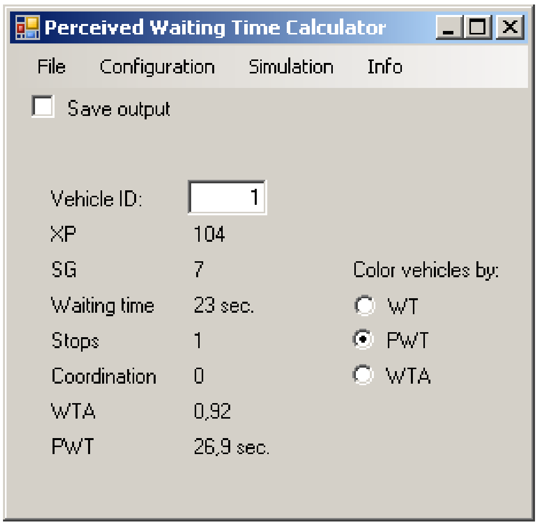


Figure 6.3: Application to measure the PWT and UA in Vissim

For every vehicle in the simulation, the application calculates the PWT and UA using the algorithm described in section 6.4. As output from Vissim, the position and speed of the vehicles are used as input for this algorithm. The position is used to determine the intersection the vehicle is approaching, and the speed is used to calculate the waiting time and number of stops per intersection. The position and speed together are used to determine if there is a red or green wave between intersections.

The application knows three types of output.

At the end of the simulation an excel-file is generated with all measured data per vehicle per intersection. This file contains information like the number of stops, the waiting time, the user acceptance and the perceived waiting time, and can be used to make an ex-post evaluation of the simulation.

During the simulation it is possible to select a vehicle by entering its ID in the application. For that vehicle the application shows the current measurements, which are updated every time step (figure 6.4). This method is, for example, useful when you want to know the PWT of a vehicle in a particular situation.

Finally, with the application it is possible to colour the vehicles in the simulation corresponding their actual waiting time, user acceptance or perceived waiting time. If a vehicle has a low PWT it is white, and when the PWT increases the vehicle turns red (figure 6.4).

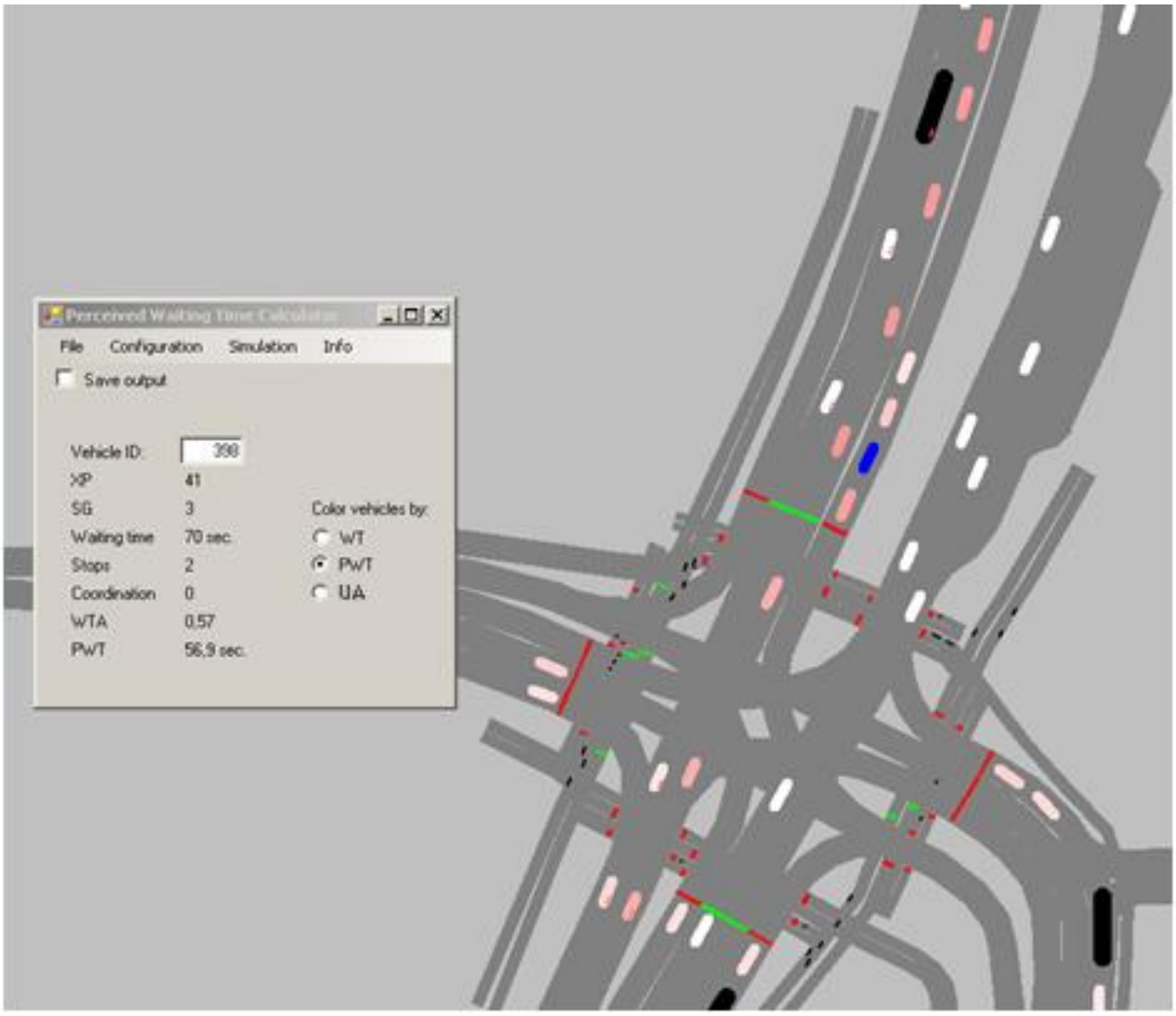


Figure 6.4: The application and Vissim. The blue vehicle is the selected vehicle; its properties are shown by the application. The other vehicles are coloured by their PWT (black vehicles are not a car).

6.4 Algorithm

An extern Visual Basic application is coded to calculate the PWT and UA during a simulation in Vissim. As explained in section 6.2 this application communicates with Vissim using the COM-Interface. Via the COM-interface the application is capable to read and change the properties of objects.

The extern application is based on the algorithm presented in figure 6.5. This algorithm read the properties of vehicles in Vissim and calculates the PWT.

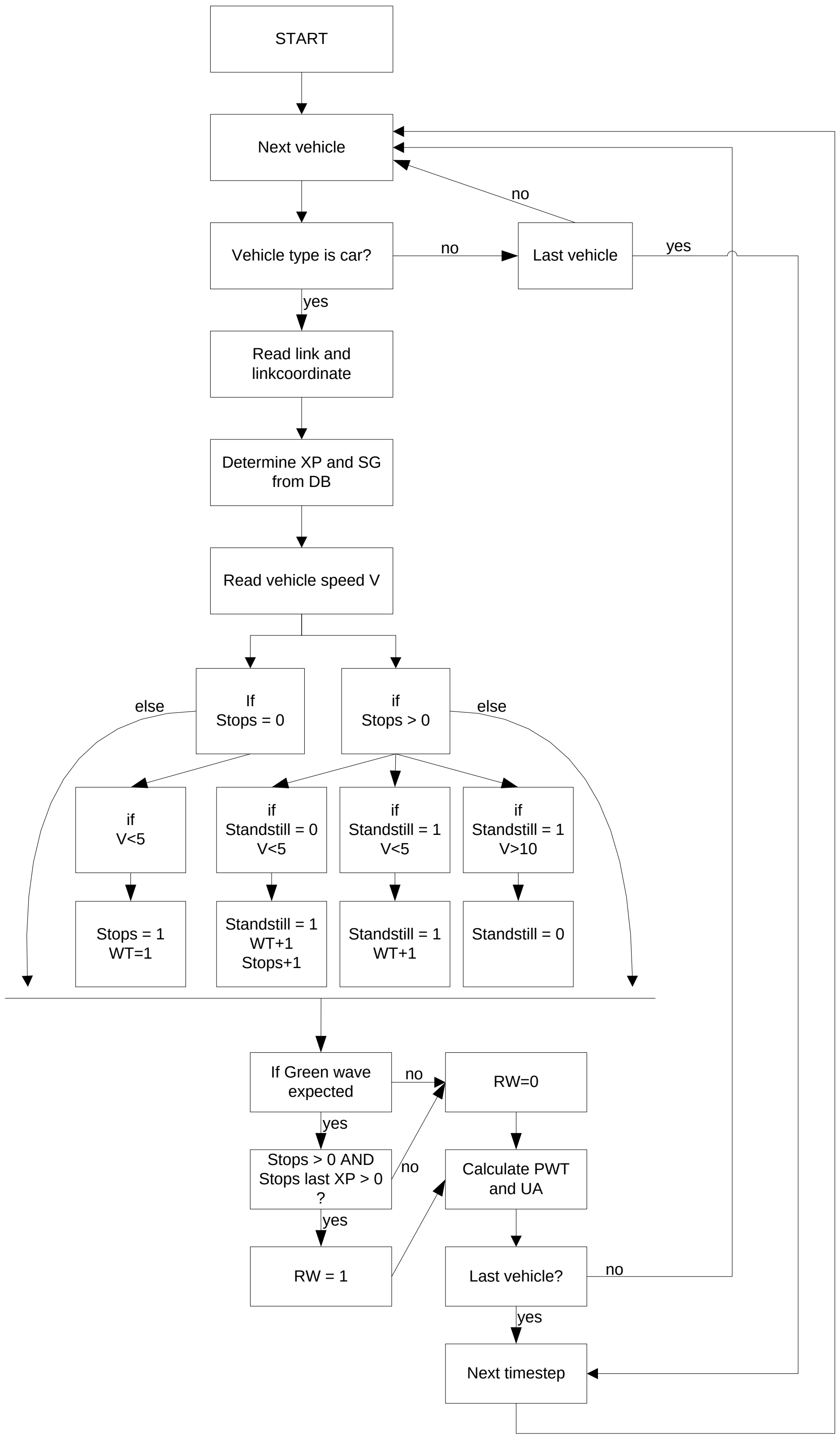


Figure 6.5: the algorithm used to calculate the PWT and UA in Vissim

The algorithm is executed every time step (1 second) for every vehicle that is a car. First the position (link and linkcoordinate) are retrieved from Vissim. From a database the application knows which intersection (XP) and signal group (SG) the vehicle is approaching.

According the Vissim (PTV, 2010), a vehicle stands still if each speed is below 5 km/h and a new stops is registered if its speed has been above 10 km/h, and drops again below 5 km/h. In the algorithm these definitions are used to measure the waiting time and number of stops at each intersection.

A second database is used to determine if coordination between the previous XP and SG, and the next XP and SG is expected. If coordination is expected, and at both intersections the vehicle made a stop, the parameter RW is 1. In all other cases this parameter is equal to 0.

Finally the perceived waiting time and its acceptance are calculated according the models in sections 5.3 and 5.4.

6.5 Summary

In this chapter the models for the perceived waiting time and user acceptance (chapter 5) are implemented in Vissim. An external application is developed in Visual Basic. This application is able to read vehicle properties (speed and position) from Vissim, and calculates per vehicle the PWT and UA.

According their calculated perceived waiting time, the vehicles in Vissim are coloured by the application. The more red a vehicle in the simulation is, the higher its perceived waiting time is. The calculated PWT and UA for all vehicles are also written to an output-file for ex-port evaluations.

7 SCENARIO ANALYSIS

7.1 Introduction

In chapter 5 two models were introduced. The first model predicts the perceived waiting time of car drivers, and the second model calculates the probability if this perceived waiting time is acceptable or not. The application discussed in chapter 6 is used to evaluate the perceived waiting time for different TLC-systems and configurations.

First, two different TLC-systems are described: a solitaire intersection control and Utopia. Secondly the networks of Den Bosch and Helmond, in which these TLC-systems are operational, are described. Finally, the user acceptance of both systems and of different configurations of Utopia are compared with each other.

7.2 TLC-systems

7.2.1 Solitaire intersection control

A solitaire traffic light controller controls one intersection without cooperating with other intersections. There a two types of solitaire controllers: fixed-timed and vehicle actuated controllers. In the Netherlands mostly vehicle actuated controllers are used.

Vehicle actuated controllers respond to the current traffic situation. This allows the length of green phases to differ over time, and not all signal groups are required to get green each cycle. To respond to the traffic situation, it is important the controller knows the current traffic situation. For this purpose, generally induction loops in the road surface are used. These detection loops register if there is a vehicle present above the loop. There are two kind of loops: stopline and approach detectors (figure 7.1).

Stopline detectors are located just before the stopline and determine if there are vehicles waiting on the corresponding lane. Only if there are vehicles waiting, the signal group turns green during the cycle. The length of the green phase is determined by the approach detectors. These loops measure the headways between vehicles. If the loop, after the minimum green phase has passed, is unoccupied, the controller assumes that vehicles that passed the loop can safely pass the stop line, and vehicles before the loop can safely come to a stop before the stop line. If the loop is unoccupied, the signal group turns safely into red.

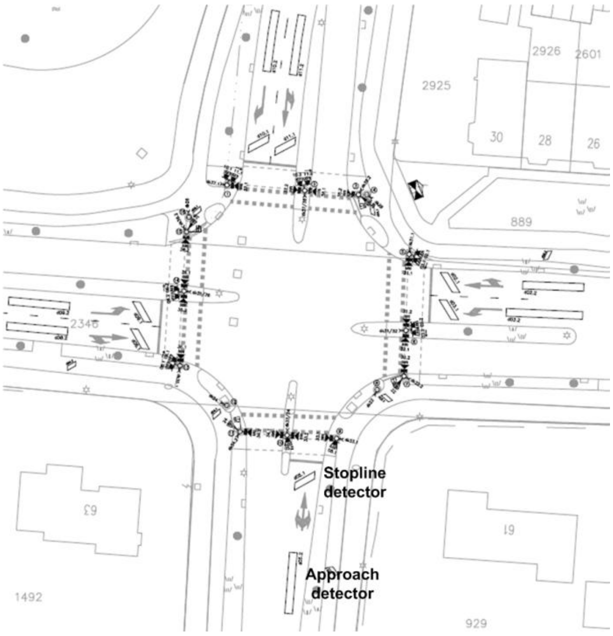


Figure 7.1: Overview of a signalised intersection with detection loops

7.2.2 Utopia

The technical reference manual of Utopia (Mizar, 1998), describes the principles of Utopia. Because of the importance of understanding the principles behind Utopia, the next passage is extracted from the manual.

Utopia (Urban Traffic Optimisation by Integrated Automation) is a specific concept designed to improve urban travel conditions by the application of fully automated control principles. Utopia control strategies aim to reduce the total time lost by private vehicles during their trips within the controlled area,

The Utopia architecture is hierarchical and decentralised: optimal control strategies are determined at the higher level on the basis of area traffic prediction, while traffic light control is actuated at the lower level according to the actual traffic conditions encountered at the intersections. This type of architecture requires a communication network between intersections and the connection of some nodes of the network to the control centre.

The optimization function for each intersection concerns the traffic control to be actuated at the central intersection only, but it provides a consistent interrelation with the control of the neighbouring intersections and takes into account traffic information and traffic control data concerning the whole network. The objective-function to be optimized consists of the terms relating to the traffic observed on the incoming link of the central intersection and those which implement the following two fundamental interaction principles:

- A strong interaction principle is implemented by taking into account the time lost at the downstream intersections by vehicles leaving the central zone;
- A look-ahead principle is implemented by taking into account traffic forecasts defined on the whole optimization horizon (120 sec) for all the central intersection's incoming links.

At the intersection level a local control unit operates for each traffic light intersection and interacts with the neighbouring local control units and with the area level. The intersection controller determines the signal settings to be applied to the traffic lights. It operates by optimizing a suitable function adapted to the current intersection traffic situation. Optimization is performed on the time horizon of the next 120 seconds and is repeated every three seconds.

In order to guarantee the optimality and robustness of control at the network level, the functional optimized the controller has been designed to apply the strong interaction concept. This requires the functional to take into account the station of neighbouring intersections.

The functional is defined by the sum of different weighted costs elements calculated on the whole optimization horizon. The optimization function finds a value for:

$$Costs = C_q + C_{qd} + C_{qp} + C_{qx} + C_{qdx} + C_s + C_{sd} + C_{sp}$$

Where:

- C_q is the cost of the delay of vehicles on incoming links.
- C_{qd} is the cost of the delay of vehicles on outgoing links. This cost actuate the strong interaction between intersections.
- C_{qp} is the cost of delay of public transportation.
- C_{qx} is the cost of vehicles exceeding the maximum queue length on incoming links. This cost takes into account queues exceeding safety thresholds which are proportional to the maximum capacity on links.
- C_{qdx} is the cost of vehicles exceeding the maximum queue length on outgoing links.
- C_s is the cost for stopped vehicles on incoming links
- C_{sd} is the cost for stopped vehicles on outgoing links
- C_{sp} is the cost for stopped public transport vehicles

Cost elements are evaluated on the whole horizon on the basis of traffic propagation rules which take into account the signal settings and the constraints on the minimum and maximum stage lengths. Different weights are allowed for different links and for different PT services.

7.3 Cities

7.3.1 Helmond

In Helmond, over 40 intersections are controlled by Utopia. One of the characteristics of this network is the strong coordination between intersections of the main roads. A small sub-network of five intersections is chosen in this study.

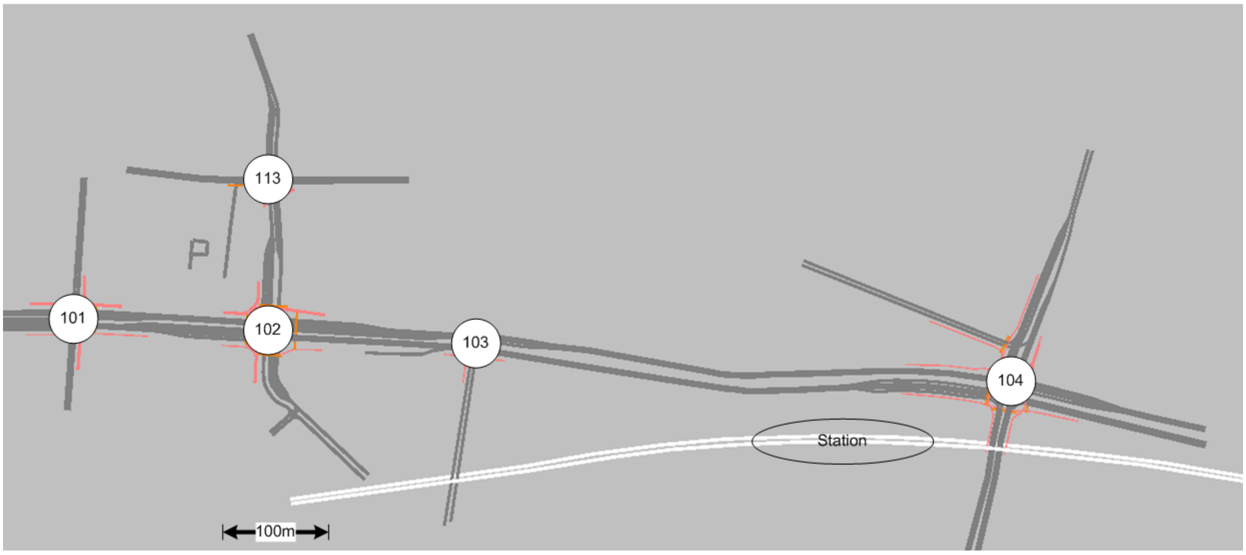


Figure 7.2: Overview of the Helmond network in Vissim

The Utopia-network in Helmond is configured to improve the flow on the main roads. Therefore, there is strong cooperation between the intersections of the main roads (intersection 101 to 103). This cooperation is expressed by the average number of 1.5-2.2 stops per vehicle on the main road between intersection 101 to 104 (van der Bijl, 2008). In addition, strong cooperation on the main road results in relatively high waiting times on the side roads.

Intersection 104 is accommodated with a train passage. When a train is in approaching the station, or haltering in the station, the train passage is closed. This results in long waiting times (up to 5 minutes) for signal groups crossing the train passage.

7.3.2 Den Bosch

The Utopia-system in Den Bosch is designed with high priorities for non-motorised traffic. Instead of optimizing control for motorized traffic, most attention is given to bicycles and pedestrians. With the last major upgrade in 2007, the average delay times for bicycles were reduced by 40-50%, and for pedestrians with 20-30% (De Jong, 2007).

In the design process of the Utopia-system, no special attention was given to the coordination between intersections. Since Utopia establish cooperation between intersections, depending on the traffic situation there could be coordination between intersections. However, in many situations there is no coordination between intersection 48 and 40, and 41 and 42.

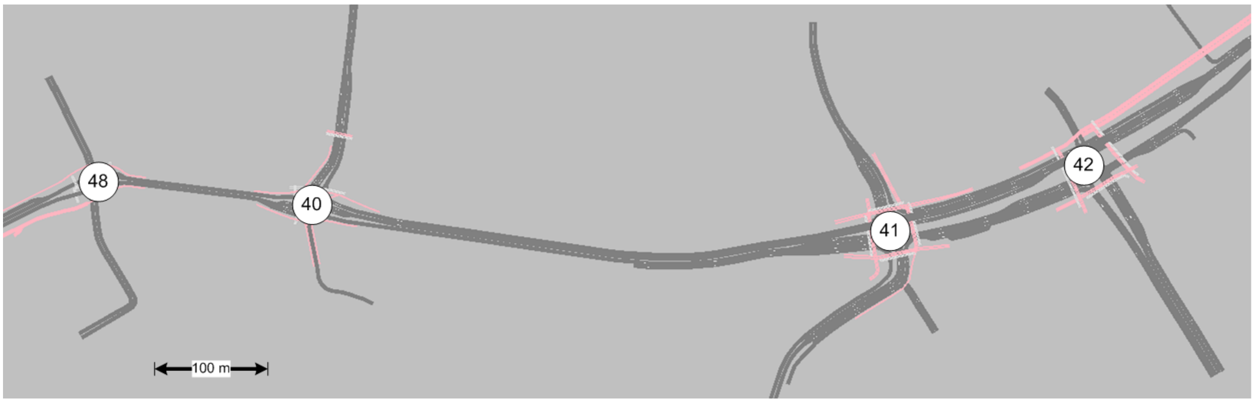


Figure 7.3: Overview of the Den Bosch network in Vissim

In the peak periods, the network is oversaturated (de Jong, 2007). Because the intersections are designed with short cycle times, the high saturated state result in long waiting time with multiple stops per intersection. However, in the off-peak hours the average delay is reduced by almost 70%, which means that both the waiting times as the number of stops in the queues are reduced.

Since 2007, the traffic flows in the network have changed because the new highway around the city has been opened in 2009 (Rijkswaterstaat, 2010). Unfortunately, no actual traffic information was available for the simulations. Therefore, the data of 2007 have been modified with field observations to generate a representative traffic situation.

7.4 Scenario analysis

In this section the solitaire control and different configurations of Utopia are compared. For the different TLC-systems the user acceptance is evaluated. This indicates how the scenarios are perceived by car drivers.

7.4.1 Helmond

In Helmond the intersection can be controlled by solitaire controller and by Utopia. When the network is controlled by Utopia, the public transport vehicles (busses) are handled with conditional priority. Depending on their delay, more or less priority is given to the busses. In this section three systems and configurations are compared with each other.

- Solitaire control: all intersections are controlled by solitaire controllers
- Utopia – Normal configuration: the intersections are controlled by Utopia. In the normal configuration there is no priority provided for PT-vehicles.
- Utopia – Priority: the intersections are controlled by Utopia. In this configuration the weights in the cost function for PT-vehicles are maximized, resulting in almost absolute priority for the busses.

Table 7.1 shows the average performance of vehicles per intersection for the three scenarios. The average performance of the scenarios is more or less equal. The mean perceived waiting times are equal and, in average, the overall user acceptance is high. All results of the simulations are provided in Appendix F.

Table 7.1: Average performance per intersection per vehicle

Scenario	**Waiting time**	**Stops**	**PWT**	**UA**
Solitaire control	27 sec.	0.8	38 sec.	0.9
Utopia – Normal	28 sec.	0.6	39 sec.	0.8
Utopia – PT-priority	28 sec.	0.7	37 sec.	0.8

Table 7.1 shows the average performance, which is good for all scenarios. However, if most vehicles perceive waiting before a traffic light as acceptable, the few vehicles with a low user acceptance are not represented in these numbers. Table 7.2 shows the total number of evaluated vehicles and the number of vehicles with a low user acceptance.

In the solitaire controlled scenario 10% of the vehicles have an unacceptable perceived waiting time. In both scenarios with Utopia control, the number of vehicles with unacceptable perceived waiting times is 12%. Regarding the waiting time perception, the solitaire control performs slightly better.

Table 7.2: Overview of the user acceptance (UA) of the scenarios

Scenario	**Evaluated vehicles**	**Vehicles with UA < 0.5**	
Solitaire control	981	9084	10%
Utopia – Normal configuration	1047	9061	12%
Utopia – PT-priority	1048	9057	12%

Figure 7.4 shows the differences between the solitaire control and the Utopia control with Utopia configuration. The figure clearly shows that on most left-turns and side roads there are more unacceptable waiting times in the Utopia controlled scenario. This is a result from the coordination between intersections, where the green phases on the main roads are longer.

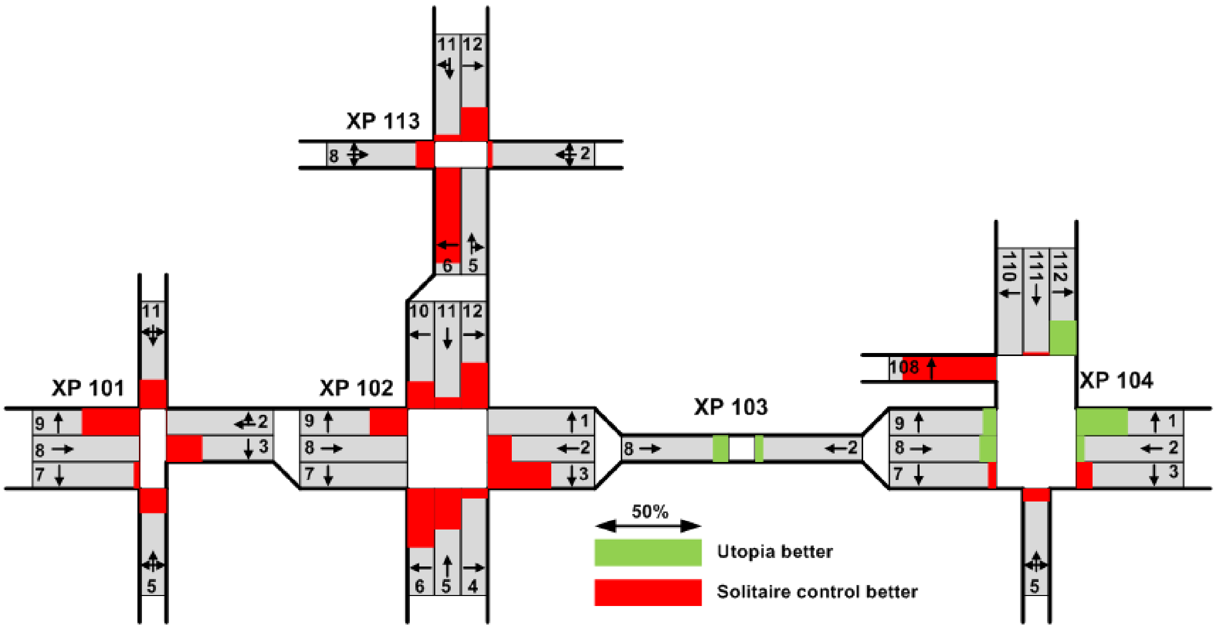


Figure 7.4: Comparison of the number of vehicles with an unacceptable perceived waiting time for the solitaire controlled and the Utopia scenario. The sizes of the red and green bars indicate the differences between the two scenarios: if the grey bar is totally filled 50% more of the vehicles passing that signal group have an unacceptable perceived waiting time, and if the gray bar is empty the number of vehicles with an unacceptable perceived waiting time is equal.

Figure 7.5 shows the differences between Utopia controlled situations with and without priority for public transportation. As table 7.1 indicated, the total number of unacceptable waiting times for these scenarios is equal. The figure shows that there are only minor differences for the signal groups between both situations. This can be explained by the predicting algorithm of Utopia: the controller knows in advance when a PT-vehicle arrives, and only small measures are needed to provide priority. In general, these measures do no influence the users' perception.

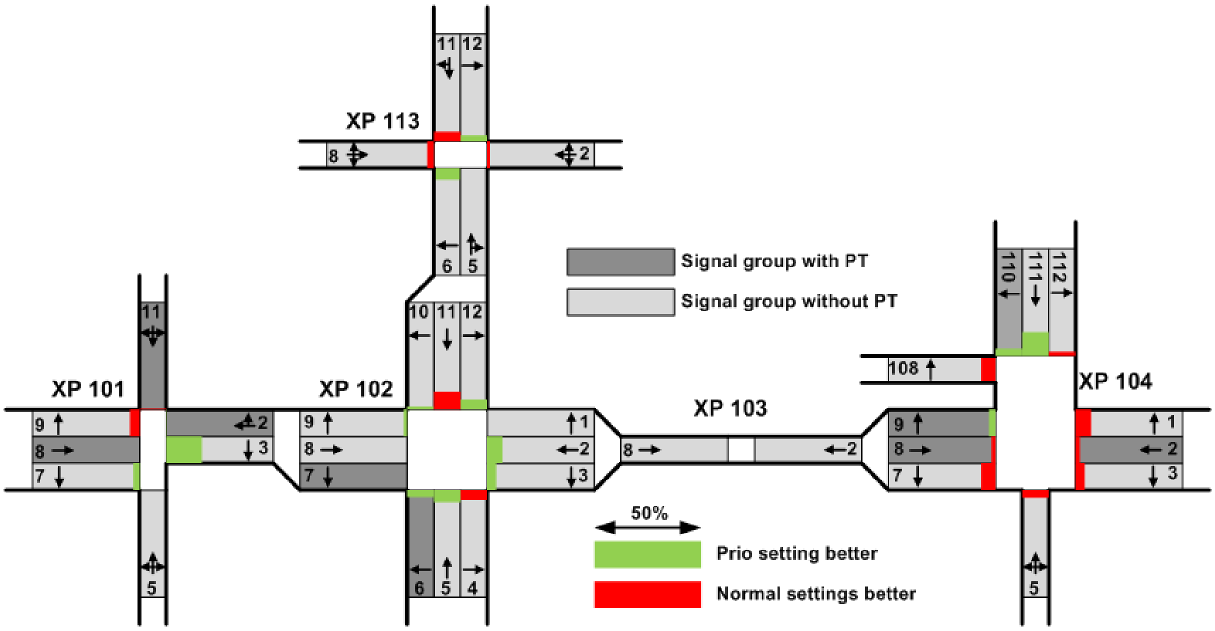


Figure 7.5: Comparison of the number of vehicles with an unacceptable perceived waiting time for the Utopia controlled scenarios with and without PT-priority. The sizes of the red and green bars indicate the differences between the two scenarios: if the grey bar is totally filled 50% more of the vehicles passing that signal group have an unacceptable perceived waiting time, and if the gray bar is empty the number of vehicles with an unacceptable perceived waiting time is equal.

7.4.2 Den Bosch

In Den Bosch only the Utopia-system can control the intersections. However, the parameters of the cost functions can be changed in order to control the traffic by other objectives. In this section three configuration are compared with each other.

- Normal configuration: this configuration is actually implemented in Den Bosch. The default weights in the cost-function are used.
- Coordination: the weights between intersection 40-48 and 41-42 are increased in order to stimulate cooperation between these intersections.
- Aggressive driving behaviour: The Utopia-system in Den Bosch is designed for vehicles driving the maximum allowed speed of 50 km/h. However, in reality people tend to drive faster on the main road. In this scenario the vehicles on the main road have a speed up to 70 km/h, while the normal configuration of Utopia is used.

Table 7.3 shows the average performance of vehicles per intersection for the three scenarios. Compared to the Utopia scenario with normal configuration, stimulated coordination between intersections in a lower average actual and perceived waiting time. Also aggressive driving behaviour results in lower actual and perceived waiting times. The average user acceptance is for all scenarios equal. All results of the simulation are given in Appendix G.

Table 7.3: Average performance per intersection per vehicle

Scenario	Waiting time	Stops	PWT	UA
Utopia - Normal	39 sec.	0.9	41 sec.	0.8
Utopia - Coordination	32 sec.	0.8	35 sec.	0.8
Aggressive	35 sec.	0.9	38 sec.	0.8

Table 7.3 shows the average performance, which is acceptable for all scenarios. However, if most vehicles perceive waiting before a traffic light as acceptable, the few vehicles with a low user acceptance are not represented in these numbers. Table 7.4 shows the total number of evaluated vehicles and the number of vehicles with a low user acceptance.

In the normal configuration scenario, which is implemented in Den Bosch, 20% of the car drivers experience an unacceptable waiting time. Their perceived waiting time is relative high, which may result in complaints, speed and red light violations. Driving faster on the main road and stimulation of coordination between intersections reduce the number of unacceptable waiting times in the network.

Table 7.4: Overview of the user acceptance of the scenarios

Scenario	Evaluated vehicles	Vehicles with UA < 0.5	
Utopia - Normal	7951	1604	20%
Utopia - Coordination	7977	1196	15%
Aggressive	8022	1442	18%

Figures 7.6 and 7.7 provide an overview of the differences between the three scenarios per signal group. Figure 7.6 shows that on the main road the number of unacceptable perceived waiting times is reduced on the main road. The perceived waiting times are mostly increased on signal groups 10 and 12 of intersection 40. For most directions, the coordination-configuration reduces the number of unacceptable perceived waiting times.

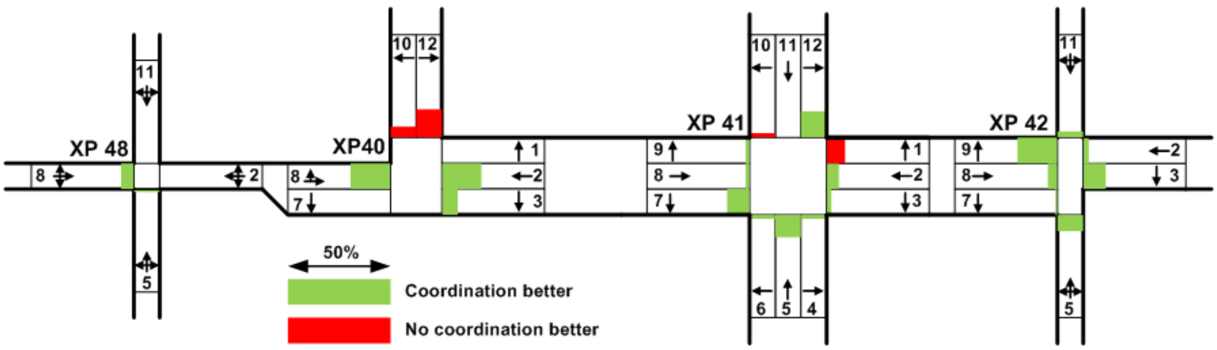


Figure 7.6: Comparison of the number of vehicles with an unacceptable perceived waiting time for Utopia controlled scenarios with normal configuration and stimulated priority. The sizes of the red and green bars indicate the differences between the two scenarios: if the grey bar is totally filled 50%

more of the vehicles passing that signal group have an unacceptable perceived waiting time, and if the gray bar is empty the number of vehicles with an unacceptable perceived waiting time is equal.

Figure 7.7 shows the difference in user acceptance between the normal scenario and the scenario with increased speed on the main roads. This figure shows that driving faster from intersection 42 to 48 (signal groups 2) result in a decreased of unacceptable waiting times, while driving eastbound the acceptance is slightly lower.

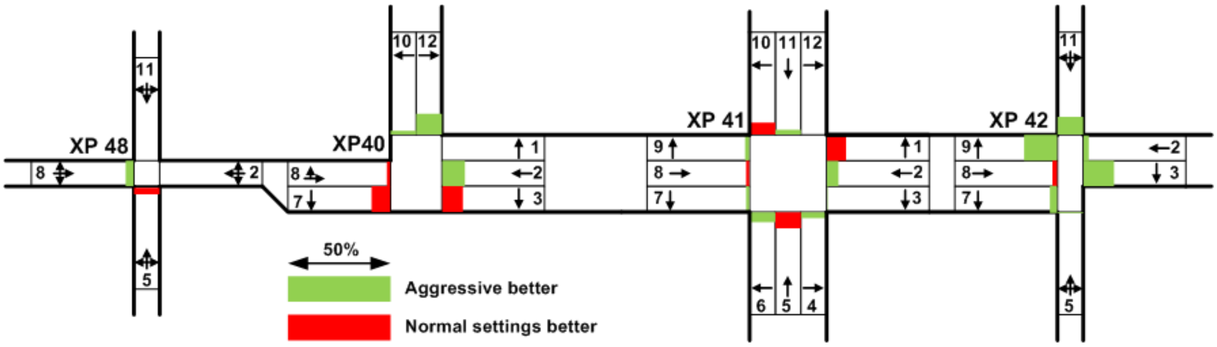


Figure 7.7: Comparison of the number of vehicles with an unacceptable perceived waiting time for Utopia controlled scenarios with and without aggressive driving behaviour. The sizes of the red and green bars indicate the differences between the two scenarios: if the grey bar is totally filled 50% more of the vehicles passing that signal group have an unacceptable perceived waiting time, and if the gray bar is empty the number of vehicles with an unacceptable perceived waiting time is equal.

Based on the results of the simulation study, the users' perception of the Utopia system in Den Bosch can improved by adjusting weights in the cost function to stimulate coordination between intersection. Also, driving faster than allowed increases the users' perception. Therefore the local authorities could increase the maximum speed, or another configuration of Utopia is needed to discourage faster driving.

7.5 Summary

In this chapter the developed algorithm, presented in chapter 6, is used to evaluate the user acceptance of several scenarios in Vissim. In the Helmond and Den Bosch network solitaire controllers are compared with Utopia and different configurations of Utopia are compared with each other.

The most notable comparison between a solitaire and Utopia controlled scenario in Helmond. The average performance of both scenarios is more or less equal, but when controlled by Utopia the user acceptance of the left-turns and side roads is worse. This is a result from the coordination between intersections, where the green phases on the main roads are longer.

8 DISCUSSION

8.1 Introduction

In this study a model to estimate the users' perception of car drivers at signalised intersections is proposed. The perceived waiting time is selected as an indicator of the users' perception, and is calculated as a function of the actual waiting time, the number of stops in the queue and the presence of a green or red wave between adjacent intersections. This model is used to evaluate the user acceptance of traffic lights a priori of implementing a system on the streets.

In this chapter the used research method on the achieved results are discussed. Both the strengths and weaknesses of the methods are described, and also the impact of the used method on the results in mentioned. The assumptions made in this study are evaluated and the some implications of the study are described.

8.2 Research method

The most critical part of this study was the conducted online video survey. The survey was used to determine the relations between the factors found in the literature study and the users' perception. The results of the survey were used to model the PWT and the user acceptance. Therefore it is important that the retrieved data from the survey represent how the respondents experience waiting at a traffic light.

The online video survey has two advantages over other methods: the costs are low and many respondents can participate. However, it is arguable if watching a movie meets reality. Besides the discussed factors in this study, the users' perception mainly depends on a feeling of car drivers. It is questionable if these feelings are well presented by watching a movie on a computer.

An example of a feeling influencing the users' perception is the unused green time of conflicting traffic. According to literature, unused green time is an important factor in the users' perception of a signalised intersection: car drivers do not accept waiting before an 'empty' intersection. However, according to the results of the survey the unused green time is not a factor influencing the users' perception. Apparently, the annoyance of waiting for an empty intersection in real-life is not the same as waiting for an empty intersection in a movie.

In addition, in the validation-process a real-world experiment was executed. While driving a predetermined route over signalised intersections, car driver were asked for their perceived waiting time. The results of this experiment meet the results of the determined models. This suggests that the unused green time is not influencing the users' perception.

Based on this study and the fact that video surveys are rarely used in this perspective before, it is unsure whether the feelings of car drivers are well presented with an online video survey. Therefore, the results of this study should be interpreted with caution.

8.3 Results

In this study the perceived waiting time was selected as an indicator of the users' perception of signalised intersection. The perceived waiting time describes how long car drivers experience their waiting time, and depends on three factors: the actual waiting time, the number of stops in the queue and the presence of a red wave between intersections. The relations between these factors and the perceived waiting time can be described as follows:

- There is a quadratic relation between the actual and perceived waiting time. Both short and long actual waiting times are perceived longer as they are, while average waiting times (40-60 seconds) are perceived as they are.
- Multiple stops in the queue decrease the perceived waiting time. The size of this reduction depends on the actual waiting time: the longer the actual waiting time, the greater the reduction of the perceived waiting time.
- When passing two adjacent intersections, car drivers do not like stopping at both intersections. A short stop at the second intersections results in a high perceived waiting time. However a long stop is perceived shorter than it is.

Other studies confirm the determined model of the perceived waiting time. According to literature, the three factors have a significant influence on the users' perception. Wu et al. (2009) found a quadratic relation between the actual and perceived waiting time, while studies regarding the perceived Level-of-Service concluded that besides the actual waiting time the number of stops and green/red waves are of importance.

In the determined model, the actual waiting time is very important. The actual waiting time not only has a quadratic relation with the perceived waiting time, but it also influences the impact of the number of stops and the presence of a red wave. The importance of the actual waiting time rises the question of the perceived waiting time is a good indicator of the users' perception. Other indicators, like the perceived Level-of-Service, attach less value to the actual waiting time and more to other factors.

For two reasons the personal characteristics of car drivers are excluded in this study. Wu et al. (2009) concluded that these characteristics have only a limited influence on the perceived waiting time and, because the model is designed to be used in Vissim, personal characteristics cannot be measured.

At the beginning of the online video survey respondents were asked for their personal characteristics. Based on these questions the following observations are made:

- The average perceived waiting time of males is 11 seconds lower than that of females in the same situation.
- Older people have a higher perceived waiting time than younger people, the perceived waiting time increases 1 second every 5 years.

- Higher educated car drivers have a perceived waiting time 20 seconds lower than lowly educated drivers.
- More relaxed drivers have a higher user acceptance than other drivers.

Based on these observations it is discussable if it is valid to exclude the personal characteristics in this study. Not all car drivers have the same users' perception, therefore it is better to include the personal characteristics in the model. On the other hand, it is not possible to measure the personal characteristics in Vissim and therefore there is no added value of implementing these characteristics in the model.

8.4 Implications

Waiting for a traffic light is comparable with waiting for a cash desk in a shop. When there is a queue at the desk, you expect to wait for some time. Therefore a short waiting time is perceived longer as it is, while a normal waiting time is perceived as long as it is. Nobody likes waiting for a long time, therefore long waiting times are perceived longer as they are.

Also the time the customers before you take to pay at the desk is of importance of your perceived waiting time. If it takes a long time you get annoyed because you have the feeling no progress is made. On the other hand, when the speed is high and you are moving forward slowly, you perceive the waiting time shorter as it is.

To increase the user acceptance of a traffic light, knowledge of the users' perception of the system is important. A lower perceived waiting time, as indicator of the users' perception, results in a higher acceptance. To increase the acceptance the following measures can be implemented:

- Prevent short and long waiting times. Due to the quadratic nature of the model, both short and long waiting times are overestimated while average waiting times are perceived as they are.
- Multiple stops in the queue result in lower perceived waiting times.
- If there is a red wave between two adjacent intersections, a short stop at the second results in an increase of the PWT, while a long stop decreases the perceived PWT.

According this study, a traffic light control system with a high user acceptance could have the following characteristics:

- The cost function of each vehicle exists of a quadratic relation with the actual waiting time.
- The signal groups have short green times, resulting in a short cycle.
- Coordination between adjacent intersections is only necessary if the waiting times at each intersection are below 40 seconds.

8.5 Conclusions

Further research is necessary to study the effect of unused green time of conflicting traffic on the users' perception of car drivers. According the used method in this study, the unused green time does not influence the perceived waiting time. Other research methods, for example a more realistic driving simulator, could result in an influence of the unused green time on the perceived waiting time.

It is also possible to consider another indicator of the user assessment. An example of such indicator is the individual perceived Level-of-Service. This indicator is expected to have a less dominant relation with the actual waiting time. Therefore, other factors might become more import in the model.

9 CONCLUSIONS

In this study the users' perception of car drivers at signalised intersections is studied. The perceived waiting time is an indicator of the user assessment, and answers the question how long car drivers experience their waiting time at a traffic light. This information is useful to increase the user acceptance of a traffic light system and to spot any problems regarding this acceptance in an early stage of the design process.

An online video survey is conducted the measure the perceived waiting times of car drivers. Respondents were shown a number of movies filmed from the drivers' perspective of a vehicle passing a signalised intersection. The outcomes of this survey are used to study the effects of ten predetermined factors on the perceived waiting time.

The perceived waiting time can be described with the next model. In this model *PWT* stands for perceived waiting time, *WT* for the actual waiting time, *Stops* for the number of stops in the queue and *RW* is 1 if the driver is in a red wave between intersections.

$$PWT = \beta_0 + \beta_1 \cdot RW + (\beta_2 + \beta_3 \cdot Stops + \beta_4 \cdot RW) \cdot \boldsymbol{WT} + \beta_5 \cdot WT^2$$

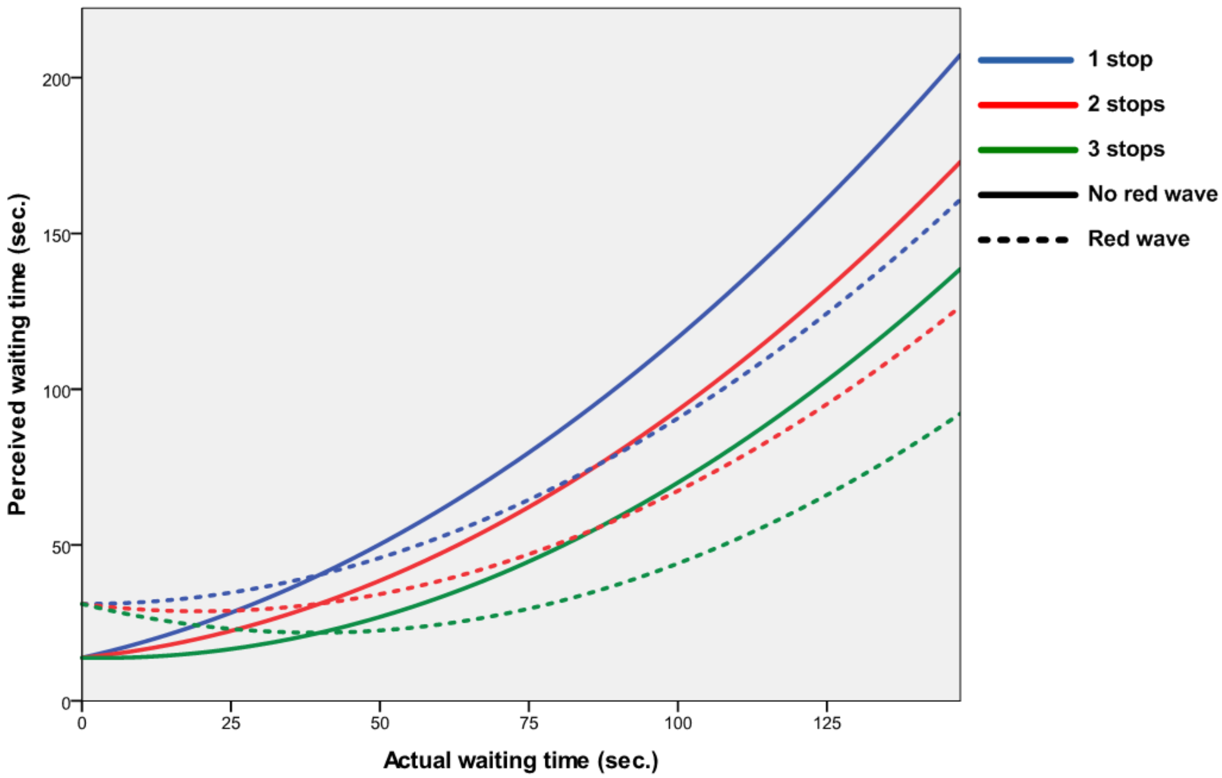


Figure 9.1: Model for the perceived waiting time

Besides the perceived waiting time, also the user acceptance is studied. The user acceptance answers the question if car drivers consider their (perceived) waiting time as acceptable or not. The user acceptance (UA) can be described with the following model. According the above model a perceived waiting time less than 66 seconds is considered as acceptable, longer perceived waiting times are considered as unacceptable.

$$\text{UA} = \frac{1}{1+e^{-3,650+0.055 \cdot PWT}}$$

The actual waiting time is the most dominant factor of the perceived waiting time. This seems obvious because respondents are asked how they consider their waiting time. A longer actual waiting time results in a higher perceived waiting time, this relationship is quadratic.

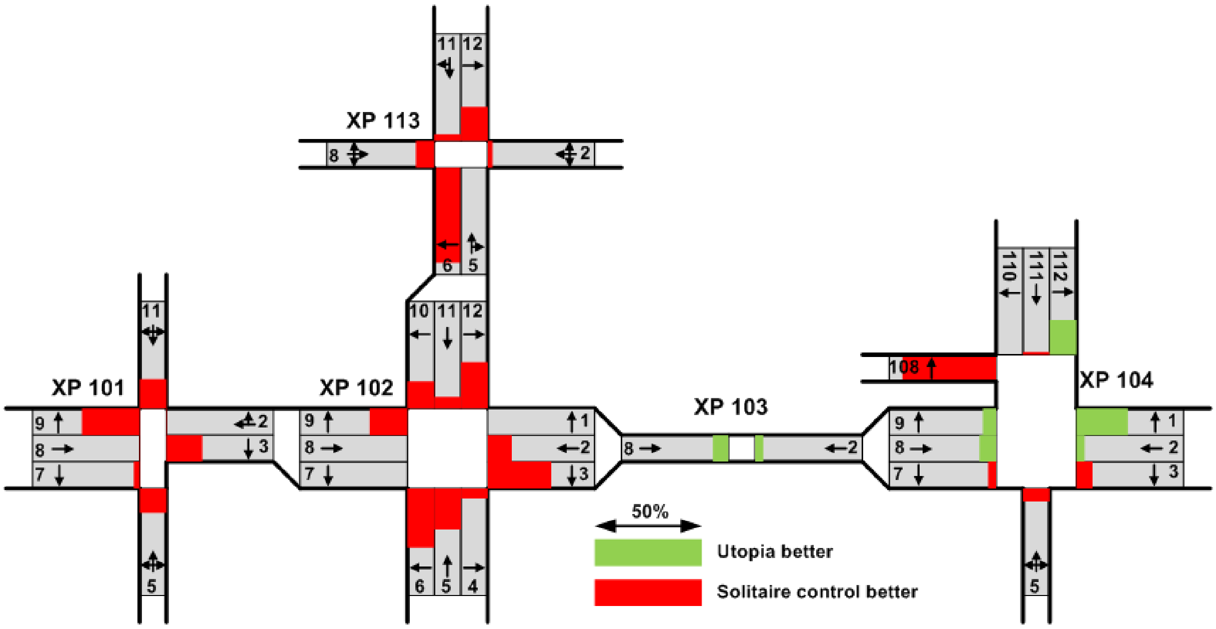
The number of stops made in the queue is usually seen as an indication of a long actual waiting time. However, the model suggests that drivers prefer making more stops above standing still for the same time. Apparently, the perception of time is different when driving and stopping compared to just standing still. This can be explained by the fact that while driving and stopping the driver is active, and less attention to time is given.

When passing two adjacent intersections, driver dislike stopping at both intersections. A short stop at the second intersection is perceived as relatively long. However, the waiting time perception of a longer stop is lower than the actual waiting time. It could be that drivers are irritated when they are forced to stop, but as the waiting time increases surrender themselves to it.

An external application for Vissim is developed in this study. Using the COM-Interface, this application is capable of reading vehicle data from Vissim, calculating the perceived waiting time and user acceptance and colouring the vehicles in Vissim according their perceived waiting time. Also an output-file is generated, containing for each individual vehicle the perceived waiting times per signal group.

This application can be used to evaluate the perceived waiting time of car drivers in a traffic-simulator. Using this information, during the design-process of a traffic light system the users' perception of the system can be increased. It is also possible to compare several alternative systems or configurations.

In this study, several comparisons are made. The most important comparison is an evaluation of the user acceptance for both Utopia and solitaire controllers in the Helmond network. The next figure shows that for the left turns and side roads more vehicles expire an unacceptable waiting time in the Utopia-scenario. Due to the network optimization of Utopia, traffic on the main road is prioritized resulting in higher perceived waiting times on other signal groups.



This study proves that the user acceptance of a traffic light controller not only depends on the actual waiting time, but also on the number of stops in the queue and the presence of green/red waves between intersections. These factors are represented in the perceived waiting time, which estimates how long car drivers estimate their waiting time before a traffic light.

To improve the user acceptance of a system, in the design process attention to all factors should be given. A combination of the factors results in the most acceptable system. For example, a long waiting time with multiple stops might be more acceptable than a shorter waiting time with just a single stop. Shorter green times with a short cycle might be a better configuration than long green times with a long cycle.

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APPENDIX A – FACTORS INFLUENCING THE USERS' PERCEPTION

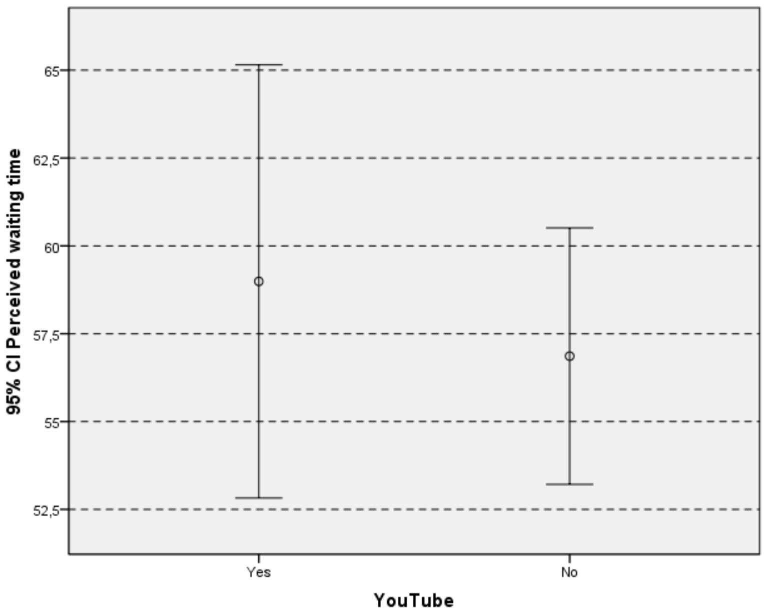
Author(s)	Factors
Pécheux (2000)	• Delay • Traffic signal efficiency • Arrows/lanes for turning vehicles • Visibility of traffic signals from queue • Clear/legible signs and road markings • Geometric design of intersection • Leading left-turn phasing scheme • Visual clutter-distractions • Size of intersection • Pavement quality • Queue length • Traffic mix • Location • Scenery/aesthetics • Presence of pedestrians
Zhang (2004)	• Traffic signal responsiveness • Ability to go through the intersection within one cycle of light changes • Availability of left-turn only lanes and protected left-turn signal for vehicles turning left • Pavement marking for separating and guiding traffic • Pavement quality • Waiting time • Heavy vehicles such as trucks and buses that are waiting ahead • Availability of right-turn only lanes for vehicles turning right
Flannery and Pedersen (as cited in Lee, Kim and Pietrucha, 2007)	• Long gaps in traffic on the main road • Quality of signing and traffic markings • Confusion about what lane to be in • Smoothness of pavement • Whether they perceive the road as being safe • Information about delays • Interference from bicycles or pedestrians in the roadway
Lee, Kim and Pietrucha (2007)	• Traffic signal waiting time • Length of gaps in traffic on the cross-street • Traffic signal operations • Traffic signal visibility • Information guidance systems • Physical features of the intersection
Pécheux, Pietrucha and Jovanis (2000)	• Situational characteristics • Personal characteristics • Value of time and time use • Temporal relevance • Temporal urgency • Actual delay • Signal/intersection characteristics • Estimation paradigm • User experience and expectations

APPENDIX B – IMBEDDED VS YOUTUBE MOVIES

As explained in section 4.4, not all respondents were able to watch the imbedded movies in the survey. Therefore, it was also possible to watch the movies on YouTube. There is only one difference between the imbedded and YouTube movies, on YouTube the elapsed and total time of the movie is shown.

Next figure shows the mean perceived waiting time for imbedded movies and movies watched on YouTube. The average PWT for the YouTube movies looks slightly higher, but according a performed T-Test there is no significant difference between both techniques ($\alpha > 0.1$).

In the analysis of the results of the survey it is safe to assume that there is no difference between the imbedded and YouTube movies.



95% confidence interval of the mean PWT for movies watched on YouTube and the imbedded movies

APPENDIX C – MOVIES ON YOUTUBE

Movie	Youtube
MOV025_2	http://www.youtube.com/watch?v=VK1NGEK5HTI
MOV026_1	http://www.youtube.com/watch?v=5jVlG-7jGws
MOV027_2	http://www.youtube.com/watch?v=k9bPOrb_txg
MOV02B_1	http://www.youtube.com/watch?v=381bkF76NNE
MOV02B_2	http://www.youtube.com/watch?v=Dz_OVooNSIE
MOV02B_3	http://www.youtube.com/watch?v=r3GGXjGR9Fc
MOV02B_4	http://www.youtube.com/watch?v=Id8-NwbZwWc
MOV02B_5	http://www.youtube.com/watch?v=k3g0L33WMYw
MOV02C_3	http://www.youtube.com/watch?v=d9Fub5FUjv0
MOV02C_4	http://www.youtube.com/watch?v=9SNRNQtHGHU
MOV02D_1	http://www.youtube.com/watch?v=Y0hY06KTGmw
MOV02D_2	http://www.youtube.com/watch?v=gsKVi817ViI
MOV02D_3	http://www.youtube.com/watch?v=V6LWgJMMOYU
MOV032_2	http://www.youtube.com/watch?v=flk7uW_0Trs
MOV032_3	http://www.youtube.com/watch?v=P1YQepOJOsM
MOV032_4	http://www.youtube.com/watch?v=27iaClRWAdM
MOV033_1	http://www.youtube.com/watch?v=A7T6lVDA798
MOV033_3	http://www.youtube.com/watch?v=bpsWUO4V1W0
MOV036_2	http://www.youtube.com/watch?v=vRwC-vjZ5rE
MOV037_1	http://www.youtube.com/watch?v=8NRXwy4JPFE
MOV038_4	http://www.youtube.com/watch?v=hlbuNKdbvwY
MOV038_7	http://www.youtube.com/watch?v=OQWY6z1Cfik
MOV038_9	http://www.youtube.com/watch?v=_M-LfXfU1KY
MOV039_2	http://www.youtube.com/watch?v=Q4qK6kvJG7g
MOV03B_6	http://www.youtube.com/watch?v=cBbmhMYblV4
MOV03F_3	http://www.youtube.com/watch?v=yvzNDLKKGgI
MOV03F_4	http://www.youtube.com/watch?v=NdljF8gLeUQ
MOV03F_5	http://www.youtube.com/watch?v=3ynRQJDFJ4c
MOV043_2	http://www.youtube.com/watch?v=AgdQVSRaerI
MOV043_5	http://www.youtube.com/watch?v=9zV1CoTU2PI
MOV047_1	http://www.youtube.com/watch?v=pHguBybujY4
MOV047_12	http://www.youtube.com/watch?v=x31KErPeqaU
MOV047_14	http://www.youtube.com/watch?v=7FGVopbdbjc
MOV047_3	http://www.youtube.com/watch?v=Cs5HAyA8LS0
MOV047_4	http://www.youtube.com/watch?v=7XsulQE2-Zc
MOV047_6	http://www.youtube.com/watch?v=b9xvE146XEU
MOV048_4	http://www.youtube.com/watch?v=xIh9gw9bxx8
MOV048_5	http://www.youtube.com/watch?v=0WsQM4WV65U

APPENDIX D – MOVIE PROPERTIES

Movie	City	XP	SG	Waiting time	Unused green	Stops	Coordination
MOV025_2	Den Bosch	48	8	134	16	3	-
MOV026_1	Den Bosch	48	2	44	16	2	-
MOV027_2 (1)	Den Bosch	40	1	52	32	1	-
MOV027_2 (2)	Den Bosch	40	61	0	0	0	yes
MOV02B_1	Den Bosch	14	2	83	18	3	-
MOV02B_2 (1)	Den Bosch	41	8	23	0	1	-
MOV02B_2 (2)	Den Bosch	42	8	62	29	1	no
MOV02B_3	Den Bosch	41	8	23	0	1	-
MOV02B_4	Den Bosch	42	8	62	29	1	-
MOV02B_5	Den Bosch	71	5	25	25	1	-
MOV02C_3 (1)	Den Bosch	42	2	0	0	0	-
MOV02C_3 (2)	Den Bosch	41	2	51	13	1	no
MOV02C_4	Den Bosch	41	2	51	13	1	-
MOV02D_1	Den Bosch	41	8	18	0	1	-
MOV02D_2 (1)	Den Bosch	41	8	18	0	1	-
MOV02D_2 (2)	Den Bosch	42	8	39	0	1	no
MOV02D_3	Den Bosch	42	8	39	0	1	-
MOV032_2 (1)	Den Bosch	41	8	32	3	1	-
MOV032_2 (2)	Den Bosch	42	8	76	40	1	no
MOV032_3	Den Bosch	41	8	32	3	1	-
MOV032_4	Den Bosch	42	8	76	40	1	-
MOV033_1	Den Bosch	42	2	18	18	1	-
MOV033_3 (1)	Den Bosch	42	2	18	18	1	-
MOV033_3 (2)	Den Bosch	41	2	0	0	0	yes
MOV036_2 (1)	Helmond	103	2	15	11	1	-
MOV036_2 (2)	Helmond	102	2	0	0	0	yes
MOV036_2 (3)	Helmond	101	2	19	0	1	no
MOV037_1	Helmond	704	12	137	0	2	-
MOV038_4	Helmond	101	11	65	27	1	-
MOV038_7	Helmond	113	11	57	9	1	-
MOV038_9	Helmond	104	8	86	0	1	-
MOV039_2	Helmond	902	2	21	0	1	-
MOV03B_6	Helmond	101	8	45	42	1	-
MOV03F_3	Helmond	104	2	114	42	1	-
MOV03F_4 (1)	Helmond	103	2	0	0	0	-
MOV03F_4 (2)	Helmond	102	2	57	21	1	no
MOV03F_5	Helmond	102	2	57	21	1	-
MOV043_2 (1)	Helmond	102	9	17	0	1	-
MOV043_2 (2)	Helmond	113	6	20	0	1	no
MOV043_5	Helmond	704	12	30	20	1	-
MOV047_1	Helmond	902	6	73	10	1	-
MOV047_12	Helmond	113	5	64	13	1	-
MOV047_14	Helmond	104	110	99	0	1	-

MOV047_3	Helmond	102	2	111	27	2	-
MOV047_4	Helmond	704	8	16	0	1	-
MOV047_6 (1)	Helmond	113	11	75	24	1	-
MOV047_6 (2)	Helmond	102	12	81	16	1	no
MOV048_4	Helmond	503	12	92	0	2	-
MOV048_5	Helmond	503	1	60	36	1	-

APPENDIX E – VALIDATION

City	XP	Waiting time	Stops	Coordination	PWT	WTA	model PWT	model WTA
Helmond	704	152	2	yes	200	no	182	no
Helmond	106	19	1	yes	23	yes	24	yes
Helmond	902	46	1	yes	45	yes	46	yes
Helmond	105	36	1	yes	50	no	37	yes
Helmond	102	73	2	yes	70	yes	60	yes
Helmond	101	22	1	no	30	yes	34	yes
Helmond	704	24	1	yes	30	yes	28	yes
Helmond	702	23	1	yes	27	yes	27	yes
Helmond	702	14	1	yes	20	yes	21	yes
Helmond	704	35	1	yes	30	yes	36	yes
Helmond	101	20	1	yes	20	yes	25	yes
Helmond	104	33	1	yes	35	yes	35	yes
Helmond	104	94	1	yes	120	no	107	np
Helmond	102	64	1	yes	50	no	66	yes
Helmond	701	75	2	yes	70	no	62	yes
Helmond	702	49	1	yes	55	no	49	yes
Helmond	704	19	1	yes	25	yes	24	yes
Helmond	113	69	1	yes	45	yes	72	no
Den Bosch	41	40	1	yes	45	yes	41	yes
Den Bosch	42	89	1	yes	50	yes	99	no
Den Bosch	?	4	1	yes	7	yes	16	yes
Den Bosch	?	18	1	yes	15	yes	24	yes
Den Bosch	41	48	1	yes	50	yes	48	yes
Den Bosch	40	6	1	yes	3	yes	17	yes
Den Bosch	48	11	1	yes	5	yes	19	yes
Den Bosch	41	28	1	no	20	yes	36	yes
Den Bosch	41	42	1	yes	30	yes	42	yes
Den Bosch	41	115	2	yes	115	no	116	no
Den Bosch	42	34	1	no	45	no	38	yes
Den Bosch	42	55	1	yes	60	yes	56	yes
Den Bosch	41	48	1	yes	70	yes	48	yes
Den Bosch	40	6	1	yes	8	yes	17	yes
Den Bosch	48	6	1	no	7	yes	31	yes
Den Bosch	48	16	1	yes	20	yes	22	yes
Den Bosch	40	17	1	no	25	yes	33	yes
Den Bosch	41	33	1	yes	40	yes	35	yes
Den Bosch	42	8	1	yes	10	yes	18	yes

APPENDIX F – SIMULATION RESULTS HELMOND

Results Helmond solitaire control

XP	SG	Number of vehicles	Average waiting time	Average Stops	Average PWT	Average UA	Vehicles UA < 0.5	
101	**2**	799	11	0,78	22	0,91	0	0%
101	**3**	7	14	0,86	18	0,92	0	0%
101	**5**	148	14	0,76	19	0,92	1	1%
101	**7**	33	8	0,67	12	0,95	0	0%
101	**8**	838	9	0,61	13	0,95	0	0%
101	**9**	37	20	0,84	24	0,89	0	0%
101	**11**	164	17	0,84	21	0,91	1	1%
102	**1**	0	0	0	0	1,00	0	0%
102	**2**	656	12	0,64	20	0,91	0	0%
102	**3**	53	18	0,79	22	0,90	0	0%
102	**4**	21	16	0,67	19	0,93	0	0%
102	**5**	141	18	0,79	22	0,90	1	1%
102	**6**	61	17	0,79	21	0,91	0	0%
102	**7**	9	6	0,67	12	0,95	0	0%
102	**8**	824	12	0,72	21	0,91	0	0%
102	**9**	89	16	0,87	21	0,91	0	0%
102	**10**	102	19	0,87	24	0,89	1	1%
102	**11**	98	18	0,78	22	0,90	1	1%
102	**12**	97	17	0,74	21	0,91	0	0%
103	**2**	714	20	0,74	24	0,88	26	4%
103	**8**	965	26	0,91	31	0,83	69	7%
104	**1**	150	60	1,07	68	0,57	63	42%
104	**2**	525	38	0,88	42	0,74	96	18%
104	**3**	158	96	0,98	148	0,42	91	58%
104	**5**	243	92	0,96	144	0,45	128	53%
104	**7**	196	130	1,20	236	0,38	119	61%
104	**8**	555	36	0,81	40	0,76	99	18%
104	**9**	210	48	1,06	51	0,65	69	33%
104	**108**	151	36	0,88	42	0,75	28	19%
104	**110**	92	35	0,88	41	0,75	18	20%
104	**111**	73	110	0,95	193	0,40	43	59%
104	**112**	99	56	0,92	69	0,58	36	36%
113	**2**	260	15	0,84	19	0,92	1	0%
113	**5**	210	13	0,82	18	0,93	0	0%
113	**6**	17	16	0,94	23	0,90	0	0%
113	**8**	83	15	0,84	20	0,92	0	0%
113	**11**	132	10	0,67	15	0,94	0	0%
113	**12**	72	17	0,85	22	0,91	0	0%

Helmond normal Utopia control

XP	SG	Number of vehicles	Average waiting time	Average Stops	Average PWT	Average UA	Vehicles UA < 0.5	
101	**2**	782	6	0,34	11	0,95	1	0%
101	**3**	6	40	1,00	45	0,71	1	17%
101	**5**	148	32	0,89	34	0,79	18	12%
101	**7**	36	15	0,61	19	0,90	1	3%
101	**8**	835	11	0,49	13	0,94	2	0%
101	**9**	37	45	0,84	51	0,65	10	27%
101	**11**	164	30	0,85	34	0,80	23	14%
102	**1**	0	0	0	0	1,00	0	0%
102	**2**	645	30	0,72	32	0,81	72	11%
102	**3**	54	50	0,96	55	0,62	16	30%
102	**4**	21	24	0,76	27	0,86	1	5%
102	**5**	141	36	0,84	39	0,75	28	20%
102	**6**	61	46	0,95	51	0,66	17	28%
102	**7**	8	7	0,75	11	0,95	0	0%
102	**8**	816	6	0,28	8	0,96	0	0%
102	**9**	92	25	0,65	29	0,81	16	17%
102	**10**	103	24	0,65	27	0,83	14	14%
102	**11**	97	21	0,69	24	0,86	6	6%
102	**12**	98	39	0,94	44	0,72	21	21%
103	**2**	717	4	0,33	6	0,98	0	0%
103	**8**	966	2	0,20	4	0,99	0	0%
104	**1**	151	41	1,17	43	0,74	27	18%
104	**2**	522	29	0,74	34	0,79	76	15%
104	**3**	161	102	1,09	146	0,35	105	65%
104	**5**	239	109	0,99	187	0,40	140	59%
104	**7**	192	172	1,61	376	0,35	124	65%
104	**8**	561	30	0,86	34	0,80	57	10%
104	**9**	210	51	1,05	55	0,65	56	27%
104	**108**	151	125	1,56	196	0,35	94	62%
104	**110**	92	38	0,88	42	0,72	18	20%
104	**111**	73	102	1,03	156	0,38	44	60%
104	**112**	99	35	0,83	39	0,75	20	20%
113	**2**	260	24	0,91	28	0,86	7	3%
113	**5**	212	10	0,56	13	0,95	0	0%
113	**6**	18	47	1,00	55	0,60	8	44%
113	**8**	83	27	0,81	31	0,82	7	8%
113	**11**	132	15	0,57	18	0,91	4	3%
113	**12**	72	36	0,92	40	0,75	11	15%

Helmond Utopia with PT-priority

XP	SG	Number of vehicles	Average waiting time	Average Stops	Average PWT	Average UA	Vehicles UA < 0.5	
101	**2**	789	7	0,32	11	0,95	0	0%
101	**3**	5	31	1,00	35	0,81	0	0%
101	**5**	148	31	0,88	33	0,80	18	12%
101	**7**	37	9	0,43	11	0,95	0	0%
101	**8**	833	10	0,50	13	0,95	1	0%
101	**9**	38	44	0,97	49	0,66	12	32%
101	**11**	164	32	0,88	35	0,79	24	15%
102	**1**	0	0	0	0	1,00	0	0%
102	**2**	649	27	0,79	30	0,84	25	4%
102	**3**	55	43	0,98	47	0,69	14	25%
102	**4**	21	22	0,67	24	0,87	2	10%
102	**5**	141	38	0,94	43	0,76	20	14%
102	**6**	61	41	0,90	46	0,70	15	25%
102	**7**	9	9	0,33	11	0,94	0	0%
102	**8**	819	6	0,32	9	0,96	0	0%
102	**9**	94	28	0,72	32	0,79	15	16%
102	**10**	100	28	0,73	33	0,80	12	12%
102	**11**	97	27	0,87	31	0,82	14	14%
102	**12**	96	37	0,91	42	0,74	16	17%
103	**2**	722	5	0,38	7	0,97	0	0%
103	**8**	959	3	0,30	6	0,97	0	0%
104	**1**	151	49	1,24	52	0,67	38	25%
104	**2**	525	35	0,86	38	0,76	87	17%
104	**3**	157	122	1,24	184	0,30	109	69%
104	**5**	240	105	1,01	164	0,37	149	62%
104	**7**	200	135	1,55	208	0,29	142	71%
104	**8**	560	26	0,79	30	0,82	66	12%
104	**9**	199	48	1,04	52	0,67	47	24%
104	**108**	151	143	1,95	231	0,31	104	69%
104	**110**	92	35	0,86	38	0,76	15	16%
104	**111**	73	93	0,96	141	0,44	36	49%
104	**112**	99	40	0,88	44	0,71	22	22%
113	**2**	260	26	0,84	28	0,85	10	4%
113	**5**	213	11	0,54	14	0,94	0	0%
113	**6**	18	47	0,94	52	0,63	7	39%
113	**8**	78	30	0,79	34	0,79	9	12%
113	**11**	132	22	0,77	25	0,86	10	8%
113	**12**	72	31	0,90	35	0,79	9	13%

APPENDIX G – SIMULATION RESULTS DEN BOSCH

Den Bosch normal Utopia

XP	SG	Number of vehicles	Average waiting time	Average Stops	Average PWT	Average UA	Vehicles UA < 0.5	
40	**1**	1	51	1,00	51	0,70	0	0%
40	**2**	666	73	1,68	71	0,54	258	39%
40	**3**	20	107	2,30	109	0,38	12	60%
40	**7**	11	189	3,18	274	0,25	8	73%
40	**8**	501	56	1,18	54	0,64	133	27%
40	**10**	122	42	1,28	42	0,73	28	23%
40	**12**	191	51	1,39	49	0,67	56	29%
41	**1**	79	49	1,05	53	0,65	24	30%
41	**2**	735	45	0,94	44	0,70	177	24%
41	**3**	254	29	0,72	31	0,80	38	15%
41	**4**	216	30	0,78	33	0,79	31	14%
41	**5**	65	36	0,75	39	0,73	16	25%
41	**6**	100	50	0,97	55	0,61	36	36%
41	**7**	75	64	1,08	69	0,51	35	47%
41	**8**	562	35	0,85	38	0,76	93	17%
41	**9**	49	36	0,80	40	0,74	10	20%
41	**10**	53	33	0,81	37	0,77	10	19%
41	**11**	45	38	0,84	43	0,71	10	22%
41	**12**	40	45	0,88	51	0,64	13	33%
42	**2**	936	21	0,53	23	0,86	81	9%
42	**3**	62	51	0,89	56	0,58	27	44%
42	**5**	592	61	1,16	67	0,56	238	40%
42	**7**	217	42	0,90	47	0,67	65	30%
42	**8**	543	30	0,63	31	0,80	61	11%
42	**9**	40	62	1,08	67	0,49	21	53%
42	**11**	35	57	1,00	64	0,54	16	46%
48	**2**	757	8	0,65	18	0,93	0	0%
48	**5**	152	19	0,82	22	0,90	1	1%
48	**8**	480	16	0,70	19	0,90	32	7%
48	**11**	143	16	0,79	20	0,92	0	0%

Den Bosch Utopia with coordination

XP	SG	Number of vehicles	Average waiting time	Average Stops	Average PWT	Average UA	Vehicles UA < 0.5	
40	**1**	2	44	1,00	44	44	0	0%
40	**2**	667	50	1,35	50	48	132	20%
40	**3**	21	95	2,14	95	92	11	52%
40	**7**	11	144	2,82	144	147	8	73%
40	**8**	501	33	0,95	33	35	37	7%
40	**10**	122	49	1,23	49	48	34	28%
40	**12**	191	66	1,61	66	65	82	43%
41	**1**	87	54	1,17	54	57	34	39%
41	**2**	734	38	0,88	38	40	134	18%
41	**3**	253	35	0,86	35	37	33	13%
41	**4**	215	30	0,79	30	33	27	13%
41	**5**	65	31	0,75	31	33	9	14%
41	**6**	99	45	0,88	45	50	34	34%
41	**7**	75	49	0,92	49	53	26	35%
41	**8**	557	29	0,73	29	32	80	14%
41	**9**	49	34	0,82	34	39	9	18%
41	**10**	53	37	0,77	37	42	11	21%
41	**11**	45	38	0,84	38	41	10	22%
41	**12**	40	31	0,80	31	35	8	20%
42	**2**	941	17	0,50	17	19	57	6%
42	**3**	67	46	0,90	46	50	22	33%
42	**5**	591	51	1,02	51	55	192	32%
42	**7**	219	43	0,92	43	46	64	29%
42	**8**	546	21	0,69	21	27	37	7%
42	**9**	42	45	0,93	45	52	14	33%
42	**11**	35	56	1,00	56	62	15	43%
48	**2**	769	7	0,54	7	16	0	0%
48	**5**	152	18	0,84	18	23	0	0%
48	**8**	479	6	0,45	6	9	3	1%
48	**11**	143	17	0,80	17	21	0	0%

Den Bosch normal Utopia with aggressive driving behaviour

XP	SG	Number of vehicles	Average waiting time	Average Stops	Average PWT	Average UA	Vehicles UA < 0.5	
40	**1**	3	2	0,33	5	0,98	0	0%
40	**2**	687	56	1,55	52	0,66	190	28%
40	**3**	20	99	2,35	91	0,38	14	70%
40	**7**	11	183	3,27	223	0,23	9	82%
40	**8**	501	57	1,13	54	0,63	141	28%
40	**10**	122	47	1,30	46	0,71	26	21%
40	**12**	191	43	1,34	41	0,74	37	19%
41	**1**	86	66	1,21	76	0,54	34	40%
41	**2**	742	38	0,90	40	0,74	137	18%
41	**3**	250	31	0,80	34	0,79	37	15%
41	**4**	215	29	0,73	31	0,81	25	12%
41	**5**	65	41	0,83	45	0,69	21	32%
41	**6**	99	46	0,94	50	0,65	31	31%
41	**7**	73	62	1,04	68	0,50	33	45%
41	**8**	563	30	0,77	34	0,78	102	18%
41	**9**	49	34	0,80	38	0,77	9	18%
41	**10**	53	33	0,70	37	0,74	13	25%
41	**11**	45	32	0,82	36	0,76	11	24%
41	**12**	40	50	0,88	54	0,62	13	33%
42	**2**	941	17	0,49	19	0,89	57	6%
42	**3**	66	48	0,97	54	0,64	19	29%
42	**5**	591	57	1,09	60	0,58	234	40%
42	**7**	219	40	0,84	45	0,69	58	26%
42	**8**	544	32	0,76	35	0,79	73	13%
42	**9**	41	56	0,98	62	0,56	15	37%
42	**11**	35	53	0,94	58	0,59	13	37%
48	**2**	788	11	0,81	23	0,91	0	0%
48	**5**	152	19	0,76	23	0,89	6	4%
48	**8**	480	13	0,69	16	0,92	14	3%
48	**11**	143	17	0,77	20	0,91	0	0%