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LINKING ROADSIDE COMMUNICATION AND INTELLIGENT CRUISE CONTROL ; EFFECTS ON DRIVING BEHAVIOUR

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ABSTRACT

This paper describes a driving simulator experiment in which an Intelligent Cruise Control (ICC) was combined with short-range communication (SRC) with the road side. This offers the possibility to obtain in-car preview information about relevant conditions on the road ahead. ICCs studied varied in the way this information was used: informative (leaving it to the driver whether to adjust his speed) or intervening (i.e. making the ICC automatically obey the speed limit). Also the way in which the information was presented to drivers was varied (visual, acoustic, or haptic feedback). Subjects were confronted with a number of critical scenarios.

As expected, an ICC results in a reduced proportion of small time headways. With regard to speed choice it was found that only the intervening systems results in a speed reduction on sections with a special speed limit. However, there seems to be a compensating mechanism in that actively reducing a driver's speed on a few limited sections makes him drive faster on other parts. It also appeared that the combination of ICC with in-vehicle information resulted in a somewhat later braking reaction of the driver in situations the ICC could not cope with. In conclusion, the combination of ICC with different forms of in-vehicle information appears to show specific effects on driver behaviour, not all of them being favourable.

1 INTRODUCTION

The application of advanced technology in road traffic finds itself in the stage where control over the longitudinal aspects of the driving task comes into sight. Much effort is put into the development of Intelligent Cruise Controls (ICCs), which are systems capable of regulating not only a vehicle's speed, but also the following distance to a lead car. Within the PROMETHEUS CED 5 framework a number of Autonomous Intelligent Cruise Controls (AICCs) has actually reached demonstrator or prototype status. The term 'Autonomous' refers to the fact that these AICCs operate without communication with other vehicles or with the roadside.

Systems capable of regulating both speed and following distance essentially take over the longitudinal control part of the driving task. This changes the role of the driver from controlling (i.e. in the loop) to monitoring the ICC's functioning (i.e. out of the loop). Only in situations the ICC cannot cope with, the driver has to take over control. Possible advantages of such a system are an improvement of driving comfort, and also of safety since the ICC maintains a safe distance. A possible drawback is that the use of ICC could reduce the driver's alertness, which may have a negative impact on safety, especially in relatively rare critical situations where the driver has to take over control.

In the area of telematics a variety of developments with possible applications in traffic is taking place. Short-range communication (SRC) based on beacons would allow to send information from the roadside to the vehicle. This could provide in-vehicle preview information on relevant dynamic or static road conditions ahead, such as the traffic or weather situation, possibly improving traffic flow and traffic safety.

New possibilities arise when ICC is integrated with SRC. Such a combined system could be constrained to be purely informative, leaving all action to the driver. However, it could also automatically use a maximum speed received from the roadside in the ICC. It could suggest and initiate overrulable actions itself, or it could initiate non-overrulable actions.

This paper describes an experiment which has been conducted in the TNO driving simulator to study the effects of ICC/SRC on driver behaviour. This work has been carried out under contract with the Ministry of Transport, Public Works, and Water Management. The main questions were how the in-vehicle information should be presented to the driver, and what the effects are of purely informative v.s. actively intervening systems. A more detailed description of this study is given by Hogema, Van der Horst & Janssen (1994).

2 METHOD

2.1 Experimental conditions and scenarios

The assumed SRC system consists of beacons positioned at specific locations. The data transmitted are the prevailing local speed limit and, when applicable, a rationale for the speed limitation. In the present experiment, two approaches for using these data have been compared. The first was to only *inform* the driver of the speed limit, and the second approach consisted in an *intervening* system in which the ICC automatically adjusts to the speed limit. This was still accompanied by a message to inform the driver of the prevailing speed limit and/or its rationale. However, if the driver wanted, he could always drive faster by either overruling the ICC or by switching it off.

Many options are conceivable to provide the driver with *feedback* on a new speed limit, both in connection with purely informative and with intervening systems. The feedback method can range in complexity from simply informing the driver that a new speed limit has been received to more refined forms in which the driver is also informed of the value of the new limit and/or its rationale. Furthermore, the display types could be visual, acoustic, haptic, or a combination. These methods all have specific advantages and disadvantages (Lerner et al., 1993). Acoustic and haptic messages, for instance, are temporal in nature. Information on visual displays provide continuously available information, but require the driver to shift visual attention from the traffic scene to the display.

Table I ICC configurations (experimental groups).

Without roadside-vehicle communication	
control group	1
independent ICC	2

With roadside-vehicle communication		
FEEDBACK TYPE	ICC MODE	
	informative	intervening
basic	3	7
visual	4	8
acoustic	5	9
haptic	6	10

The configurations listed in Table I have been used in the experiment. Subjects drove with only a single candidate ICC. In the first two configurations (groups 1 and 2) there was no in-vehicle information: these subjects only obtained information directly from the outside world. The first group was the control group in which subjects had no ICC. In group 2 an independent ICC (i.e. without SRC) was present.

In candidate ICCs that included roadside-vehicle communication, two *ICC modes* are distinguished, i.e. an informative and an intervening mode. There were, moreover, four different *feedback types*. The basic configuration was a simple acoustic signal ('beep') which indicated that a new speed had been received from a beacon, in combination with a continuously flashing LED on the speedometer indicating that speed. The remaining three types had an additional feedback message added to this basic configuration. The visual feedback consisted of standard traffic signs displayed on a small colour monitor, indicating both the speed limit and its rationale. The acoustic feedback consisted of a spoken message informing the driver of the new speed limit and its rationale. Finally, the haptic feedback consisted in a short vibration on the gas pedal, supported by an acoustic explanation.

The experimental runs were mainly composed of normal driving situations without a special speed limit or extreme manoeuvres of the other traffic. This was the 'standard' or 'normal' scenario of driving on a 120 km/h motorway. Every now and then, a subject would be confronted with a more or less critical scenario in which a certain maximum speed applied:

- a 100 km/h speed limit for no apparent reason,
- a 80 km/h speed limit because of a relatively sharp curve in the road, and
- a 50 km/h speed limit because of a traffic queue.

The control logic of the ICCs implemented for the present experiment was largely based on the Daimler-Benz approach to AICC as described by Müller & Nöcker (1992). In the absence of a lead vehicle the ICC provides *speed control*. In this case the control loop aims to keep the actual speed of the vehicle equal to the reference speed set by the driver. If a lead vehicle is detected, the ICC switches automatically to *distance control*. In this mode the following distance is controlled at an appropriate value (in the current experiment a time headway of 1.5 s). By means of switches, the driver can turn the ICC on or off, and adjust the reference speed. The reference speed is shown by means of a LED on the speedometer, and when a lead vehicle is detected, a LED bar on the dashboard gives an indication of the following distance. There is one major difference between the Daimler-Benz AICC and the ICC used in this study. The Daimler-Benz AICC allows the driver to take his foot off the gas pedal when the ICC is active. The ICCs used in the present experiment only functioned as long as the subject kept his foot on the gas pedal: releasing the gas pedal automatically switched the ICC off. This was done as a safety measure, preventing the driver from having to search for the brake pedal in case of an emergency. In addition, haptic feedback by means of the active gas pedal would not be possible if the driver did not have his foot on the pedal.

Following the PROMETHEUS AICC-philosophy, the system is meant to increase comfort, and has limited decelerating capabilities. Consequently it is not able to deal with a much slower lead car or hard braking manoeuvres of a lead car. In these cases the driver has to take over control. With this in mind the 'traffic queue' scenario was designed in such a way that the driver had to take some form of action if he wanted to avoid a collision.

Each subject was confronted twice with all scenarios, once in a *free-driving* situation (without leading cars) and once in a *car-following* situation.

2.2 Procedure

The experiment was conducted in the driving simulator of the TNO Human Factors Research Institute (see Van der Horst, Janssen, & Hoekstra, 1991). During experiments, the subject is seated in a fixed base mock-up of a Volvo 240 and has all normal controls (steering wheel, accelerator, brake, etc.) at his disposal. Based on the control signals, a vehicle model with the dynamic characteristics of a Volvo 240 computes the state of the vehicle. Feedback of steering forces is given to the driver by means of an electrical torque engine, and of sound by an electronic sound generator (noise of engine, wind, and tyres). The momentaneous position and heading angle are transmitted to a Computer Generated Image system (CGI, Evans & Sutherland ESIG 2000). This system computes a video image of the visual scene as seen from the position of driver. The image is projected on a screen in front of the mock-up by means of a high-resolution projector (visual angles: 50° horizontally, 35° vertically).

Sixty male subjects participated in the experiment. They all had a driving licence for at least three years and they drove at least 10 000 km a year.

Each subject completed two blocks: the first block consisted of control runs, i.e. without the support of an ICC or communication system, and the second block the driver would have one specific form of ICC. All combinations of the three critical scenarios and free-driving/car-following conditions occurred once in each block. If the subject was to enter the scenario in a car-following situation, two lead cars appeared in the simulation several kilometres before the onset of the scenario.

Before starting the ICC block, each subject received thorough operating instructions and a training run. It was explicitly stated that the ICC is not an anti-collision system that is capable of dealing with emergency situations.

The roadside information was given on Variable Message Signs (VMSs) above the road, which were present at every 500 m on the entire route. The VMSs showed maximum speeds signs and when applicable also a sign stating the rationale for the speed restriction (i.e.,'curve' and 'queue'). On the 'standard' road sections the standard motorway speed limit of 120 km/h was not explicitly indicated by traffic signs or feedback messages. This is in correspondence with the functioning of the Dutch Motorway Control and Signalling System which is being implemented in the Netherlands on a large scale (Rijkswaterstaat, 1992). Likewise, the SRC did not send information to the vehicle on these sections.

After having completed the last run subjects filled out a questionnaire regarding their subjective impressions of the ICC. The questionnaire, which was developed in earlier research on collision avoidance systems (Janssen, Brookhuis, & Kuiken, 1993), comprised nine specific questions, each allowing a rating on a five-point scale as an answer, with items such as 'useful', 'helpful' and 'alerting'.

3 RESULTS

In the analysis, a distinction was made between free-driving and car-following situations, based on a 5 s time headway criterion. The results were analysed by means of analysis of variance (ANOVA).

3.1 Free-driving speed

The ANOVA for the ICC conditions 1 and 2 (i.e., the control group compared to the independent ICC group), with block number, group number, and scenario as factors showed the same main effect of scenario [$F(3,30)=383$, $p<0.001$] (Fig. 1a). In both blocks, there was a trend showing that the mean speed was higher in the control group than in the independent ICC group [$F(1,10)=3.1$, $p<0.1$].

The ANOVA on the mean free-driving speed with scenarios, feedback type and ICC mode as independent variables showed a significant interaction between block number and scenarios [$F(3,120)=16.1$, $p<0.001$]. A post hoc test showed that the presence of ICC (in block 2) lowered the mean free-driving speed in the 'queue' scenario [$p<0.01$], but also that it raised the speed on the 120 km/h sections [$p<0.001$].

A significant third order interaction existed between ICC mode, block number (i.e. with vs. without ICC), and scenarios [$F(3,120)=4.0$, $p<0.01$]; see Fig. 2b. In the informative condition, the post hoc test revealed no effect of ICC on the mean free-driving speed in any of the three critical scenarios [all $p>0.74$], and a slight speed increase on the 'standard' sections [$p<0.01$]. In the intervening condition, on the other hand, the post hoc test showed that free-driving speeds were lowered by ICC in the queue and curve scenarios [$p<0.001$ and $p<0.05$, respectively], but on the 'standard' sections the speed was raised when introducing ICC [$p<0.001$]. This speed increase was higher in the intervening condition than in the informative condition [$p<0.001$].

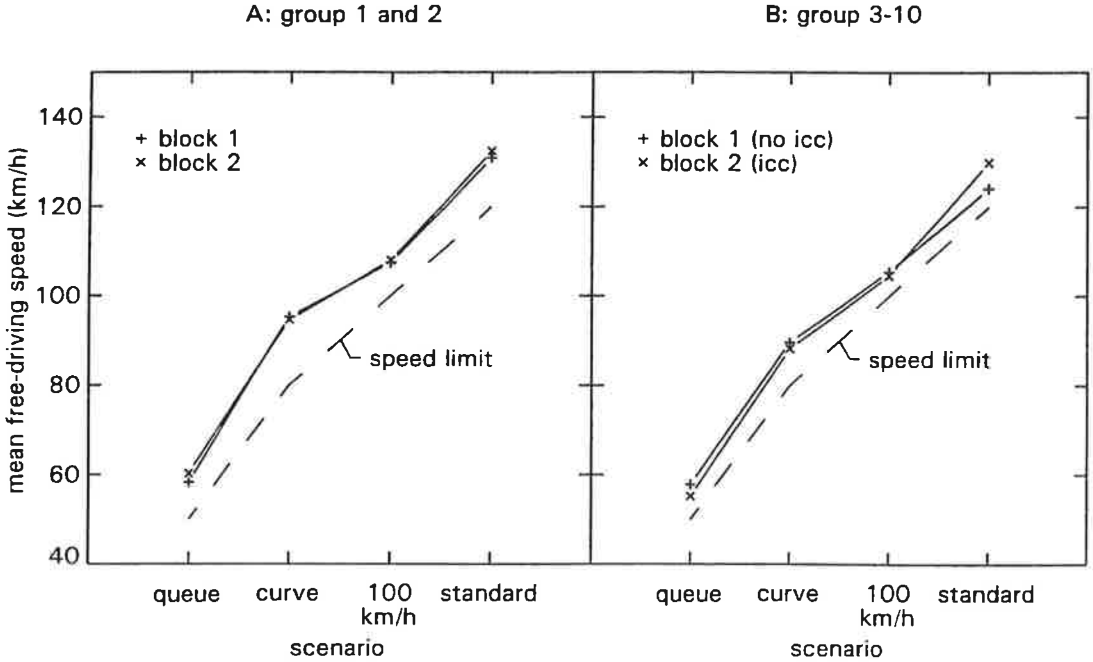

Fig. 1 Mean free-driving speed as a function of scenario and block. A: control group and independent ICC. B: ICCs with communication.

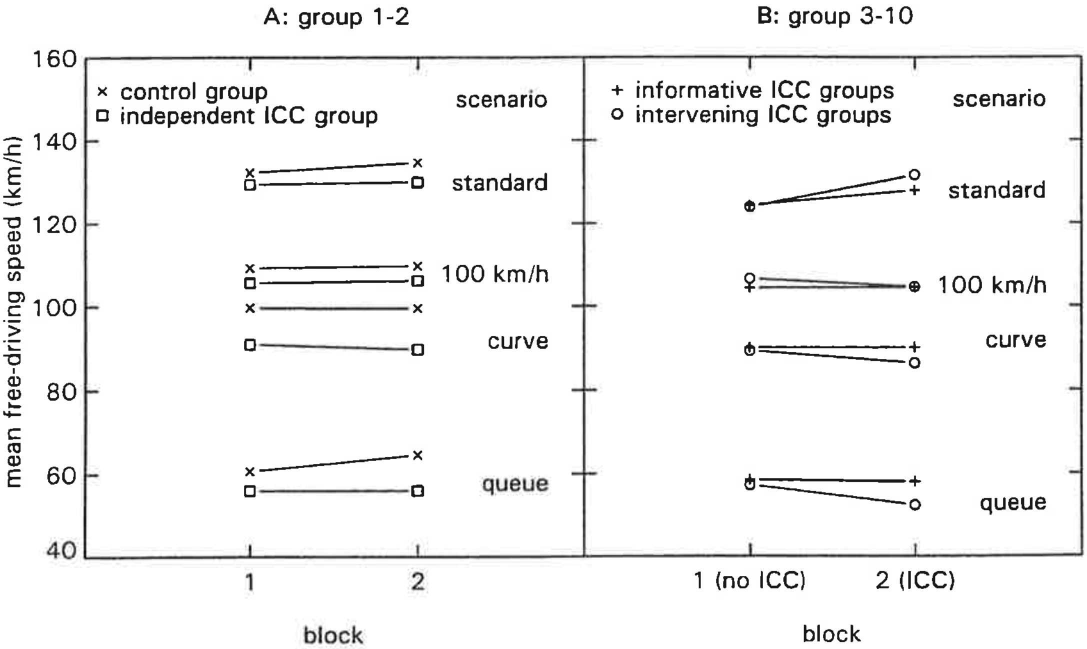

Fig. 2 Mean free-driving speed as a function of scenario, block, and ICC mode. A: control group and independent ICC. B: ICC with communication.

3.2 Car-following behaviour

Two parameters describing car-following were analyzed: the percentage of time subjects were in a car-following situation (as defined by a time headway of less than 5 s), and the percentage of following during which the time headway was less than

1 s. The results showed that the percentage of time subjects were in a car-following situation was not influenced by any of the ICCs.

The percentage of following during which the time headway was less than 1 s was also analyzed. As Fig. 3b shows, the percentage of short headways is smaller in the presence of ICC. However, for the control group, the percentage of small headways was smaller in the second block than in the first block as well. Apparently, a factor like getting used to the scenarios may have played some role here in the control group.

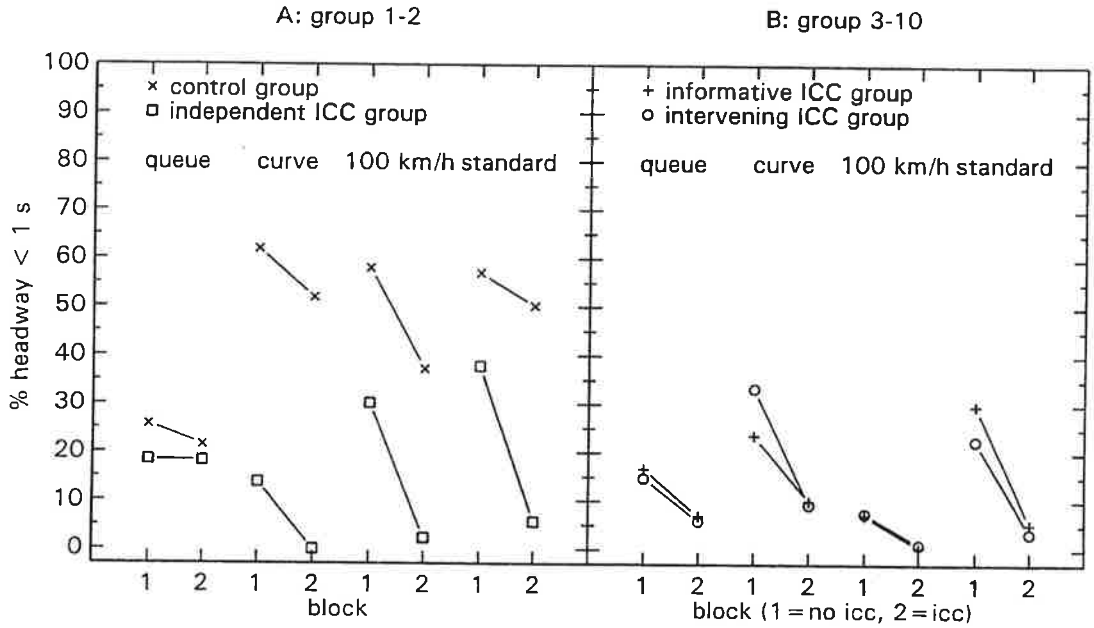

Fig. 3 The percentage of time headway < 1 s (over all following situations) as a function of scenario and of block number. A: control group and independent ICC. B: ICCs with SRC.

3.3 Approaching queues

Those episodes in which the subject approached the stationary traffic queue without the presence of leading cars were analyzed separately. The ANOVAs with ICC mode, feedback type, and block number as factors revealed effects of ICC presence on several Time To Collision (TTC) measures: TTC at the moment the gas pedal was released (TTC_{gas}), TTC at the moment the brake pedal was depressed (TTC_{br}), and the minimum TTC value over the entire approach manoeuvre (TTC_{min}). These variables were all smaller when ICC was present. The averages are listed in Table II.

Table II Results of ANOVAs on approach variables (group 3-10).

Variable	Mean, no ICC (block 1)	Mean with ICC (block 2)	F(1,40)	*p*
TTC_{gas}	11.1 s	9.5 s	10.5	0.005

Variable	Mean, no ICC (block 1)	Mean with ICC (block 2)	F(1,40)	*p*
TTC_{br}	9.3 s	7.9 s	8.0	0.01
TTC_{min}	4.6 s	3.9 s	4.9	0.05
$Dist_{gas}$	368 m	321 m	6.2	0.02
$Dist_{br}$	299 m	265 m	3.7	0.07

Since the free-driving speed on the section prior to the queue scenario was overall highest in the ICC conditions a decrease in TTC measures would be obtained if the subjects reacted at a constant distance to the queue. An ANOVA on $Dist_{gas}$ and $Dist_{br}$ (the distance to the queue at the moment the gas is released and the moment the brake is pressed, respectively) was carried out to investigate this possibility. $Dist_{gas}$ was significantly smaller when ICC was present, and $Dist_{br}$ showed a nearly significant decrease. Hence, the smaller TTC values can be attributed both to the higher approach speeds *and* to the smaller distance to the queue at which the deceleration is initiated.

3.4 Questionnaire results

Rating results on the nine separate scales showed that subjects were reasonably satisfied with most systems. Most non-favourable judgments were on the 'alertness' scale, obviously reflecting a belief that ICC-systems may cause driver inattention. The questionnaire results were subjected to a dimensional analysis on the basis of the earlier findings from Janssen, Brookhuis, & Kuiken (1993). Two *relative* factors 'Perceived Usefulness' and 'Perceived Comfort' were sufficient to cover the original nine rating scales. Differences in these factors could not be related to the ICC's underlying design dimensions.

4 DISCUSSION AND CONCLUSIONS

The general expectations of ICC (regardless of the presence of in-vehicle information) are that, compared with a human driver, speed and following distance are controlled with less variation. The standard deviation of the free-driving speed was seen to decrease in some ICC conditions. With respect to car-following it was found that the percentage of short time headways (< 1 s) was lowered by introducing ICC, as could be expected by a system that aims at maintaining a headway of 1.5 s. The mean headway was not significantly affected by the existence of an ICC, so the reduced percentage of short headways was not obtained at the cost of an overall increase of headways.

However, the main subject of this study was not ICC as such, but ICC combined with a SRC system that provides in-vehicle information. It was found that in the critical scenarios a reduction of the mean free-driving speed was only obtained when the posted speed limit was automatically put into the ICC. On the standard road sections, where no beacons were present, the mean free-driving speeds *increased* after introducing the intervening ICC/SRC system. There seems to be a compensating mechanism in that actively reducing a driver's speed on a few limited sections makes him drive faster on other parts. Given the relation between speed and traffic safety (Nilsson, 1984), this can be considered as an adverse effect. A straightforward measure to prevent this compensatory effect seems to be to use beacons on the 'standard' sections as well, that is to give information and/or intervene when the speed limit is 120 km/h. However, when the driver has the liberty to disengage or overrule the system, the effectivity of any intervening system might be reduced correspondingly.

ICCs are generally designed for a limited range of accelerations and decelerations. This implies that in emergency-like situations the driver must take over control. There are several reasons why a driver, in such a situation, could react later compared with the condition without ICC. First, the ICC could cause a decreased alertness of the driver. Second, even if the driver is aware of the dangerous situation, he could have too much confidence in the ICC's capabilities to deal with it. Third, the presentation of in-vehicle information at the same time that a critical situation is developing could distract the driver's attention from the traffic. Important questions are first on what information in the visual field drivers base their decision to intervene, second whether they can judge correctly what the ICC's limits are, and third when and how the driver should be warned if the ICC cannot cope with the situation.
In this experiment, the most critical scenario was the approach to a stationary traffic queue. When there was support of an ICC/SRC system, the mean approach speed was higher, and the braking started at a smaller distance to the queue, resulting in smaller TTC values at the onset of braking. Also the minimum TTC as reached over the entire manoeuvre was lowered after adding ICC. The quantitative results show that the effects only constitute a moderate shift towards a minimum-margin situation.

An effect of feedback type was not found on any of the dependent variables. The basic feedback gave no different results from more sophisticated systems. What may have played a role here is that all in-vehicle information was essentially redundant, since the speed limit and its rationale were always visible on the roadside VMS. When considering the implementation of these systems in reality, the roadside information would always be required as long as not all vehicles have in-vehicle information. Differences between the various feedback systems may occur when they would be exclusively in-vehicle, that is, when no roadside information would be present.

With respect to having to keep one's foot on the gas pedal while the ICC was on, a number of disadvantages was found. Many subjects complained about that MMI approach: apparently it strongly reduces the subjective comfort provided by an ICC. The current approach was based on two considerations. The first is that it is safer if the driver keeps his foot on the pedal because in a sudden emergency situation his foot is at a well-defined place. Secondly, feedback by means of an active gas pedal can only be applied with the foot on the pedal. However, with respect to the safety issue, one may also argue that the brake reaction time can be reduced when the driver does not have to have his foot on the gas pedal: he can anticipatorily keep his foot near the brake pedal.

The subjective results showed that the subjects were reasonably satisfied with most systems. There was a general tendency, however, to judge ICCs as potentially diminishing alertness while driving. Comments of that nature were also explicitly made by a number of subjects after the experiment.

In conclusion, we have found evidence that different forms of ICC combined with in-vehicle information show fairly consistent effects on driver behaviour, not all of them being favourable. A configuration where a beacon automatically passes speed limits on to the ICC can be effective to reduce speeds in critical scenarios. However, drivers appear to compensate for such automatic speed reductions by driving faster on sections without beacons. Additional measures would be required to prevent this. At the same time there is some evidence that the combination of ICC with a beacon system resulted in somewhat later braking of the drivers in situations the ICC could not cope with, although this is only a moderate shift towards a minimum safety situation.

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