

Speed Recommendations During Traffic Light Approach: A Comparison of Different Display Concepts

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Abstract

Projects like INVENT² or Travolution³ aim at optimizing traffic flow in cities by linking vehicles and infrastructure elements using infrastructure-to-car communication technologies. Traffic lights equipped with transmitters are able to inform the approaching vehicles about the current and future state of the traffic light control. This information can be used to optimize the speed profile while approaching an intersection. As current vehicles will not perform any speed changes autonomously, an intuitive and easy-to-read human machine interface is needed to present the speed recommendations to the driver.

Three different ways of in-vehicle information presentation were evaluated with 27 participants in a static driving simulator. The first variant is a simple countdown which presents the remaining seconds of the red or the green phase, respectively. The second variant shows the minimum or maximum speed recommendation in a textual manner. The third alternative uses a red and green area on the speed indicator scale.

All three approaches were tested regarding their comprehensibility, acceptance, effectiveness and distraction. The results indicate that the non-textual speed indicator display is preferred by most of the individuals and also has advantages concerning minimization of acceleration and deceleration actions.

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² <http://www.invent-online.de>

³ http://www.vt.bv.tum.de/uploads/rbraun/Travolution_Plakat_2007-07-09_TUM-VT.pdf

Introduction

Traffic flow optimization has always been an important research topic considering growing cities and increasing traffic density. The main motivation behind all measures taken is to reduce CO₂ emissions and to make travelling for drivers more comfortable. This includes expanding the road infrastructure and also improving the throughput of existing traffic routes by establishing intelligent traffic flow management mechanisms. Optimizing traffic light control strategies is not longer a local problem addressing single intersections but rather a global task involving many intersection points at the same time (e.g. Hewage & Ruwanpura, 2004, and De Oliveira et. al., 2006). Such measures could be even more effective by influencing the drivers' behaviour individually. One possible way to assist the driver is to display information about the traffic light phases while the car is approaching an intersection. Some countries use digital countdown displays or static green wave speed recommendations mounted directly to traffic lights. These displays are designed to help the driver choose an appropriate speed in order to pass the traffic light during the green phase. However, these signals are equal for all drivers approaching the intersection and do not take individual traffic conditions into account (e.g. vehicles driving ahead). Additionally, Kidwai et. al. (2005) state that countdown traffic lights have only little effect on traffic throughput.

Infrastructure-to-car communication can be used to present additional information concerning the current traffic light state to the driver within the car and with respect to his own position and speed. It is important to choose the display type with care as intersections are highly complex situations and additional visual cues may cause distraction.

Concepts

Three different display concepts for traffic light assistance were designed by HMI experts during a brainstorming session and then implemented in a driving simulator environment.

Countdown Human Machine Interface (HMI)

The first one was a simple countdown which displays the remaining time in seconds of the current traffic light phase. The information is shown directly as text and supported by a LED display around it which gives a graphical representation of the number (further referred to as "Countdown HMI"). Figure 1 shows a few snapshots.

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Figure 1: Countdown HMI: Remaining seconds in the green phase⁴

Minimum/Maximum speed HMI

As it might be hard for drivers to deduce an appropriate velocity given only the remaining time, an alternative display type was designed. Using the remaining time in the current phase of the traffic light and the distance to the traffic light, the car computer is able to estimate whether it is possible to pass the traffic light during the green phase and, in that case, calculate a speed recommendation. Basically, the HMI needs to address four scenarios: 1. It is not possible to pass the traffic light during green phase at all. 2. No speed change is necessary to pass the traffic light. 3. Acceleration is required. 4. Deceleration is required.

Taking these facts into account, the second concept was a combination of symbols showing speed recommendations in plain text (referred to as “Min/Max HMI” from now on). Figure 2 shows some examples.

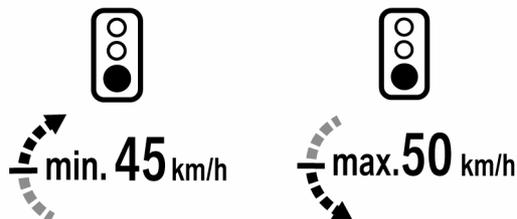


Figure 2: Min/Max speed recommendation HMI

Speed indicator HMI

The “Min/Max HMI” displays the boundary speed which needs to be exceeded in case of a minimum recommendation or must not be exceeded in case of a maximum recommendation. However, the recommendation should rather be a velocity range than a specific speed. Thus a third concept based on Voy et. al. (1981) and Haller (1995) was implemented which makes use of the speed indicator. Coloured areas are overlaid onto the speed indicator: a green area means that travelling in this speed range will allow passing the green traffic light

⁴ For coloured versions of the images please visit <http://extras.hfes-europe.org/>

whereas a red area indicates that stopping at the traffic light will be necessary. Figure 3 shows an example where acceleration is required.

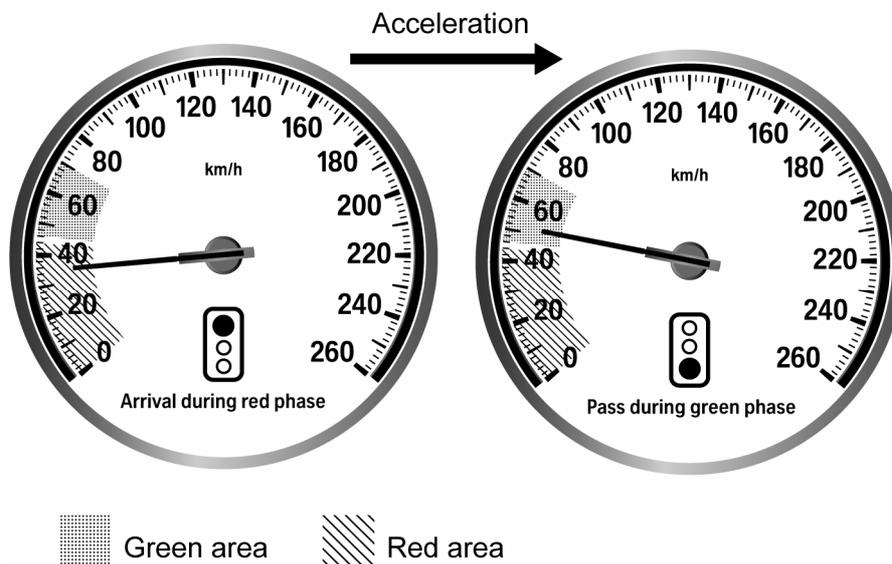


Figure 3: Speed indicator HMI

Since colour-blind persons might have problems to differentiate between the red and green areas on the speed indicator scale, an additional icon was added. This icon shows the expected state of the traffic light on arrival based on present speed. Replacing red and green by different colours is an option, but might weaken the correspondence to the traffic light and thus lead to worse comprehensibility for non-colour-blind persons. Nevertheless, no colour-blind persons were invited for this experiment to avoid an additional disturbance variable in the setup.

Experimental design

The goal of the experiment was to determine which HMI should be implemented in a real prototype car equipped with wireless communication technologies and fully programmable displays.

Comprehensibility during first exposure

Especially for car manufacturers, it is important to use a clear and intuitive information representation within the vehicle as the displays should be comprehensible without reading a manual. Thus participants of the study were asked to pass several traffic lights in the

simulator and state their understanding of the HMI during a short interview afterwards. No additional explanation was given in advance. Every participant experienced only one of the three HMI types during the first exposure driving session.

Effectiveness

A traffic light HMI is considered objectively effective if it leads to driving behaviour which is optimal with respect to fuel consumption. Having a realistic consumption model of a real vehicle in the driving simulator is quite complex, as many factors are of influence: environmental conditions, climate controls within the vehicle, engine management system, etc. Therefore, the requirement of minimal fuel consumption was interpreted as follows: the main goal of the HMI is to prevent the driver from performing any unnecessary accelerations or decelerations while approaching the traffic light. As an aggregated value for a single approach, we use the integral of the absolute value of the vehicle's acceleration. Any speed changes - acceleration and deceleration - lead to a greater integral value. Therefore lower values indicate better performance of the HMI. The integration limits were 300m before and 50m after the traffic light.

Acceptance

General data like age, gender and simulator experience was collected prior to the experiment in a demographic questionnaire. During the main part of the experiment, participants experienced each HMI type during a "main session" (details see "Experimental Procedure"). After each main session participants had the opportunity to evaluate the HMI which they just had seen before on a five-point Likert Scale with respect to various aspects (see "Single system evaluation" in Table 1). There was also room for answers to three open questions: Aspects they liked/disliked and suggestions for improvement. After completing all main sessions participants compared the three HMI types on a Likert Scale with respect to distraction and comprehensibility (see "System comparison" in Table 1).

Visual behaviour

During the whole experiment, eye tracking was used to estimate the amount of time that drivers spent reading the additional displays. As a first approach, the time when the driver's glance was not on the road was accumulated from 300m before to 50m after the traffic light.

Simulator Setup

The experiment was conducted in a fixed-base driving simulator equipped with a five-screen projector imaging system (Figure 4). Each screen had a height and width of 2.8 m. The field

of view for the participants was approximately 240°. No rear or mirror views were used during this experiment.



Figure 4: Simulator and mock-up setup⁵

Experimental procedure

The participants were invited to take part in a simulator study without being given any detailed information about the system under investigation. After completing a short training session to familiarize themselves with the driving simulator, each person was confronted with one of the three HMIs. During a short interview after the first two simulator sessions, comprehension of the HMI was tested. A between subjects design was used since an explanation of the first HMI would influence comprehension of all following HMIs dramatically. Although the HMI types “Min/Max” and “Countdown” are predestined for being presented in a head-up display, they were both shown inside the speed indicator to avoid an unintended comparison between head-down and head-up display positions with regard to visual behaviour.

For the four main sessions a within subjects design was used (the three HMI types and a baseline). Prior to every session, the HMI was explained to the subjects and correct comprehension was ensured. Participants drove through a route in an urban environment in the simulator with traffic lights every few hundred meters. The order of the four sessions was randomized. During every main session, subjects passed at least twelve traffic lights with six different scenarios implemented (referred to as factor “scenario”):

1. “Always red”: It is not possible to pass the traffic light during green phase at all
2. “Always green”: No speed change is necessary to pass the traffic light

⁵ In this picture, only three of five projectors are active

3. "+5 km/h": Acceleration by 5 km/h is required
4. "+15 km/h": Acceleration by 15 km/h is required
5. "-5 km/h": Deceleration by 5 km/h is required
6. "-15 km/h": Deceleration by 15 km/h is required

Each scenario was presented twice (factor "recurrence") and in randomized order to the participants during each main session. All subjects were asked to maintain a constant speed of approximately 60km/h when no reasons for changing speed existed (traffic lights or HMI displays). Every main session (except baseline) was followed by a questionnaire prompting (the individuals) for their subjective opinion. After finishing all sessions, the subjects filled out a concluding questionnaire which gave them the opportunity to compare the three HMI types directly.

Participants

27 participants, 23 men and four women, took part in the driving simulator experiment; their mean age was 29 years; six persons had prior driving simulator experience; no spectacle wearers were invited due to the eye tracking equipment used. For this first experiment, no persons with colour-blindness were invited.

Results

Comprehensibility during first exposure

The responses collected during the short interviews were categorized: "Instantly understood", "understood after some traffic light passes" and "not understood". It turned out that almost all the subjects understood how the HMI worked and what its purpose was after the first exposure session. This was true for all three HMI types.

Effectiveness

Figure 5 shows velocity profiles of the subjects, the mean value and the standard deviation for the baseline and the speed indicator HMI relatively to the distance to the traffic light in meters. The following scenario is shown: the traffic light is red and turns green while the driver is approaching. The traffic light control is triggered in a way that the maximum speed recommendation presented lies roughly 15 km/h below the current velocity of the vehicle.

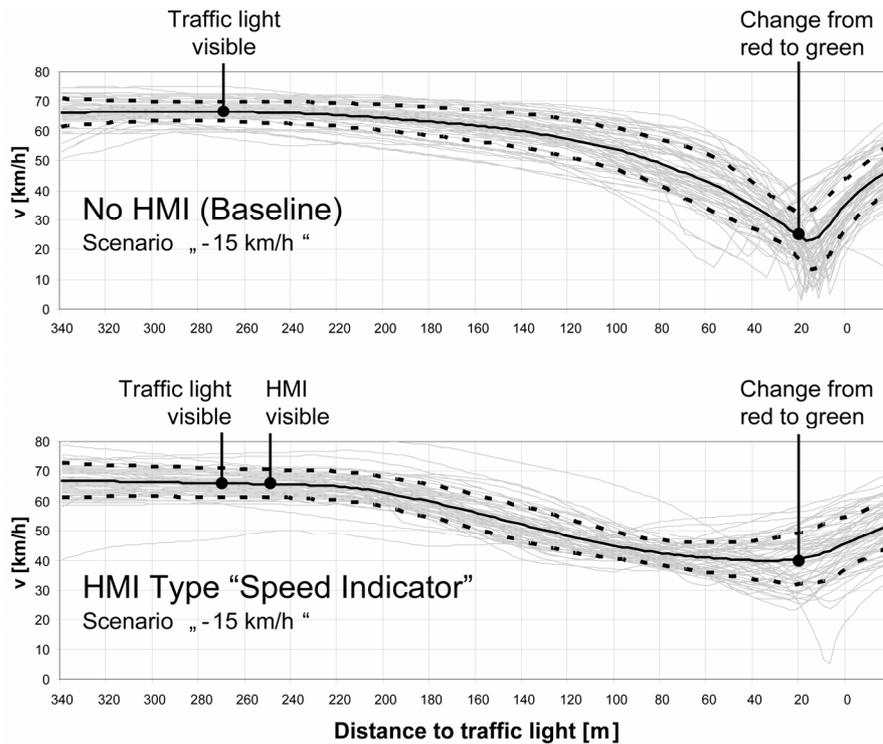


Figure 5: Speed profiles and standard deviations for the baseline and the “Speed Indicator” HMI for scenario “-15 km/h”

It can be seen that the drivers decelerated less and reacted earlier when a speed recommendation was shown. The traffic light became visible between 300 and 250 meters distance from the traffic light, depending on the scenario. The HMI was displayed starting from 250 meters distance to the traffic light. An analysis of variances with repeated measures of the objective acceleration integral measure showed a significant effect for the factor “HMI type” ($F(3, 54)=10.02, p<.001$) and “Scenario” ($F(5, 90)=108.60, p<.001$). No learning effect could be seen as the recurrence of the scenario for one HMI type did not show a significant effect. Figure 5 shows the results for all HMI types and scenarios.

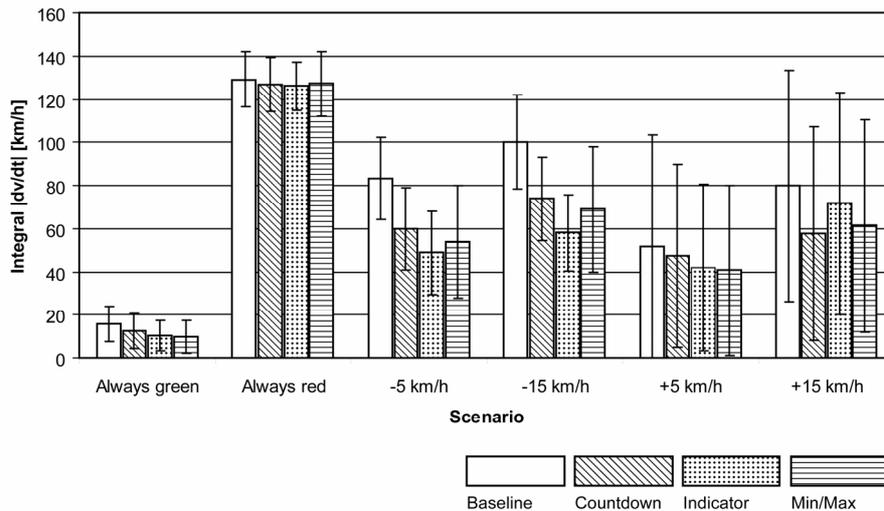


Figure 6: Effectiveness of different HMI types and standard deviation

As expected, scenario “Always green” leads to small and “Always red” to large integral values. As deceleration and acceleration are treated equally by using the absolute value, the scenario “Always red” sums up to approximately 120 km/h: Drivers need to decelerate from 60 km/h to zero and then accelerate again to 60 km/h after the traffic light. The other four scenarios lie somewhere in between these two extremes.

Wilcoxon tests were used to determine significant differences in HMI performance. The speed indicator HMI was significantly more efficient than the baseline and more efficient than the other two HMIs in scenarios “-5 km/h” and “-15 km/h”. Even in the scenario “Always green” all HMIs showed some advantage compared to the baseline. Scenarios “+5 km/h” and “+15 km/h” have extremely large standard deviations: As the drivers were not forced to react to the HMI but were instructed to behave as they would in a real world situation, some decided to follow the recommendation – and passed the traffic light, and others did not – and stopped in front of the traffic light. Therefore, some cases in this group tend towards scenario “Always green” and others towards scenario “Always red”.

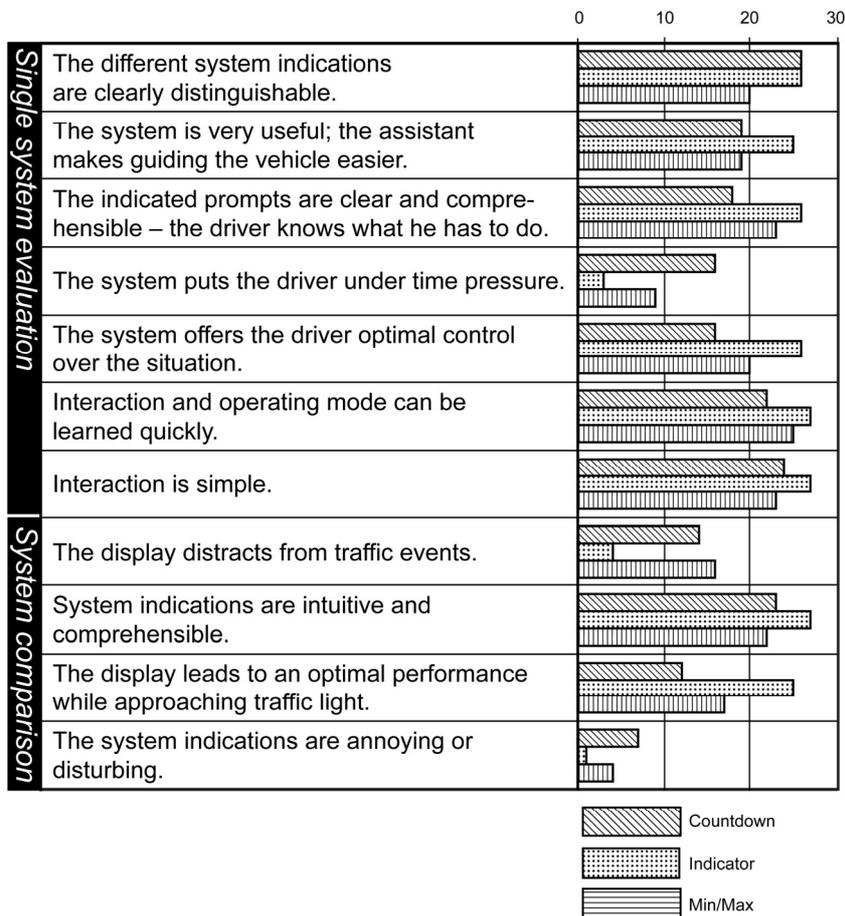
Generally, high speed variability might also be an indicator for a suboptimal understanding of a certain HMI display. Thus this measure could reflect the comprehension during the driving task (in contrast to the direct evaluation of comprehension during first exposure).

Acceptance

Acceptance was evaluated based on the questionnaires the participants filled out after each main session and after completing all main sessions. Table 1 shows the statements

(meaning might vary due to translation from German) and the rating for each HMI type. Apparently almost all the responses are in favour of the speed indicator HMI.

Table 1: Questionnaire statements and number of participants who agreed to them



Visual behaviour

Every glance at the assistance display, respectively the speed indicator, was logged from 300m before to 50m after the traffic light.

Figure 7 shows the average glance frequency distribution for one example scenario. It can be seen that most glances are below two seconds and that on average, eight scans are required during one traffic light pass to perceive the HMI display. The countdown HMI produces slightly more but shorter glances than the other two HMI types. The AAM statement of principles (AAM, 2002) for in vehicle information systems states that the 85th percentile of all glances should be below two seconds, which is true for all display variants (Figure 8).

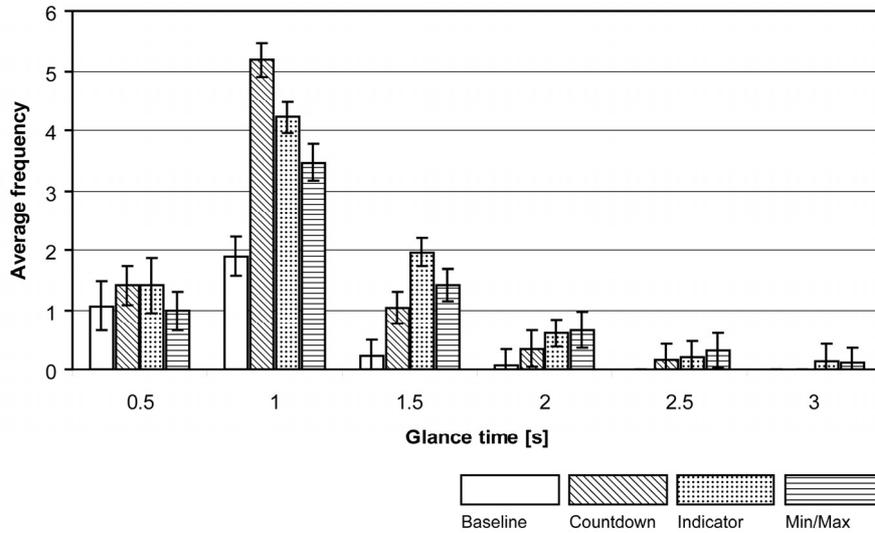


Figure 7: Average glance frequency against glance duration and 95% confidence interval for scenario “-5km/h”

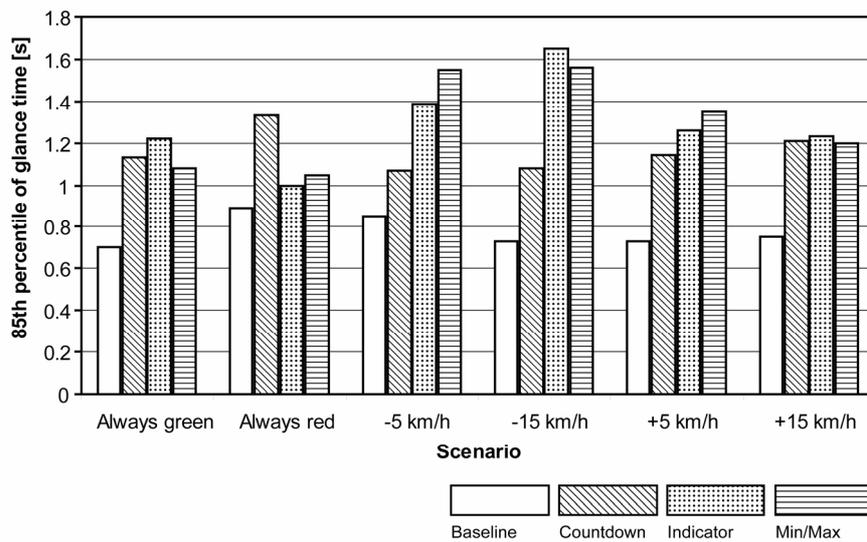


Figure 8: 85th percentile of glance times for all scenarios

Discussion

In this setup, no other traffic was present to allow an experimental setup without any disturbance variables and to assure that the intended scenarios occurred reliably. Although most of the glances were below two seconds, the number of glances was relatively high. It is expected that a natural traffic environment would reduce the number of glances. The countdown HMI is more predictable than the other two HMIs because it does not depend on the vehicle’s speed and position and changes in regular time intervals. Therefore, subjects looked at that display less often and for shorter times. In a real world situation, the velocity-

based HMIs might be faster to understand as time-based displays require the driver to extrapolate the vehicle's future position. An additional experiment focusing on visual behaviour will be conducted including a more complex and realistic driving course.

Besides usability aspects, many legal issues need to be solved before a system like this could be brought to market. Not giving any recommendations above the local speed limit is a basic requirement. How much of the amber phase is treated as green by the system for example can have a major effect on acceptance, but also has many safety implications on the other hand.

As the experiment was not intended to find any gender effects, the sample was unbalanced. Future studies should include the influence of gender on acceptance and efficiency of the HMI variants.

In order for the driver to benefit from the traffic light HMI, a high penetration grade is desirable. If a traffic light does not transmit its current and future status, no recommendation can be displayed. Image recognition using an on-board camera can detect the current but not the future status of a traffic light. Thus its use is restricted to showing information indicating the existence of a traffic light without being able to give a dedicated speed recommendation. In case of a very high penetration grade, image recognition could avoid confusion for the driver as the vehicle is able to display explanatory information: "There is a traffic light but no speed recommendation can be calculated due to missing radio signal."

Since traffic lights could potentially serve as repeaters for car-to-car communication, network effects can be expected that may accelerate the rollout of wireless-enabled traffic lights (Matheus, 2004).

In summary, it can be stated that the speed indicator HMI has advantages concerning acceptance and efficiency. Therefore, it was implemented in a prototype car. Additional field tests need to show the suitability for daily use under real traffic conditions.

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