Factors Influencing Compliance to Tactical Driver Advice: An Assessment Using a Think-Aloud Protocol*

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***Abstract*— Connected Cruise Control (CCC) is an in-car driver support systems that aims to improve throughput in dense motorway traffic by advising drivers how to drive. The system is currently under development within a HTAS project. It will integrate lane advice, headway advice and speed advice. CCC will not take over vehicle control. This makes its effectiveness dependent on the drivers ability and willingness to comply to the advice. In the present study we used a think-aloud protocol, during the first on-road field-test of the CCC system, to assess drivers' initial reactions to the advice. From the transcripts we extracted factors that can influence compliance to tactical driver advice. These factors can be used to formulate hypotheses about driver compliance to CCC.**

I. Introduction

In the past decade innovation in driver support systems is more and more focussing on improving throughput and traffic flow. Rather than re-routing traffic to less congested routes, emerging systems aim to improve the distribution and the behaviour of vehicles on a given road. An example of such a system is an adaptive cruise control that uses vehicle-to-vehicle communication to improve string stability [1]-[3]. However, even without actively controlling the vehicle, advisory systems offer support to drivers, in order to improve their driving behaviour while remaining in total control of their vehicle. Instead of assuming control over the vehicle, these systems provide information and advice about appropriate driving behaviour [4], [5].

An example of such a driver-in-the-loop system, currently under development in a HTAS project, is Connected Cruise Control (CCC) [6]-[8]. CCC offers drivers advice on the optimal speed, headway and driving lane in order to optimize the distribution of cars on the motorway and counteract the build-up and propagation of shockwaves through traffic. Drivers receive individual advice messages via an in-car, nomadic device. These individual messages are adjusted to a drivers current lane, headway and speed, the actual speed limit, the physical road layout as well as the drivers chosen route. CCC will not take over vehicle control. While this approach has certain advantages (e.g. less issues related to liability in case of system failure, faster market penetration) it also makes the effectiveness of the system dependent on drivers ability and willingness to comply with a given advice. CCC is still at an early stage of development. However, it is important to evaluate the system with prospective users in order to study the user-system interaction and detect issues related to compliance at an early stage in the development.

A. *CCC as a rational actor*

CCC advice is generated through a process of assessing and modelling the current traffic state in order to predict the development of traffic in the near future. The current traffic state is estimated from traffic loop and floating car data. The prediction is then analysed for potential bottlenecks (i.e. situations that can lead to congestion under the estimated traffic load and vehicle distribution over the diving lanes). If a bottleneck is identified in the prediction, an algorithm determines the optimal behaviour of CCC equipped vehicles approaching the bottleneck.

Due to the wide network of sensors, the system's "perceptual horizon" and, as a result, the available bulk of situational information exceeds that of the driver. Furthermore, the systems algorithms and processing power allow CCC to deal with the amount of situational information in real time. This means that the system has the capability to find the most optimal solution to an identified bottleneck.

B. *Bounded rationality*

It has been proposed that drivers as well engage in a form of state perception and future state prediction and that, based on their own perception of the traffic situation, drivers come up with a control decision [9]. A schematic representation of how the driving task could be supported by CCC, following the control model by Minderhoud [9] is shown in Fig. 1.

However, it can be argued that the schematic model provides a too idealized description of the drivers mental processes that are involved in the choice of a behavioural reaction by a driver to a given environment. It is uncertain whether drivers constantly engage in every of the proposed steps and even if they would, whether they will do so in the proposed order. Also, in contrast to CCC, drivers may lack a degree of elaborateness in performing the mental action, required at each step, due to the lack of information and processing capacity.

The processes that lead to a control action may be more realistically described in a model that follows the principle of bounded rationality [10]. Bounded rationality acknowledges that in human decision-making, the rationality of individuals may be limited by the information they have, their cognitive capabilities, and the finite amount of time they have to make a decision [11]. For example, in some situations restricted time may demand fast actions and may not allow for elaborate future state prediction. In another situation a driver may fail to perceive a situation in its entireness or to process that information in order to make a correct prediction of a future traffic state.

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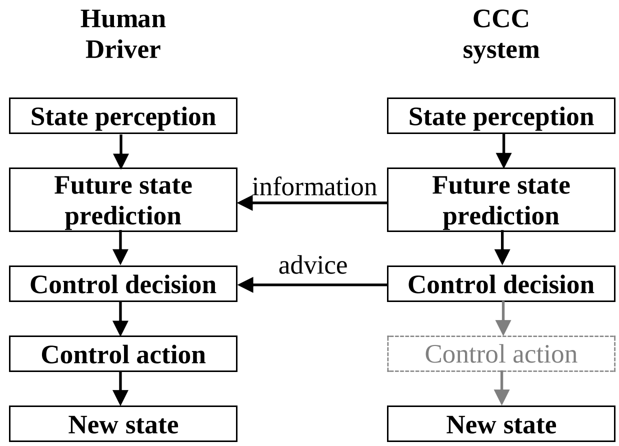

Figure 1. Schematic representation of the driving task supported by CCC (adapted from Minderhoud [9], added lines for information and advice)

Nevertheless, given an advice, drivers will rely on their own perception and comprehension of the current situation if they wish to evaluate the advice and decide on an appropriate response. The fact that CCC has access to different data sources, and differs in, processing capacity and processing speed, creates a knowledge gap between system and driver and can lead to different conclusions about the optimal behaviour in a given situation. However, the questions how drivers respond to an advice and the factors that underlie the evaluation of that advice are yet to be answered. In this study we used a think-aloud protocol to assess the cognitive reactions of drivers to CCC-advice and to gain an understanding of the factors involved in the evaluation of the advice. The obtained verbal responses will be analysed for references factors that may affect compliance.

C. *Experience and habit*

A prominent application of CCC will be to support commuting traffic during rush hours. Commuters are usually experienced with using a particular route. With that experience they may develop a set of decision shortcuts, in the form of if-then rules, to choose from an arsenal of possible behavioural responses in that situation. According to Rasmussen's framework [12] such rule based behaviour is characterized as a certain response that is chosen according to a rule that has been proven to be successful in the past. CCC may have an actual advantage in information and processing capacity, however when choosing an appropriate behavioural response, drivers may trust their experience more than they trust the advice.

D. *Perceived benefit*

Earlier support systems mainly strove to create an individual benefit for following an advice, by increasing safety or comfort or reducing individual cost (e.g. fuel). CCC belongs to a new category of driver support systems that create a beneficial effect on a collective (i.e. network) level, rather than an individual benefit for their user. It is yet unknown how beneficial the CCC advice is being perceived by individuals. And how the expected utility of an advice influences its likelihood for compliance.

II. METHOD

A. *Participants*

Thirteen participants (11 men, 2 women), aged 27 to 66 years (M: 52.9, SD: 10.8) completed the procedure. Participants had no prior experience with the system. All participants were in possession of a driver's license for at least eight years (M: 32.2, SD: 10.9) and drove at least 10.000 annual kilometres by car. All participants had experience with traffic conditions on the track (see test track). Participants received a compensation of 50 euros for their participation.

B. *Design*

A concurrent think-aloud design was used to obtain verbalisations of participants reactions at the moment that they reacted to individual advice messages. There was no independent variable. The dependent variables were the results of the content analysis performed on the driver's verbal responses to the advice.

C. *Think aloud protocol*

An elaborate measurement of the drivers initial understanding of the advice is desired. Think-aloud allows participants to verbally respond directly to a given advice, even before any behavioural actions is observed. This method is suited to give insights into cognitive processes in a natural setting [13]. The advantage of the measure in addition to a direct measure of compliance is that think-aloud provides insight into underlying cognitive processes that precede the behavioural response to a given advice.

D. *Test track*

The test track was the A20 motorway between Rotterdam Alexander and Gouda. At two locations a combination of off-ramps and on-ramps allowed for other traffic to exit or enter the motorway. In addition, a lane drop was overlapping the area of the off-ramp at one location. Fig. 2 gives an overview of the physical layout of the test track.

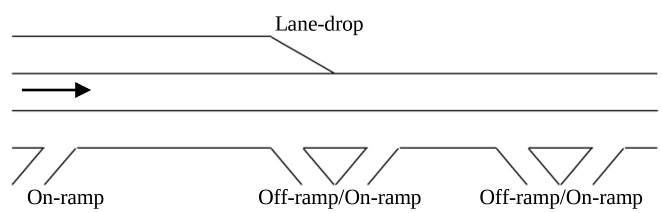

Figure 2. Physical layout of the test-track

E. *The advice*

The advice was presented in two steps. First, a motivation to the advice was presented as an icon on the in-car display (i.e. tablet PC) as well as spoken text through the external speaker of the tablet. Second, the respective advice message was presented only as spoken text.

The advice that a driver received incorporated a traffic state prediction based on current traffic loop data that was calculated on the roadside [14], as well as the current lane position of the equipped vehicle. A combinations of these variables produced an unique combination of advice messages every time the test track was travelled on. As a result not all drivers received the same advice in the same situation. Also some drivers received advice messages that others did not encounter during their experimental run. Table 1. Shows the motivations and advice messages that drivers encountered during the experiment.

TABLE I. ADVICE MESSAGES USED

Motivation icon			
Motivation text	“Attention, you are approaching the end of the traffic jam”	“Attention, chance of congestion”	“Attention, you are approaching a busy entry”
Advice text	“Keep a short but save headway”	“Go to the right lane”	1.“Adapt to the speed of the right lane” 2.“Go to the right lane”

Note. In the experiment the spoken advice messages were provided in the Dutch language.

It should be noted that these messages only denote a limited subset of possible advice messages that have been triggered by the physical layout and the traffic conditions on this particular test track.

F. *Apparatus*

For this study a Toyota Prius with automatic gear box was used as the test vehicle. The CCC human-computer interface consisted of a tablet PC (Fig. 3). Driver response was recorded using a video camera that was attached to the drivers back seat outside of the drivers field of view. Sound was recorded with a microphone that was connected to the camera.

G. *Procedure*

Experimental drives were scheduled short before evening peak traffic hours and started around 3 p.m.. Upon arrival, participants were informed about the experimental procedure and the “think-aloud” method was explained to them. Participants were asked not to try to refine their statements but to state their immediate thoughts about an advice. Participants were told that they would not necessarily have to comment on all aspects of their own driving behaviour, but rather give their impression of a given advice. Also they were informed that compliance to the advice was not compulsory. In case that participants decided not to comply to the advice, they were encouraged to state the reason that led to that decision.

After the participants had read the information and additional questions had been answered they filled out the informed consent. Subsequently, the participant and the supervisor took a seat in the instrumented test vehicle. The participant was seated in the driver seat while the supervisor took the backseat behind the passenger seat. The supervisor explained the functions of the vehicle and asked the participant to head in the direction of Rotterdam via the A20 motorway.

Figure 3. The in-vehicle system during the field trial

After a turn in Rotterdam the first session started. The supervisor turned on the camera and informed the participant that the session had started and that he/she could start with the think aloud protocol. During the recording the supervisor remained mostly silent to avoid guiding the participant in his/her response. In some cases the supervisor motivated the participant by asking questions like “What is on your mind?” or “What did you think about that advice?” in cases where the participant remained silent after an advice had been given.

Participants repeatedly drove the motorway from Rotterdam to Gouda until the end of the experiment. In 1.5 hours, every participant completed three to four runs on the test track in dense, but not congested, traffic. After every run they were given advice on how to improve the relevance of their verbal responses.

H. *Transcription of video material*

The video material was transcribed word for word. For further analysis, the transcripts were divided into blocks starting with a particular motivation and advice combination and followed by the participant’s response. For every block participant’s verbalisations were categorized into similar themes.

The emerging categories were based on the thought processes that participants engaged in after having received an advice (i.e. verification of the information provided in the advice, prediction of future traffic, intention to (not) comply). For example, utterances about the behaviour of matrix signs were placed in the category “verification of information with available information”. In other cases remarks were categorised as “verification based on experience” when participants recalled earlier experience with traffic in the situation to evaluate a given advice.

III. Results

A. *Frequency of advice messages*

During the experimental test period 61 individual advice messages were presented to participants. Table 2 breaks these down into the respective motivation and advice combinations.

TABLE II. FREQUENCY OF ADVICE MESSAGES

#	Motivation	Advice
48	End of traffic jam	Keep a short but safe headway
2	Chance of congestion	Go to the right lane
4	Dense on-ramp	Adapt to speed of the right lane
7		Go to the right lane

B. Verbalizations of Participants

Findings will be presented per motivation/advice combination. Prominent themes that emerged from verbal responses are presented per motivation/advice combination alongside a choice of verbalisation that best exemplify that theme.

1) End of traffic jam / Keep a short but safe headway

The time from the advice until the first visible sign of the end of the traffic jam varied. Sometimes there was an immediate increase in speed observable, at other times there was no visible indication that the traffic jam was about to end. A common reaction to the motivation was that participants tried to verify, whether the traffic jam actually ended in the following minutes. Therefore, participants frequently observed the behaviour of their environment (i.e. nearby vehicles as well as matrix signs and other traffic further down the road).

"Matrix signs are showing 50 km/h. Therefore I don't think that this is the end of the traffic jam. It's just slowly driving traffic."

"Matrix signs are showing 70 km/h. This would correspond with the end of a traffic jam."

"I am a bit suspicious whether I can trust that information and whether this is indeed the moment where traffic is dissolving. I might as well, all of a sudden, come to a hold. Particularly as I can see the matrix signs in the distance and they show a lower speed than what I am currently driving."

Also participants searched for verification of the end of a traffic jam by observing the development of traffic around them as well as their own speed over the minutes following the advice.

"Well, he [the system] *was right, we are driving again."*

"The advice does not correspond with my own perception. I don't have the feeling yet that the end of the traffic jam is approaching."

"I saw indeed that traffic is dissolving."

Several times participants, that were searching for signs of traffic dissolving, perceived a slowing down of traffic less than a minute after the advice.

"Look there is a traffic jam approaching again, while the system tells me that the traffic jam would dissolve."

"Look we are visibly slowing down. When you receive the information that the end of the traffic jam is approaching, then you would not expect having to reduce your speed."

"Is this the end of the traffic jam, or the beginning of the traffic jam?"

Some participants perceived the advice as an instruction to increase rather than reduce their headway.

"Yes, I think this is a good advice, I shall indeed keep more distance."

"I gladly accept the advice to keep a safe headway."

Other participants were not sure about what a "short but safe" headway actually meant.

"What is a short and safe headway?"

"But what is short and what is safe?"

2) Chance of congestion / Go to the right lane

In one of the two situations, at the time of the advice, the participant was on the middle lane, approaching the combined lane drop and off-ramp. Initially he refused to comply to the advice. For that he drew on his prior experience with the situation.

"No, not really… I find that I just have to stay on this lane. Also because I am experienced with the traffic here."

However, about half a minute later this participant actually did comply. At the time that the advice was issued the right lane appeared to be crowded with two trucks in front of the participant. After he had passed the two trucks he did change lanes immediately.

The other participant was on the left of two lanes approaching the second off-ramp. He appeared determined to follow his own prediction of a future traffic state, also drawing on his experience and concluding that under these circumstances it would make no sense to change to the right lane.

"I don't get this. Why the right lane? There is an off-ramp approaching and the right lane becomes congested regularly. If I go right it will become even more congested. Therefore, I will stay on the left lane."

Later he remarked that his non-compliance had been the correct decision as matrix signs stopped to indicate a reduced speed.

"Matrix signs are off again. So after all it was the right decision to stay on the left lane and not to follow the advice to go to the right."

3) Dense onramp / adapt speed to the right lane

In all four occasions the "adapt speed" advice triggered a lane change to the right with it. When the immediate lane change was addressed with one participant it appeared that it had been triggered by the speed adjustment.

"Yes, actually I did change immediately. It was a bit of an automatism."

Although the advice was only to adapt their speed to the right lane, other participants as well appeared to have interpreted it as a lane change advice.

"My normal behaviour would be to change as soon as I reach the traffic sign that tells me to. However now I will pass this vehicle and change to the right."

"Seems to me that this advice is a bit early, however I will follow the instruction [changes to the right]*."*

4) Dense on-ramp / Go to the right lane

Participants encountered this advice a total of seven times. However at three times, the participant had already changed to the right lane less than ten seconds earlier. Those lane changes were premature and often the result of an advice to adapt to the speed of the right lane. At one occasion the participant was already driving on the right lane for three minutes to where he had previously changed from the on-ramp. All of these times the advice was received with confusion because the advised behaviour had already been carried out.

In an occasion where the advice had been given correctly, one participant referred to his experience with the road to explain his decision not to comply to the advice.

"I won't do that. Because I know that it will all be over at the off-ramp. Therefore I stay in this lane."

And again, a participant referred to the matrix signs and the current traffic behaviour to evaluate the motivation and advice.

"The advice may be helpful. I cannot interpret it so well at this point, as traffic is still driving. But I see the matrix signs lighting up. So… well… useful advice maybe… for throughput."

One participant, driving on the left of three lanes" did not know which lane was meant in the advice "change to the right lane". Either the lane on her right or the right lane of the motorway.

"So, now I don't know if it [the system] *meant the lane all the way to the right or the middle lane."*

She complied to the advice in the right way, by changing to the adjacent lane to the right. Then she kept on observing the further development of traffic on the lane where she had changed to. As traffic on her new lane appeared to slow down, while traffic on the right lane of the motorway was still driving, she concluded that she must have complied in the wrong way.

"I think that I should have gone all the way to the right lane."

IV. Discussion

A. End of traffic jam /Keep a short but safe headway

Often participants were trying to verify the information that was provided as a motivation to the advice. This was done mainly by observing the road ahead in search of any visible signs that the prediction would indeed come true. The information that they used included matrix signs, the behaviour of traffic further down the road, as well as their own speed over the coming minutes. In sum, drivers used information that they could perceive at that time while also observing the development of traffic over time. This behaviour exemplifies the difference of available information between the system and the driver. While the system makes predictions about traffic development based on loop data and traffic modelling, drivers searched for indicators about the correctness of the received information by observing their current environment. In the experiment this led to situations where participants mistrusted the system when they themselves could not see the end of a traffic jam.

Complying to the advice oftentimes meant putting trust in the systems predictions. In this light the cases of a "short headway" advice, where participants had to brake again due to another shockwave or traffic jam, will inhibit the formation of trust in the information given by the system. Mistrust bears negative implications for the behavioural compliance with the advice. One participant expressed this thought very clearly by remarking that the information and advice are not beneficial if he still has to constantly keep his attention on the traffic to see whether the congestion actually dissolves or not.

B. Chance of congestion / Go to the right lane

These two situations exemplify how drivers experience can negatively influence compliance. In both cases the advice triggers an active subjective evaluation of the situation by the driver. And in both cases the advice was incongruent with the drivers opinion about what might be considered the best behaviour in that certain situation. Non-compliance with incongruent advice may become more likely and frequent the more experience drivers have with a route (i.e. commuting traffic).

In one example we can see this very well: the participant does not comply and keeps observing the outcome of his decision. As he perceives the situation evolving the way he had predicted, he sees it as a confirmation that his non-compliance was indeed the right choice. Also these situations hint at drivers expectations of the individual benefit that they expect to gain from following CCC advice. In situations where the system does not advise a manoeuvre, that drivers think is beneficial for them, they are less willing to comply.

In the other example the participant complies later. It appears that his refusal to comply immediately was because he was searching for a more opportune moment to do so. Therefore we may need to distinguish between two outcome evaluations. A long term and a short term. The former is concerned with the final benefit of following the advice, while the latter is about the most opportune timing of compliance.

C. Dense on-ramp / Adapt to speed of the right lane

Reactions to this advice show that even when a certain behaviour is advised, sometimes the resulting behaviour can turn out differently. An explanation may be that in most cases drivers on the left lane, who, due to an advice adapt their speed to the middle lane, will have to slow down. However, while they remain on the left lane they would cause irritation among the other drivers behind them on that lane. This causes the lane change to the right.

A similar explanation may be that drivers are used to adapt their speed in order to change lanes. Therefore a rule may be followed, either consciously or unconsciously, that after adapting your speed to an adjacent lane you change to that lane. This would be more in accordance with the comments of participants who regarded the speed advice as a lane change advice.

D. Dense on-ramp / Go to the right lane

The low compliance (i.e. two out of seven) to the advice was due to the fact that that in three situations the participant had already carried out a lane change, to the right lane, short before the advice had been given. This shows how fast situations can change in traffic. An advice can be outdated at the time that it is given. Also the "adapt speed to the right lane" advice that sometimes preceded the "go to the right lane" advice played a certain role by triggering an early lane change.

Again the advice contradicted one participant's own opinion about how to best approach the situation, leading to non-compliance. In two other situations where a lane change was easily possible and participants had no incongruent opinions, compliance was the case, despite occasional uncertainty which lane was meant with "the right lane". Again the situation was monitored after the advice had been complied to. And again the evaluation of the advice was determined by the beneficial effect that compliance had for the participant. A participant assumed that she misunderstood the advice as it did not improve her situation.

E. General discussion

There are several reoccurring themes in the participants response to the advice. After having received information as a motivation participants found themselves guessing over its credibility. However, the credibility of the information was not always verifiable from the information that participants were able to perceive at that moment, especially with information about the imminent end of a traffic jam. Usually over time, cues were found in the behaviour of other traffic or matrix signs that would deem the information useful or not. It can be argued that providing more information about the situation would further reduce the knowledge gap an may lead to more trust in the advice. However it appears that a correct prediction of a future traffic state by the system may be a more promising alternative to enhance the built-up of trust in the system over time.

The participants in the experiment had experience with the test track. This led to situations where the advice was incongruent with what participants considered the optimal behaviour in these situations. It also became clear that participants definition of an optimal advice were often different from that of the system. For participants in the experiment this optimal behaviour usually meant the most beneficial behaviour for them.

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