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Car Drivers' Perception and Acceptance of Waiting Time at Signalized Intersections

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Abstract—**While waiting at a traffic light, drivers' perceived waiting time can differ from the actual waiting time. Through a comprehensive video survey this paper shows that the perceived waiting time depends not only on the actual waiting time but also on other factors such as the number of stops in the queue and the presence of a red wave between adjacent intersections. Both waiting times with very short and very long durations are likely to be overestimated. Compared to a long standstill waiting, moving and stopping several times at the same intersection (due to short signal cycles) lead to lower perceived waiting times. When passing two adjacent intersections, car drivers dislike stopping at both intersections, especially if the second stop is relatively short. Based on the survey results, models are proposed for estimating drivers' perception and their acceptance of waiting time. These models have been validated by a real-world experiment.**

I. Introduction

KNOWLEDGE of car drivers' perception of signalized intersections is important for increasing their acceptance of the traffic light control system. Besides optimizing its control according the objectives of the road authorities, a good traffic light controller should also take the user perceptions into account. A low acceptance level may result in red light or speed violations; it is also likely that drivers alter their route choice to avoid a "notorious" traffic light.

Traditionally, user perceptions of signalized intersections are not included in the design process of traffic light controllers. Only in the evaluation stage when complaints are received concerning the operation of a controller, road authorities start to consider improvements of the control system in order to increase the user acceptance.

Waiting time is often used as the main measure of performance (MOP). In the Highway Capacity Manual [1], the Level-of-Service for a signalized intersection is evaluated by the average waiting time. Average waiting time is also considered as the most important indicator of service in the Netherlands [2]. Road authorities often receive complaints from road users about the long waiting times at certain traffic lights, confirming the importance of waiting time.

In this study we focus on user perception of waiting time at signalized intersections. Car drivers may perceive their waiting time differently than the actual waiting time [3]. The perceived waiting time is assumed to be a function of the actual waiting time. Other factors, such as the number of stops experienced when queuing at the traffic light, also influence the perceived waiting time [4]. Therefore these factors are also considered in this study.

The paper starts with a literature review on the most important factors influencing drivers' perception of waiting time (section II). Section III then introduces the modeling framework, followed by set-up of the video survey in section IV. Section V provides data analysis of the survey results and the proposed models, which are validated by the real world experiment in section VI. Section VII concludes the paper with discussions on the findings and points for further investigation.

II. Literature Review

The perceived waiting time is not necessarily equal to the actual waiting time. If the driver pays more attention to time, more time units are recorded in the driver's mind, and the subjective duration of waiting becomes longer [3]. This implies that the perceived waiting time depends not only on the actual waiting time, but also on factors that occur during the waiting process. These factors can be divided into three categories (Fig. 1) [3], [5]–[8]. A fourth category is excluded here which represents the personal characteristics of the driver, such as trip purpose and personality, because their influence on the perceived waiting time is minimal [4].

Different factors have different levels of influence on the perceived waiting time, while there are also cross-influences among these factors. Fig. 2 shows the relationship between the factors found in literature and the perceived waiting time. Earlier research showed that four factors (shaded in Fig. 2) are most dominant: actual waiting time, unused green time, number of stops in queue and green wave.

The actual waiting time is the time spent by the car driver when queuing at the intersection. It is the most important variable influencing user perception of the intersections [3], [4], [6].

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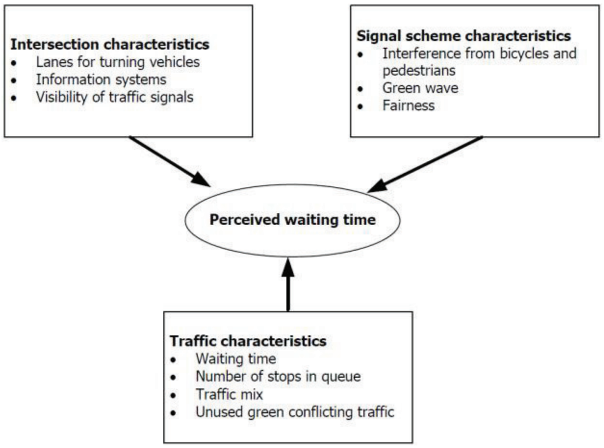

Fig. 1. Factors influencing drivers' perceived waiting time can be divided into three categories: intersection, signal scheme and traffic characteristics. Only the most important factors of each category are listed here.

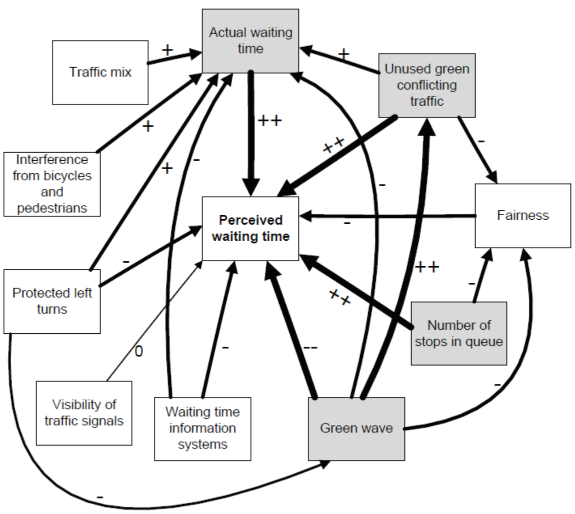

Fig. 2. Relationship between the factors and the perceived waiting time can be derived from driver surveys reported in literature [3], [5]–[8]. A plus sign (+) represents a positive correlation and a minus sign (-) a negative one. The number of signs indicates the strength of the correlation.

The unused green time of conflicting traffic is the time period when the vehicle is waiting at an empty intersection. Most car drivers consider this as annoying [9].

The number of stops in the queue is a commonly used MOP. It is measured by the number of times a vehicle has to stop in the queue at the intersection. The majority of car drivers consider it as important to go through the intersection within one signal cycle [8]. As the cycle time is not equal for all intersections and the cycle time can vary over time, the number of stops has no relation with the actual waiting time.

Green wave is what drivers experience when they can drive through several signalized intersections in a row with a minimum of stops and delays. This becomes likely when adjacent traffic lights are coordinated by the traffic light controller [10]. Car drivers are most of the time unfamiliar with the existence of signal coordination. Even if there is no coordination, a green wave can still be experienced. Car drivers have a pleasant feeling while driving in a green wave, and an unpleasant feeling while in a red wave (i.e. stopping several times in a row) [4].

III. Modeling Framework

In this study we focus on the relationships between perceived waiting time and actual waiting time, and between perceived waiting time and user acceptance. We consider user acceptance (UA) of a signalized intersection to be a function of perceived waiting time (PWT),

$$UA = f(PWT).$$

The acceptance level is a real value between 0 and 1; it represents the probability that a road user finds the waiting time acceptable. Personal characteristics are excluded here, so the above model should be interpreted as a description of the overall (or average) acceptance level, rather than the acceptance by each individual user.

Based on the findings in literature (section II), we consider perceived waiting time to be a function of actual waiting time (WT), unused green time of conflicting traffic (UGT), number of stops in the queue (Stops), and presence of a red wave (RW), i.e.

$$PWT = f(WT, UGT, Stops, RW).$$

In this model, the actual waiting time is expected to have the biggest influence on the perceived waiting time. Besides this advanced model, a simple model is also considered:

$$PWT = f(WT).$$

IV. Video Survey

A. Method of Survey

To calibrate the above models of user acceptance and perceived waiting time, a survey with car drivers is conducted. Based on literature, five survey methods can be distinguished [4], [7]. Table I provides a comparison of these methods based on three aspects.

Video survey is selected in this study because of its low costs, high realism-costs ratio, and potential to attract a large number of respondents. The disadvantage of a video survey is its low realism level, e.g. speed and acceleration are only experienced through the visual channel.

TABLE I
Methods of Survey

Method	Costs	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

* Respondents: the amount of participants/respondents typically associated with a method.

B. Survey Set-up

In the video survey, respondents are shown a number of movies of reasonable realism. To prepare for the survey, a total of 44 movies have been filmed from the driver's perspective (Fig. 3). Each movie represents a scenario where signalized intersection(s) is approached and then passed; in each scenario a combination of the factors as described in section II becomes relevant. The movies are 1 to 4 minutes in length: in some movies, a single intersection is passed; in other movies multiple intersections are passed in a row.

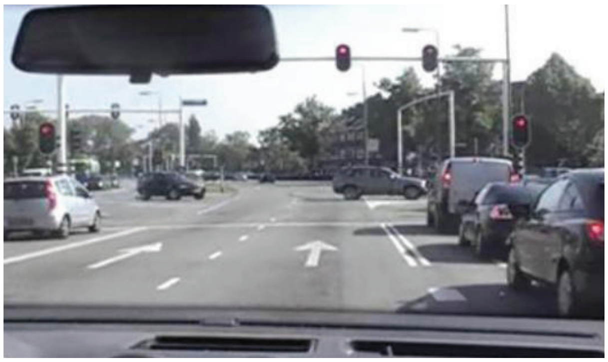

Fig. 3. Respondents of the video survey view movies that are shot from the driver's perspective. This strengthens the feeling that the respondents are driving the vehicle.

The prospective approach [3] is adopted in this study. Respondents are first informed of the purpose of the survey. They then watch 4 to 5 movies; these movies are randomly drawn from the 44 movies. Immediately after each movie the respondent is asked to estimate the waiting time experienced at the intersection(s) in the movie and to indicate whether the waiting was acceptable or not.

The prospective approach is favored over the retrospective approach (i.e. do not inform the respondents of the survey purpose before the movies) for two reasons. Firstly, the retrospective approach becomes problematic when each respondent watches more than one movie; they may suspect the purpose at the second or third movie. This makes comparing the movies with each other difficult. Secondly, when drivers wait at traffic lights, there is no other task involved. We therefore assume that delay estimation will become "prospective."

V. Results and Findings

The video survey took place in summer 2010. A total of 159 respondents participated in the survey. In average, each movie has been viewed by around 17 respondents. This resulted in 730 measurement data of user perception and acceptance to be used in the regression analysis.

A. Perceived Waiting Time: Simple Model

Fig. 4 plots the average perceived waiting time per intersection. Only intersections with positive actual waiting time in the movies are considered here; intersections with no waiting are excluded from the analysis. There appears to be a positive correlation between the actual and perceived waiting time. Two models are estimated from the survey data:

Linear model: $PWT = \beta_0 + \beta_1 \cdot WT$;

Quadratic model: $PWT = \beta_0 + \beta_1 \cdot WT + \beta_2 \cdot WT^2$.

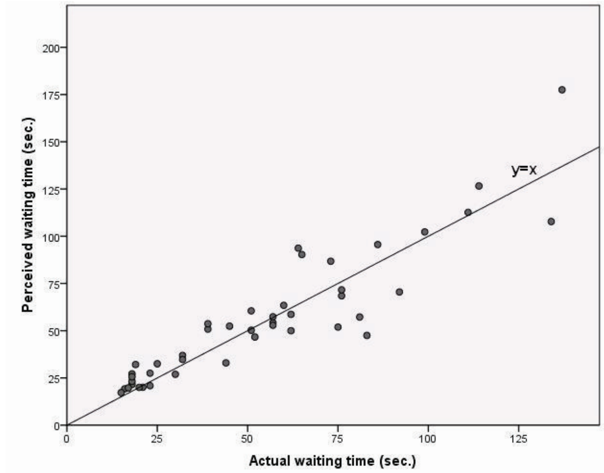

Fig. 4. The average perceived waiting time vs. the actual waiting time per intersection. Each movie is viewed by a number of respondents (varies between 11 and 28). Most movies contain only one intersection; a few movies include 2 or 3 intersections. The average value of the perceived waiting times is plotted here per intersection.

The regression results are shown in Table II. Both models are statistically significant (with p-values equal to 0.00). However, the quadratic model ($R^2 = 0.842$) has a slightly better goodness of fit than the linear model ($R^2 = 0.833$).

Research in literature, e.g. [4], also finds a quadratic model to be the best in describing the perceived waiting time. This is confirmed in this paper. The quadratic model indicates that both short and long waiting times are overestimated, whereas intermediate waiting times are perceived as they are. This could be explained as drivers dislike short waiting times (why do I have to stop at all?) as well as long waiting times (why do I have to wait this long?).

TABLE II
PWT Simple Model: Regression Results

	Linear-model		Quadratic-model	
	Value	Significance	Value	Significance
β_0	4.210	-	12.236	-
β_1	0.949	0.00	0.616	0.01
β_2	-	-	0.003	0.15

For significance, the p-value is shown here; a lower p-value indicates a higher statistical significance.

B. Perceived Waiting Time: Advanced Model

Besides the actual waiting time, there are other factors that influence the drivers' perceived waiting time. The most dominant ones are identified as the unused green time of conflicting traffic, the number of stops in the queue and the presence of a red wave between adjacent intersections (section II).

In this study, due to the limited angle of view in the movies, respondents may not observe the unused green time as they would in a real-world experiment. This is reflected in the survey results, which shows that there is no significant correlation between the unused green time and the perceived waiting time.

To account for the effects of the number of stops in the queue and the presence of a red wave, several advanced models have been tested. In the end the model below is adopted for its simplicity and goodness of fit. This model is a modification of the quadratic PWT-model, where β_0 and β_1 are replaced by more complex terms in order to capture the effects of the number of stops in the queue and the presence of a red wave. This model is expressed as follows:

$$PWT = (\beta_0 + \beta_1 \cdot RW) + (\beta_2 + \beta_3 \cdot Stops + \beta_4 \cdot RW) \cdot WT + \beta_5 \cdot WT^2. \quad (1)$$

Here RW is a binary variable (1 or 0) denoting whether a red wave is present or not. The regression results for this model are shown in Table III ($R^2 = 0.907$).

TABLE III
PWT ADVANCED MODEL: REGRESSION RESULTS

	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 regression results confirm that the number of stops in the queue has a significant influence on the perceived waiting time. Interestingly, this influence is realized as a negative impact on the perceived waiting time. This can be attributed to the observation that, when an additional stop is required while waiting at the same intersection, some attention of the driver is drawn to the maneuver of accelerating and stopping. Thus less time units are recorded for the waiting activity, leading to a lower perceived waiting time compared to cases with the same waiting time but no additional stops. It can also be the case that the sense of progressing or moving forward (albeit not fast and not smooth), instead of standing still for a long time, reduces the perceived waiting time. Moreover, the reduction in the perceived waiting time appears to be proportional to the actual waiting time.

The presence of a red wave comes into play when the driver has to stop at two or three consecutive intersections. This is shown to influence the perceived waiting time at the second (and third) intersection in varying ways: when the actual waiting time at the second intersection is relatively short, the perceived waiting time increases due to presence of the red wave; when this waiting time is relatively long, the perception decreases. The boundary in between is estimated to be when the actual waiting time is 40 seconds long. This indicates that car drivers dislike making a short stop at the second intersection (why do I have to stop again? why is there no coordination?). However, they seem to "surrender" themselves when the second stop is long (I am in bad luck today).

Fig. 5 illustrates the outcomes of the model for different scenarios. As can be seen, the advanced model can predict the average perceived waiting time per intersection with good precision. Same as in the quadratic model, the convex shape of the curves indicates that waiting times that are very short or very long are prone to "over-perception" or overestimation. In other words, both short and long waiting times are disliked by drivers while "normal" waiting times are accepted.

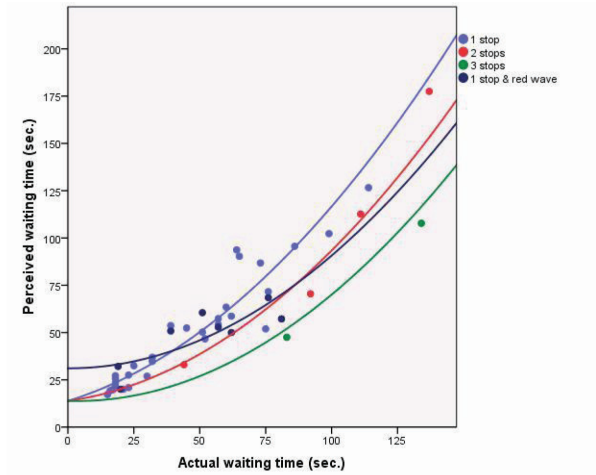

Fig. 5. The average perceived waiting times (dots) vs. the predicted values by the advanced model (lines). Each dot represents an intersection. The number of stops in the queue is distinguished by the different colors. Red wave only occurred to intersections with 1 stop necessary; this is represented by a separate color.

C. Driver Acceptance

Drivers' acceptance of the waiting time at an intersection is also studied in the video survey. Here individual driver's acceptance is measured as a binary variable: the waiting time is either acceptable (1) or not acceptable (0). The mean of the acceptance values by drivers using the intersection gives the acceptance level of that intersection, which is no longer binary but takes a real value between 0 and 1.

We consider the acceptance level of an intersection to be a function of the perceived waiting time according to the advanced model, and not that of the actual waiting time. A Sigmoid function [11] is adopted here:

$$UA = \frac{1}{1 + e^{\beta_0 + \beta_1 \cdot PWT}}. \quad (2)$$

The regression results are shown in Table IV.

TABLE IV
UA MODEL: REGRESSION RESULTS

	Value
β_0	-3.650
β_1	0.055

Fig. 6 shows the relationship between user acceptance and the perceived waiting time. The proposed model fits the observed data quite well. According to the model, more than 50% of the drivers would find the waiting time acceptable when the perceived waiting time is less than 66 seconds. Two bends are observed in the UA curve at $PWT = 42$ and

$PWT = 90$. Acceptance of waiting time between these two critical values is highly correlated to the length of the waiting time. On the other hand, waiting time below 42 seconds are almost universally accepted whereas waiting time above 90 seconds is almost always rejected. Specialists from the industry also confirm these intervals based on their own experiences.

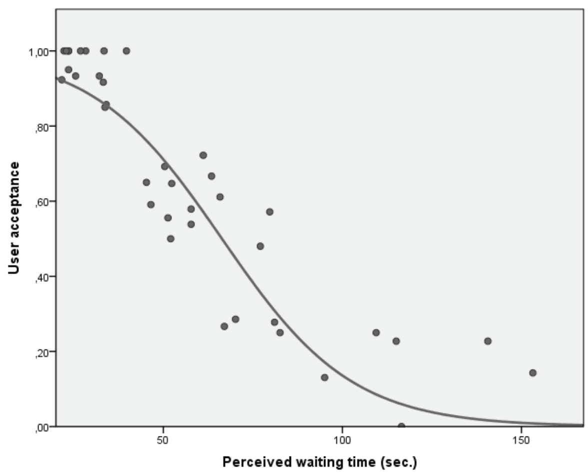

Fig. 6. Relationship between user acceptance and the perceived waiting time. Dots represent mean observed values whereas the curve represents model prediction.

VI. Real-world Experiment

Finally we conducted a real-world experiment to validate the models. In this experiment, car drivers were asked to drive a predetermined route with a surveyor in the vehicle. After each signalized intersection, the car driver reported the perceived waiting time and acceptance of it. The surveyor measured the actual waiting time, number of stops in the queue and whether a red wave was present.

Car drivers from two Dutch cities (Helmond and Den Bosch) participated in the experiment. In total 37 situations of intersection encounter were collected. These situations differed in terms of the actual waiting time (between 4 and 152 seconds), the number of stops in the queue (1 or 2) and the signal coordination between intersections.

The collected data were confronted with the regression results in section V. For the advanced PWT model, an R^2 of 0.870 was derived between the observed PWT and the predicted PWT. This indicates a high accuracy of the advanced PWT model in predicting drivers' PWT.

For the UA model, the summary statistics are shown in Table V. Out of the 37 situations, car drivers find the waiting times at 29 of them acceptable and 8 of them unacceptable. For each situation, the UA model gives a user acceptance level between 0 and 1. For the 29 accepted situations, 27 of them have a predicted UA level above 0.5, showing good agreement. However, for the 8 unaccepted situations, 5 of them have actually a predicted UA level above 0.5; it seems likely that the model underestimates the amount of drivers who would find an intersection unacceptable.

TABLE V
UA Model: Validation Results

Situations of intersection encounter	Occurrence
User accepts the waiting time	29
where the predicted UA≥0.5	*27*
where the predicted UA<0.5	*2*
User does not accept the waiting time	8
where the predicted UA≥0.5	*5*
where the predicted UA<0.5	*3*

VII. Conclusions and Discussions

In this paper we proposed models to estimate drivers' perception and acceptance of waiting time at signalized intersections. The perceived waiting time is given as a function of the actual waiting time, the number of stops in the queue and the presence of a red wave between adjacent intersections. Parameters in the proposed models are derived from the results of an intensive video survey. The models are also validated by a real-world experiment.

The actual waiting time is the most dominant factor for the perceived waiting time. The survey results show that both short and long waiting times are likely to be overestimated, whereas normal waiting time (between 40 and 60 seconds) are usually perceived as they are.

The number of stops in the queue is often seen as an indicator of a long actual waiting time. However, our results suggest that, given the same length of actual waiting time, car drivers actually prefer making more stops above standing still for the whole time. The perception of time is different when driving and stopping compared to idling.

When passing two adjacent intersections, car drivers dislike stopping at both intersections. A short stop at the second intersection is perceived as relatively long. Drivers often feel irritated when there is apparently no coordination between adjacent traffic signals.

Due to the limited view of the respondents when watching the movies, the factor of unused green time of conflicting traffic is left out in this study. However, specialists in the industry and past studies both suggest that the unused green time is an important factor of the user perception. Therefore, in further research other survey-methods could be used to study the effect of the unused green time in more detail.

For the driver acceptance model in this paper, personal characteristics such as driver personality and trip purpose have been left out. However, we believe that individual driver's acceptance of the waiting time depends greatly on trip purpose. This relationship can be the subject of a future study.

The results of this research have interesting implications for optimizing signal control at intersections. Current signal designs are mostly based on the minimization of actual delays. Since there is a non-linear relationship between perceived and actual delays, the minimization of perceived delays can lead to a different signal design which improves user acceptance.

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