Improving traffic flow on motorways through individual driver advice: A social dilemma?

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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. The advice that drivers receive does not always work in their individual benefit. However, collective action by a greater amount of CCC users can improve the traffic situation as a whole, resulting in reduced overall travel time. Therefore CCC runs the risk of creating a social dilemma (a give-some dilemma); A situation where individual road users contribute to a common good (that is traffic flow) while refraining from actions that would work in their individual benefit, but that on the other hand could pose a harm to traffic flow. We present the social dilemma underlying the adoption of CCC and discuss solutions to the dilemma.

Keywords

Connected cruise control, driver support system, traffic flow, social dilemma, cost/benefit analysis

1 Introduction

In the past decade innovation in driver support systems has focussed increasingly on the improvement of throughput and traffic flow. Rather than re-routing traffic to less congested routes, these system aim to improve the distribution and the behaviour of vehicles on a given road. A semi-automatic example of such a system is an adaptive cruise control that uses vehicle-to-vehicle communication to improve string stability are (Flemisch et al. 2008; van den Broek, Ploeg & Netten, 2011; Ploeg, Serrarens & Heijenk, 2011). However, further down on the automation spectrum, systems offer support to drivers who want to improve their driving behaviour while remaining in total control of the vehicle. These systems provide information or advice about the appropriate driving behaviour (van den Broek, Netten, Hoedenmaeker & Ploeg, 2010; Happee et al., 2011;). An example of such a driver-in-the-loop system, currently under development in a HTAS project, is Connected Cruise Control (Klunder, Jonkers & Schakel, 2011; Van Koningsbruggen, Daalderop & Nootenboom, 2011; Martens, Risto & Wilschut, 2011).

Connected Cruise Control (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. Drivers will 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 as well as the desired route.

As stated above, CCC will not take over vehicle control. While this approach has certain advantages (such as less issues with liability in case of system failure, faster market penetration) it also makes the effectiveness of the system dependent on the drivers ability and willingness to comply with the given advice. In the present paper we focus on potential challenges regarding drivers acceptance of and compliance with the system. For that we assume that the acceptability of CCC, from the viewpoint of the user, depends on a perceived balance of, on one side, the factors that can be considered the “cost” of using the system and, on the other side, the beneficial effect that the system creates.

2 The cost of using CCC

Interaction with CCC, requires that drivers receive, process and act on the advice given through an in-car system. This interaction can be perceived as tiring, annoying, compulsory or in other ways reducing a drivers perceived comfort or safety and may therefore be considered a cost of using the system. The following are examples of how the cost of using CCC can present itself to drivers.

2.1 Conscious execution of automated tasks

According to Rasmussen’s framework (1999) driver behaviour can be categorized as knowledge based, rule based and skill based behaviour. The more skill based a behaviour is the less mental processing is involved in exerting that behaviour. With more driving experience behaviours that are involved in vehicle control and manoeuvring become increasingly skill based and with that increasingly automated (Fitts and Posner, 1967). For experienced drivers, behaviours such as keeping ones preferred headway or adjusting ones speed while merging into an adjacent driving lane may be considered skill based. However, when drivers are asked to adjust their headway to a certain distance or adapt their speed to a certain value before changing lanes, these previously automated tasks again require more conscious processing. Although, the conscious execution of previously automated behaviours does not have to be a threat to driver safety, drivers may still perceive it as an additional effort when using the system.

2.2 Interruption of secondary activities

Following a discussion of the human factors issues related to CCC (Risto, Martens & Wilschut, 2010), it decided that the advice will be presented primarily in the form of spoken messages, supported by visual cues. This form of presentation minimizes the additional visual load in an already heavily vision based task. While this is a preferred solution in terms of driver safety, frequent auditory advice messages may reduce driver comfort. The advice can be perceived as disturbing other activities such as the listening to music, radio or having a conversation. Therefore, the required, prolonged interaction with the advisory system may be perceived as another cost of using CCC.

2.3 Requests for unpopular behaviours

There can be several reasons why an advised behaviour has a low popularity among drivers. One reason is that it puts the driver in an undesired position for an extended amount of time. Examples might be an advice to drive on the right most lane where a lot of trucks drive at lower speed. Or to leave room for merging vehicles. During an experiment with a preliminary system these advices have been perceived as disadvantageous by test drivers (Risto & Martens, 2012).

Another reason for an unpopular advice is one that requires a driver to act against a social norm. The norms of the society, expressed in the perceived expectations of others play an important role in behavioural theories (Ajzen & Fishbein, 1980). Hoedemaeker (1999) identified compliance to a social norm as a fundamental driver need. Vlassenroot (2010) also considered social norm as a factor influencing acceptability. The manifestation of a social norm is context dependent. In traffic a social norm can express itself in the form of a common behaviour that is followed by the majority of road users such as a certain speed at which all vehicles on a lane are driving. Regardless of this speed being above or under the official speed limit. In traffic theory it has been proposed that, as traffic becomes more dense, the behaviour of a vehicle is determined increasingly by the behaviour of other vehicles (Ranney, 1999). A vehicle that deviates from the norm may be punished by others drivers around him for disrupting the traffic flow, even, or just because he is the only one driving at the official speed limit.

2.4 Reduced autonomy and perceived dependence on the system

To extend the time a which traffic is flowing on a nearly congested road, CCC optimizes the distribution and behaviour of vehicles currently on that road. The system models the development of traffic using up-to-date traffic loop and flowing car data to make predictions about the state of traffic in the near future. If a bottleneck is identified in this predictions, an algorithm determines the optimal behaviour for CCC equipped vehicles.

The systems “perceptual horizon” and as a result the available bulk of situational information greatly exceed that of the driver. Yet, even if drivers were able to

perceive all the information they would still lack the knowledge and processing capacity to make the sort of predictions that the system produces.
The systems superior situation awareness and processing capacity are eventually used to produce a beneficial effect on traffic flow. However, the inequality of knowledge and insight can make it difficult for the driver to understand the motivation behind any given advice and may lower the acceptance of the advice and the system as a whole.
The advice is based on various factors that remain outside the grasp of drivers, such as the current state of traffic, the predicted state and the way groups of CCC equipped vehicles are assigned one of two mutually supporting advice messages. Advice message may change due to small variations in one of these factors. As a result drivers will not receive the same advice in similar situations and will not be able to predict the advice that they receive in a given situation. The implications are that the driver has to put himself in a constant dependency to what he perceives as a “black box” in order to exert the required behaviour.
Still drivers have their own opinions on the optimal behaviour in situations that are familiar to them. With experienced they develop a set of if-them rules to choose from an arsenal of possible behavioural responses in that situation. According to Rasmussen’s framework (1983) such rule based behaviour is characterized as a certain response that is chosen more or less conscious according to a rule that has been proven to be successful in the past. CCC advice might challenge these evolved set of rules, while promoting a different behaviour in a situation familiar to the driver. When an advice is incongruent with the drivers preferred behaviour in that situation, the driver will be less likely to comply with it. There are less severe cases of incongruence. When the system gives an advice in a given situation for which the driver does not have a preferred behaviour, he may be more open for the advice. In turn, the driver may have a preferred behaviour that is not challenged by the system. Still in this case, a driver may experience uncertainty whether or not to perform a certain rule based manoeuvre if it has not been advised by the system.
With CCC a “second opinion” is introduced into the decision making process of drivers. Although the systems messages should be seen as a mere advice, for CCC to be effective, the driver is required to follow them closely. The system may therefore be seen as challenging a drivers autonomy. Drivers may not be willing to give up part of their autonomy without the confidence that using the system will, in turn, bring them closer towards their driving goals.

3 The benefit of using CCC

There are several aspects of the user-system interaction that can be considered a “cost” of using the system to create the benefit that CCC aims to provide. That is, to improve (or not to further disrupt) the flow of traffic that is near congestion. Whether or not the system will have any effect depends on the percentage of vehicles on the road that is equipped with CCC (i.e. its penetration rate) and further the number of advice messages that are actually followed (i.e. its compliance rate).
A survey amongst Dutch drivers indicated that an observable beneficial effect would be the foremost incentive for driver to use CCC and to comply with the given advice (Risto & Martens, 2011). However, the way in which an act of compliance with the system manifests itself in traffic might not appeal to drivers who hope to gain an individual benefit from using the system.

In motorway traffic, the outcome of certain driving manoeuvres, does only marginally affect the driver who exerted them, while having a strong effect on the traffic stream behind him. Therefore each driver is exposed to the effect of the collective action of the drivers in front of him. Already in 1971 Schelling articulated, how this applies to inconsiderate behaviours that may harm the flow of traffic, by stating: “Unorganized, they [the drivers] are at the mercy of a decentralized accounting system according to which no […] driver suffers the losses that he imposes on the people behind him” (p.66). The same mechanics also apply to efforts to improve traffic flow. It can be questioned, whether the beneficial effect that is created by an individual driver will, in any way, pay itself back to the same driver. A driver complying to CCC advice may find himself not creating an individual benefit for himself, but rather reducing the chance that traffic behind him will suffer from traffic flow breakdown. Each individual driver who is using the system is therefore working to produce a common good (i.e. improved traffic flow), that is shared by a group that he does not belong to. These drivers are dependent on their fellow driver in front of them, their ability and willingness to follow CCC advice, in order to benefit themselves.

4 A social dilemma

The situation described above shares great similarities with that of a social dilemma (Dawes, 1980, Kollock, 1998). Every driver would benefit the most when every other driver would cooperate by obtaining and using CCC. However, individually a driver may not gain from using the system and may be better off not using the system.

The situation fits the description of a public good or give some dilemma. The public good can be characterized as a resource that is shared between all members of a group regardless of whether or not they contribute to the preservation of that good. Other examples of public goods are clean air, road infrastructure or law enforcement. In the same way flowing traffic on a dense motorway can be characterized as a public good that may be sustained as well as depleted by individual actors.

An common phenomenon in social dilemma situations is free-riding. Free-riders voluntarily or involuntarily benefit from the availability of a public good without contributing to it. In theory the effectiveness of CCC and with that the collective benefit for all road users increases, at high penetration rates. But even then every driver would be tempted to free-ride, eluding the cost of using the system while still benefiting from the efforts of his fellow road users.

A factor that has been shown to increase the likelihood to free-ride is group size (Komorita & Lapworth, 1982; Fox & Guyer, 1977). Therefore, the large population of road users facilitate free-riding. Not only does the individuals contribution have a lower perceived impact, increasing group size may spread the harm caused by free-riding, and makes it easier to free-ride anonymously (Dawes, 1980).

Even if drivers have no intention to free ride, they may fear that the penetration or compliance rate is not sufficient to actually cause a visible improvement in traffic flow. So to avoid having the cost of using CCC without benefiting from it (in game theoretic terms this constitutes as being the sucker) drivers may choose not to use CCC altogether. In a survey among Dutch automobile drivers the fear of being a sucker was reflected by a high number of drivers requesting that the system should be mandatory, and therefore used by all road users, as a precondition for using it themselves (Risto & Martens, 2011).

5 Solutions to the dilemma

In the context of CCC we will now discuss the feasibility of solution strategies that have proven successful with social dilemmas in the past.

Kollock (1998) divided solutions to social dilemmas into three categories. Motivational solutions assume that not all actors in the dilemma behave egoistic, considering their own as well as on others benefit. Drivers with such a pro-social motivation might value the collective benefit as important as their individual one. Therefore they might be willing to contribute towards a solution from that all road users would benefit, even in the absent of an individual benefit.

Another motivational solution, assuming a pro-social attitude in actors, would be to promote group identity among road users to increase cooperation due to in-group altruism. For example, group identity profoundly increased likelihood of cooperation within a group of participants showing higher levels of personal restraint in a commons dilemma (Brewer & Kramer, 1986).

However, group identity may be difficult to establish in traffic where individual drivers usually do not know or share a bond with one another, other than being on the same road at the same time. In traffic interactions between individuals are short timed and unlikely to be repeated in the future and if they occur there is usually no record of past interactions. This anonymity has shown to lower the rate of cooperation in a social dilemma situations (Fox & Guyer, 1978; Jerdee & Rosen, 1974).

In this situation drivers can be expected to behave selfishly because they do not feel accountable for their individual actions (Kollock, 1998). In their cars drivers are shielded (physically as well as mentally) from their environment knowing that no one else except themselves will know whether the complied to a given advice or even uses the system at all. This feeling of unaccountability may be further amplified by the highly complex and dynamic nature of traffic that makes is almost impossible to backtrack a certain outcome to the single action of an individual driver. Rather than encouraging compliance with CCC it seems that the nature off traffic makes is more likely that driver act towards their individual benefit.

Strategic solutions to the social dilemma assume egoistic actors who value the individual benefit higher than a collective benefit. The principle of reciprocity has shown promising results in iterative social dilemma situations (for a famous example see Axelrod, (1984)). However, Kollock (1998) also states that reciprocity as a strategic solution is often limited to iterative two-person dilemmas; where a player can recall the outcome of the other players actions in previous rounds and is able to retaliate immediately in case of uncooperative behaviour.

Whereas, the short-lived nature of interactions in traffic eliminates reciprocity as a more strategic solution to encourage cooperation in a social dilemma. While, drivers are dependent on each other to receive a benefit from the collective use of the system, there is no guarantee that a driver whose compliance has reduced the likelihood of traffic flow breakdown for others will be rewarded by the same drivers in the near future.

Finally, structural solutions assume that the structure of the dilemma can be changed to reduce its dilemma character. That means either to reduce the perceived cost of using the system or increase the perceived individual benefit from using the system.

5.1 Reducing the cost of using CCC

The possible spectrum of advice messages is wide. The dimensions include among others the form (i.e. audio/visual/haptic), frequency, timing, formulation, and specificity of target values in particular can make a difference in how much effort is perceived by the driver when following a given advice.

As stated earlier the advice will have the form of spoken text supported by visual cues on the in-car display. While a higher frequency of advice messages would make the system more responsive to sudden changes of the traffic situation. The advice frequency will be restricted to a maximum of one advice per minute. This represents a trade-off between the effectiveness of the advice and the comfort of the driver. Advice messages need to be given in a way so they will not lose their validity for the duration of at least a minute or until the advice is carried out.

Also to reduce the perceive effort when carrying out advice, the messages will be given further ahead of a particular bottleneck, to give the driver enough time to carry out the advice. The message has the function to prepare the driver in anticipation of an upcoming bottleneck ahead. Less advice given at an early stage means that the driver has more time to integrate the execution of advice into his regular driving behaviour while not forcing him to carry out a particular manoeuvre in a short amount of time.

Avoiding specific values for speed or headway reduces effort involved constantly monitoring (in case of speed) or estimating (in case of headway) these values. In situation where drivers are required to make room for merging vehicles this is not formulated in a certain distance or time headway but rather as the request to leave room. In case of a lane change were drivers are advised to adapt their speed tot the speed of the vehicles on the target lane it is stated just like that rather than a target speed value. This communication strategy is chosen to leave intact the automated processes that drivers already employ to carry to these tasks. Not forcing them to engage in constant monitoring or estimating of specific values.

Other possibilities would be the partly automation of certain behaviours that are currently advised by the system. In that case the system could be implemented to communicate with driver support systems already in place such as cruise control or adaptive cruise control. Creating synergy effects between the systems may create a sense of comfort while reducing frequency and length of necessary advice messages.

If at all, behaviours that go against a social norm should be advised with great care. Not only may these have a lower compliance rate, some advice may actually work against the improvement of traffic flow when carried out by a minority. The effectiveness of these advice messages may be dependent on the penetration rate of the system on a certain part of the road.

In cases where an unpopular behaviour has to be carried out the system may limit the duration and indicate the remaining time that the behaviour has to be maintained. A driver that has to remain on the right lane to reduce the density on the left lane will be unsure how long he has to stay there and in the worst case will attempt to change to the left lane earlier that required.

It was argued that a feeling of reduced autonomy stems from incongruence between the advised behaviour and the drivers preferred behaviour, in combined with the knowledge that the systems advice has to be complied with in order to achieve the designated benefit.

A possible solution to reduce frequency of incongruent behaviours can be to provide the driver with a motivation for why he receives a certain advice in order to reduce the knowledge gap between the system and the driver. Lowering the alienation from receiving an advice that may not make sense in the situation that the driver is in at that time. Providing the driver with the information that is also use to create an advice may increase the likelihood that the driver will comprehend the reason behind a specific advice.

Although there is still a change that, provided with further information regarding the reasons for a given advice, the driver reaches a different conclusions about the optimal behaviour. Yet, it should provide him with the feeling of not being forced to accept a decision by the system, without any information about the underlying situation ahead.

Furthermore individual information about the traffic state, that is not directly perceivable by the driver, has been regarded as an additional individual benefit for the driver (Risto & Martens, 2011). Thereby increasing the systems perceived usefulness in case of a lacking individual benefit from traffic flow improvement.

5.2 Increasing the benefit of using CCC

In case the perceived lack of intrinsic reward provided by using CCC does not justify it use in the eyes of the diver, an external reward structure might need to be implemented. This reward could take the form of a system internal accounting system that awards drivers credit for compliance behaviour. At a later stage these credits can be converted into a monetary reward, a reduction on an road charge or non-buyable option such as access to special insurance benefits.

The more the driver is complying to a certain advice the higher the amount of credit awarded. A difficulty with this solution might be the feasibility of determining the degree of compliance by the driver. Furthermore, putting in place and maintaining such an external reward system is costly and bear the risk of drivers trying to game the system. However, in the initial implementation phase of the system, and external reward might act as an incentive, when intrinsic benefit is low due to user numbers not yet exceeding the minimum required penetration rate.

6 Conclusion

When focussing on traffic flow improvement rather than driver comfort and safety, driver support systems may face issues due to a lower perceived individual benefit for the driver who is supposed to use the system. In the present paper, this has been shown at the example of the Connected Cruise Control. Reducing the social dilemma character by reducing the perceived cost of using the system, while increasing the perceived benefit, may be crucial for the public acceptance of CCC.

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References

Ajzen, I., & Fishbein, M. (1980). *Understanding attitudes and predicting social behavior*. Englewood Cliffs, NJ: Prentice-Hall.

Axelrod, R. (1984). *The evolution of cooperation.* New York, NY: Basic Books.

Brewer, M. B., & Kramer, R. M. (1986). Choice behavior in social dilemmas: Effects of social identity, group size, and decision framing. *Journal of Personality and Social Psychology, 50*(3), 543–549.

Dawes, R. M. (1980). Social dilemmas. *Annual review of psychology, 31*(1), 169–193.

Fitts, P. M., & Posner, M. I. (1967). *Human performance.* Oxford, England: Brooks and Cole.

Flemisch, F., Kelsch, J., Löper, C., Schieben, A., & Schindler J. (2007). Automation Spectrum, Inner/Outer Compatibility and Other Potentially Useful Human Factors Concepts for Assistance and Automation. *Proceedings of the Human Factors and Ergonomics Society 2007– European Chapter.*

Fox, J., & Guyer, M. (1977). Group size and others' strategy in an n-person game. *Journal of Conflict Resolution, 21*, 323-338.

Fox, J., & Guyer, M. (1978). ‘Public’ choice and cooperation in n-persons prisoner’s dilemma. *Journal of Conflict Resolution, 22*, 469-481.

Happee, R., Saffarian, M., Terken, J., Shahab, Q., & Uyttendaele, A. (2011). Human Factors in the Connect & Drive Project. In *Proceedings of the 8th International Automotive Conference*. Eindhoven, The Netherlands.

Hoedemaeker, M. (1999) *Driving with intelligent vehicles: Driving behaviour with Adaptive Cruise Control and the acceptance by individual drivers* (PhD thesis), Delft University of Technology, Delft, The Netherlands.

Jerdee, T. H., & Rosen, B. (1974). Effects of opportunity to communicate and visibility of individual decisions on behavior in the common interest. *Journal of Applied Psychology, 59*(6), 712-716.

Klunder, G., Jonkers, E., & Schakel, W. (2011). A cooperative road-vehicle system to improve throughput – functioning and communication aspects. In *Proceedings of the 18th ITS World Congress*, Orlando, FL.

Kollock, P. (1998). Social Dilemmas: The Anatomy of Cooperation. *Annual Review of Sociology, 24*, 183–214.

Komorita, S. S., & Lapworth, C. W. (1982). Cooperative choice among individuals versus groups in an n-person dilemma situation. *Journal of Personality and Social Psychology, 42*, 487-496.

Martens, M. H., Risto, M. & Wilschut, E. (2011). Connected Cruise Control: Driver response to the advisory system. In *Proceedings of the 8th international Automotive Congress. International Congress on Future Powertrains and Smart Mobility,* Eindhoven, the Netherlands.

Ploeg, J., Serrarens, A. F. A., & Heijenk, G. J. (2011). Connect & Drive: design and evaluation of cooperative adaptive cruise control for congestion reduction, *Journal of Modern Transportation, 19*(3), 207–213.

Ranney, T. A. (1999). Psychological factors that influence car-following and car-following model development. *Transportation Research Part F: Traffic Psychology and Behaviour, 2*(4), 213–219.

Rasmussen, J. (1987). Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models. In *System design for human interaction* (pp. 291–300). Piscataway, NJ: IEEE Press

Risto, M., & Martens, M. H. (2010). *User acceptance of the connected cruise control and driver irritation in dense motorway traffic* (survey research report). Enschede, NL: University of Twente.

Risto, M., & Martens, M. H. (2011). *Driver behavioural reaction to the Connected Cruise Control – A simulator experiment* (unpublished experimental report). Enschede, NL: University of Twente.

Risto, M., & Martens, M. H. (2012). *Factors influencing the user acceptance of the Connected Cruise Control* (unpublished experimental report). Enschede, NL: University of Twente.

Risto, M., Martens, M. H., & Wilschut, E. (2010). Introduction to the connected cruise control and related human factors considerations. In T.P. Alkim & T. Arentze e.a. (Eds.), *11th Trail Congress Connecting People - Integrating Expertise.* Delft, The Netherlands

Schelling, T. C. (1971). On the ecology of micromotives. *The public interest, 25*, 61–98.

Van den Broek, T., Netten, B., Hoedemaeker, M., & Ploeg, J. (2010). The experimental setup of a large field operational test for cooperative driving vehicles at the A270. In *Proceedings of the 13th International IEEE Conference on Intelligent Transportation Systems*, 198–203.

Van den Broek, T., Ploeg, J., & Netten, B. (2011). Advisory and autonomous cooperative driving systems. In *Proceedings of IEEE International Conference on Consumer Electronics (ICCE)*, 279–280.

Van Koningsbruggen, P. (2011). Connected Cruise Control, a service in its own right and building block for cooperative systems. In *Proceedings of the 8th international Automotive Congress. International Congress on Future Powertrains and Smart Mobility*, Eindhoven, the Netherlands.

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.