# EARLY USER PARTICIPATION IN THE IDENTIFICATION OF USE CASE SCENARIOS FOR "CONNECTED CRUISE CONTROL"

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## ABSTRACT

Connected Cruise Control (CCC) aims to improve throughput in dense commuter traffic on motorways by advising drivers on speed, headway and lane-use via a nomadic human-machine interface. The advice is generated from a prediction of future traffic flow, based on actual traffic-loop data and is transmitted to the in-car platform via 3.5G communication. The systems advantage compared to Cooperative Adaptive Cruise Control (CACC) lies in its potential for rapid implementation and its additional support of lateral driver behaviour. It is important to note that CCC will not have direct control over the car movement. Its beneficial effect is dependent on the driver's willingness to comply with the advice. In turn, willingness to comply, in the long term, is also dependent on the perceived benefit of using the system. It is assumed, that to increase both the driver's initial willingness to comply and the perceived benefit of using the system, CCC has to reduce the frequency of situations that are seen as most unpleasant by drivers during peak hour traffic. Therefore it is important to understand what these situations are. This study determines the level of frustration caused by driver behaviour in dense motorway traffic, at a lane drop and at an on-ramp/off-ramp. The results help to identify use cases scenarios for driving simulator experiments to ensure that CCC can have a beneficial effect in these situations.

## KEYWORDS

Advanced driver assistance systems, ADAS, longitudinal support, lateral support, perceived benefit, problem awareness, use case scenario, Connected Cruise Control

# INTRODUCTION

With rising numbers of vehicles, demand on the motorways in the Netherlands is expected to rise. Especially in rush hours this translates to an increase in traffic density and a decrease in the average space between vehicles. Under such conditions traffic can become congested even without bottlenecks, such as accidents and road maintenance. Studies suggest that human behaviour contributes to congestion by causing shockwaves through the disturbance of traffic flow and by facilitating the spreading of shockwaves backwards through the traffic stream (1). Several forms of driver behaviour can be fitted into one of the two categories above. For example, drivers in nearly stationary traffic tend to change lanes more often under the wrong assumption that the other lane is progressing at a faster pace (2). This leads to traffic disruptions caused by the braking manoeuvres of vehicles in the dense traffic stream. Another example is a driver's inability to avoid small variations in relative speed and following distance that can cause fluctuations in traffic flow (3, 4). These build up in following traffic and often result in "stop and go" traffic. From an external perspective, the result of strong braking manoeuvres in dense traffic, or stop-and-go movements become visible as a wave pattern proceeding backwards through the traffic stream. Drivers are able to monitor and respond to the state of traffic in close proximity. However, in the case of upcoming shockwaves they often fail to initiate effective countermeasures. Cooperative autonomous driver support systems (e.g. Cooperative Adaptive Cruise Control) show the potential to smoothen traffic flow in nearly congested traffic. The underlying concept is to provide vehicles further up the traffic stream with downstream traffic flow information via vehicle-to-vehicle and vehicle-to-infrastructure communication. Based on this information, vehicles will be able to respond more quickly to traffic changes in their close proximity *and* to anticipate the behaviour of downstream traffic and respond accordingly. However, the market introduction of cooperative longitudinal driver support can be expected to progress slowly for technical and safety reasons. Their deep integration into cars' functionality will make it costly and labour-intensive to build them into existing cars. Furthermore, despite the claimed benefits of improved driver comfort and traffic stability, a closer look at autonomous driver support can reveal that such systems significantly change the nature of the driving task. This can result in dangerous situations as drivers adapt to their new role in the task. For example, in response to higher levels of automation drivers are "out of the control loop" because their task changes from actively operating to passively monitoring the vehicle (5). Associated with this phenomenon are different human factors problems such as loss of situational awareness, too high or too low a workload, and the possible loss of skills (6, 7). In the case of system failures, the passive monitor suddenly needs to become an active driver again, requiring a rapid response to a potentially dangerous event. It such situations, the possibility of human error will increase (8). Although the partial liberation of the driver from the driving task aims to solve problems, it can introduce others, stemming from new forms of driver-system interaction. Unfortunately these often become visible only after these systems have been introduced in the market.

The Connected Cruise Control (CCC) project is a HTAS financed research endeavour that explores the opportunities for providing traffic state information and supporting driver decision-making in order to improve the flow of congested traffic on motorways. One function of the system is to reduce string instabilities by promoting a constant speed and headway in bunching. In addition to longitudinal support, CCC may also advise the use of a certain driving lane. The advice given is based on traffic models that predict future traffic states based on loop data describing current traffic. Therefore, it extends drivers ability to anticipate traffic states several kilometres in front of them and supports their ability to react in accordance with advised changes in driving behaviour. CCC can have a beneficial effect on driver behaviour in several traffic situations by that reducing traffic disturbance and achieve a smoother traffic flow. For example, longitudinal advice can support car following on a motorway while lateral advice can achieve better distribution of cars at lane drops or motorway entries and exits. However in the development process the system has to be tested and evaluated for effectiveness in several use case scenarios. The beneficial effect of CCC in these scenarios can then be regarded as a proof of concept. Due to the range of possible applications the designers have to choose the most prominent ones to show that the system is effective. Several criteria can help the designers of CCC to choose the most adequate scenarios where the systems functionality should be tested. The following determination criteria have been identified:

1. *Frequency* - Choosing use case scenarios occurring in more frequently appearing traffic situations.
2. *Congestion potential* – Choosing use cases based on traffic situations that show a greater potential for traffic breakdown in dense traffic.
3. *Potential effectiveness* – Choice based on the expected beneficial effect that CCC can have in the traffic situations, based on traffic modelling.
4. *Efficiency* - The amount and frequency of driver advice that is needed to achieve a beneficial effect in these traffic situations
5. *Problem awareness* - The awareness of drivers that driving behaviour in these situations needs to be improved.

Although the fifth point may seem less relevant from a technical perspective, it gains importance in the development process of Connected Cruise Control, where acceptance of a given advice is essential for the systems beneficial effect. According to Vlassenroot (9) the user’s perception of the problem is a contributing factor to acceptability. Numerous other studies have shown that a high level of problem awareness can lead to increased willingness to accept solutions for the perceived problems (see for example (10, 11)). In the case of CCC, situations where the system can improve driving behaviour with high awareness levels should be chosen as use cases This could raise its perceived usefulness and may therefore affect the desire to use it.

Ideally, situations in which drivers perceive their own behaviour as problematic should guide the choice of CCC application. However, several studies have shown that a driver’s perception of his/her own driving behaviour tends to be biased towards a positive evaluation (12, 13). This tendency can lead to a less problematic evaluation of a situation than it would be perceived from an outside observer. Instead, asking for the level of irritation that drivers experience with certain situations can indicate problematic road environments while eliminating the self-report bias among respondents.

Therefore, a survey has been developed that asks drivers to give a rating of their subjective irritation with a given range of driver behaviours which can occur in one of three traffic situations: (1.) dense traffic on a motorway, (2.) a lane drop from 3 to 2 lanes and (3.) an on-ramp, off-ramp or a combination of the two. The results of this survey give valuable insight into the driver's perspective of the relevance of problematic driver behaviours. For CCC these results can indicate behaviours that the system should be able to reduce to be perceived as useful. Therefore these results can be valuable when choosing use case scenarios to test, evaluate and improve the actual effectiveness of CCC.

# METHOD

## PARTICIPANTS

Participants had to meet a number of criteria to take part in the survey. This was to ensure that the survey population resembles the anticipated target population for which CCC is being developed. Because the system is intended to be used by daily commuter traffic a certain degree of travel experience was required for participation. It was not important that participants were in possession of a car as long as they were driving an annual mileage of at least 10.000 kilometres. In the survey it was specifically asked for a drivers experience with situations in dense commuter traffic on a motorway. Therefore it was important that a certain amount of the kilometres was being driven on motorway at rush hours.

## SURVEY DESIGN

In three traffic situations that lend themselves for possible use case scenarios (i.e. dense traffic on a regular road, lane-drop and on-ramp/off-ramp), driver behaviour has been identified that can cause frustration among other road users. Unwanted driving behaviours were chosen that could be reduced through adequate speed, headway or lane advice. Table 1 gives an overview of the driver behaviours that had to be rated by participants completing the survey. The Dutch law enforcement (Koprs Landelijke Politie Diensten) has a tradition of assembling and publishing an annual top ten list of annoyances in traffic. This collection does not only look at particular driving behaviours but also at other problematic behaviours such as drunken driving and the tendency for aggressive driving. The top ten lists of 2010 and 2009 where used as an inspiration to develop examples of inappropriate driver behaviours for this survey.

Two links to the web-survey were published. One on the website of the Royal Dutch Touring Club ANWB (www.anwb.nl), another one on a Dutch, traffic related web forum (www.wegenforum.nl). After an introduction and the collection of general information, participants were presented the examples of unwanted driving behaviour. For every example, participants were asked to rate the level of irritation they generally experience when encountering the situations on the road. Their reaction was measured on a 5-point Likert-scale, while 'one' meant "Not irritating" and 'five' meant "Very irritating".

**Table 1.** Examples of inappropriate driving behaviour in three traffic situations.

| Traffic situation | Driving behaviour | |
|---|---|---|
| **Dense traffic** | **Example 1** | Other road users not adhering to the current speed limit. |
| | **Example 2** | Other road users changing lanes in congestion under the assumption that the other lane is progressing at a faster pace. |
| | **Example 3** | Getting stuck behind a truck on the right lane because other traffic is making no space to re-enter the left lane. |
| | **Example 4** | Other road users in front of you that leave too much space in front of them, thereby giving other driver's the chance to enter the lane which slows down the whole traffic on that lane. |
| | **Example 5** | Other road users that keep driving on the left most lane making it impossible to pass them. |
| | **Example 6** | Tailgating of the car behind me |
| | **Example 7** | Driving in shockwaves, requiring you to decelerate from 100 km/h to 60 km/h then accelerate back to 100 km/h only to decelerate again seemingly without any reason. |
| **Lane-drop (3 to 2 lanes)** | **Example 8** | Late mergers on a lane drop in dense traffic. |
| | **Example 9** | Other road users that make no room on the middle lane as you try to merge from the right lane. |
| | **Example 10** | Other road users that make room for two or more late mergers in dense traffic. |
| | **Example 11** | Other road users that brake hard to make room for a merger. |
| **On-ramp / Off-ramp** | **Example 12** | Other road users that make no room as you try to enter the motorway. |
| | **Example 13** | No possibility to switch to the left lane and give room to vehicles entering the motorway. |
| | **Example 14** | Other road users that change lane to the middle lane and occupy the room that I have made for vehicles entering the motorway. |
| | **Example 15** | Other road users that initially change to the most left lane after entering the motorway. |
| | **Example 16** | Other road users that change several lanes at once to take an off-ramp. |
| | **Example 17** | Other road users that enter the motorway at a low speed causing traffic on the right lane to slow down. |

# RESULTS

A total of 371 responses were received for the survey, of which 237 (64 percent) were complete and used for further analysis. Of the participants 24 percent were female, furthermore 39 percent were between 25 and 39 years and 53 percent between 40 and 64 years old. Table 2 gives an overview of the mean irritation that participants experienced in one of the three road environments. Recall that one means “Not irritating” and five “Very irritating”.

**Table 2.** Level of irritation in traffic situations

| | Dense traffic | Lane drop | On/Off-ramp |
|---|---|---|---|
| Mean | 3.6 | 3.3 | 3.5 |
| SD | 0.5 | 0.6 | 0.5 |

The results show only minor differences of mean irritation between traffic situations. A detailed representation of irritation caused by certain behaviours is shown in figure 1.

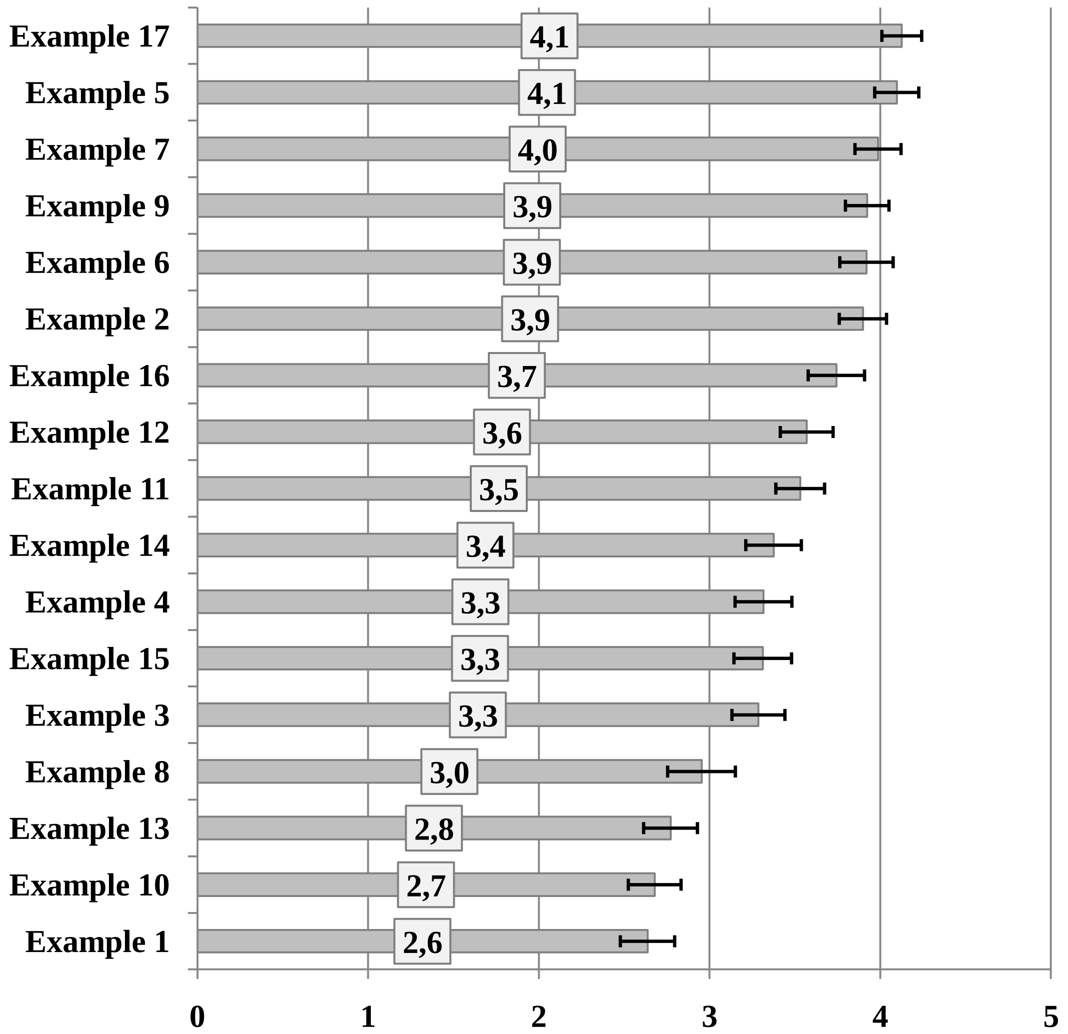


**Figure 1.** Mean irritation ratings per example, sorted in descending order with 95% confidence intervals.

As can be seen from this figure all statements cause at least a medium degree of irritation. The irritation level of the top six behaviours lies on or above the 3rd quartile which cuts off the highest 25 percent of the data. The causes of irritation among these six behaviours concern examples of lane use or lane change behaviour (Statement 2, 5 and 7), headway adjustment (Statement 6 and 9) and also speed adjustment (Statement 17).

# DISCUSSION AND CONCLUSION

As proposed earlier the road user's awareness of the problem is a contributing factor in his evaluation of the usefulness of a solution. Therefore, problem awareness should be incorporated in the choice of use case scenarios to test and improve the systems performance. It has been argued that subjective irritation with certain driver behaviours can act as an indicator of problem awareness in different road environments. The presented survey provides a means to evaluate the level of irritation caused by driver behaviours in three possible traffic situations in which CCC can be applied. In use case scenarios CCC should be able to reduce these behaviours to be perceived as more useful. In general, the driver behaviour patterns that have been deemed highly undesirable can provide ADAS developers with directions to develop solutions that have a higher chance of being perceived as desirable by road users.

The survey results indicate that the three road environments (regular motorway with dense traffic, lane-drop and on-ramp/off-ramp) cause equal levels of mean frustration with the studied participants. Therefore the data gives no indication to focus on a particular environment when developing use case scenarios. However within a particular environment not every behaviour example evoked the same level of irritation. Among the six most irritating behaviours three were related to lane use or lane change behaviour, two were related to headway and one was related to speed behaviour. This distribution lends support to the design choice that was made with CCC to support lateral behaviour in addition to purely longitudinal behaviour. Focussing on specific behaviours it can be identified what advice the system should give on order to improve the situation. For example CCC could give drivers entering the motorway (Example 17) the advice to adapt the speed of the cars on the right lane to facilitate the merging and reduce the necessity for braking manoeuvres by cars on the right lane, which could lead to traffic disturbance and shockwaves.

Finally, subjective irritation among drivers can be a valuable indicator, which problems should have priority in the development driver support systems. However, aiming to reduce driving behaviours, which lead to high levels of irritation, does not on its own result in instant acceptance of a solution. Road users may still view the developed solution as targeting the wrong cause. This reverts back to the issue of the self report bias. In the example of CCC road users have to adapt their own behaviour to produce an overall beneficial effect, although they might feel that others and not their own behaviour is the cause of the problem. Therefore targeting a highly irritating behaviour alone may not be a guaranty for user acceptance. It is rather an indication, that a system, aimed to reduce the frequency of this behaviour may be perceived as more useful compared to a system targeting a different behaviour that causes lower levels of irritation.

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# REFERENCES

(1) Sugiyama, Y., Fukui, M., Kikuchi, M., Hasebe, K., Nakayama, A., Nishinari, K. et al. (2008). Traffic jams without bottlenecks—experimental evidence for the physical mechanism of the formation of a jam. *New Journal of Physics*, 10(3), 033001.

(2) Redelmeier, D. A., & Tibshirani, R. J. (2000). Are those other drivers really going faster? *Chance*, *13*(3), 8–14.

(3) Kim, T., Lovell, D., & Park, Y. (2007). Empirical analysis of underlying mechanisms and variability in car-following behavior. *Transportation Research Record: Journal of the Transportation Research Board, 19*(1), 170–179.

(4) Brackstone, M., Waterson, B., & McDonald, M. (2009). Determinants of following headway in congested traffic. *Transportation Research Part F: Traffic Psychology and Behaviour*, *12*(2), 131–142.

(5) Bainbridge, L. (1983). Ironies of Automation. *Automatica, 19,* 775-779.

(6) Endsley, M. R. (1995). Towards a theory of situation awareness in dynamic systems. *Human Factors*, *37,* 32-64.

(7) Stanton, N. A., & Young, M. S. (1998). Vehicle automation and driving performance. *Ergonomics*, *41*(7), 1014-1028.

(8) Moray, N. (1986). Monitoring Behavior and Supervisory Control. *Handbook of Perception and Human Performance, Vol. II, Cognitive Processes and Performance*, Boff, K. R. Kaufman, L. & Thomas J. P., Eds., Wiley, New York, 40.1–40.51.

(9) Vlassenroot, S., Brookhuis, K. A., Marchau, V., & Witlox, F. (2010). Towards defining a unified concept for the acceptability of Intelligent Transport Systems (ITS): A conceptual analysis based on the case of Intelligent Speed Adaptation (ISA). *Transportation Research Part F: Traffic Psychology and Behaviour*, *13*(3), 164-178.

(10) Eriksson, L., Garvill, J., & Nordlund, A. M. (2006). Acceptability of travel demand management measures: The importance of problem awareness, personal norm, freedom, and fairness. Journal of Environmental Psychology, 26(1), 15–26.

(11) Molin, E. J. E., & Brookhuis, K. A. (2007). Modelling acceptability of the intelligent speed adapter. Transportation Research Part F: Traffic Psychology and Behaviour, 10(2), 99–108.

(12) Lajunen, T., & Summala, H. (2003). Can we trust self-reports of driving? Effects of impression management on driver behaviour questionnaire responses. *Transportation Research Part F: Traffic Psychology and Behaviour*, *6*(2), 97-107.

(13) McKenna, F. P., Stanier, R. A., & Lewis, C. (1991). Factors underlying illusory self-assessment of driving skill in males and females. *Accident Analysis & Prevention*, *23*(1), 45-52.