Understanding road users' expectations: an essential step for ADAS development

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This article indicates the need for understanding road users' expectations when developing Advanced Driver Assistance Systems (ADAS). Nowadays, technology allows more and more opportunities to provide road users with all sorts of information or even actively support aspects of the driving task. However, we should first identify how the driving task is actually performed by drivers before determining which ADAS functionalities could support the driver optimally. The results of an experiment aimed at identifying aspects of expectations drivers have in interaction situations, are used to speculate about ADAS functionalities that could potentially support the driver in the interaction aspect of the driving task.

Keywords: ADAS, design implications, expectations, traffic interactions

1. Introduction

The growing availability of Information Communication Technologies (ICT) has increased the interest of car manufacturers in applying such technologies in traffic. Amongst the variety of applications of ICT developed to be applied in traffic is the rapidly increasing development of Advanced Driver Assistance Systems (ADAS). ADAS' have been developed to support the driver by providing information or even temporarily taking over part of the driving tasks. In the introductory article in this issue the variety of ADAS is illustrated (Van der Heijden and Marchau, 2005).

We should understand that although not all ADAS are developed primarily for safety purposes, most of them could have an impact on road safety. On the one hand ADAS could be potentially beneficial by, for example, making the driving task easier (e.g., decrease workload in complex situations). However, the introduction of new technologies could also negatively influence safety through, for example, distraction by a possibly unexpected mode of assistance (e.g., frequent warning beeps, incorrect information). The implications of ADAS for road safety are a result of both the effects of intended functionality of the assistance systems and the unintended effects of using them. Studies of behavioural adaptation, which is defined as a change in behaviour that occurs in response to a change in technology, but which was not intended by the designer (OECD Scientific Expert Group, 1990), investigate such effects (Dragutinovic, Brookhuis, Hagenzieker and Marchau, 2005). An optimal ADAS application should enhance safe driving behaviour and keep negative side-effects (as mentioned above) to a minimum. Thus, it is important to have sufficient understanding of 'safe driving behaviour', when developing an ADAS application to support drivers in their driving task. Chauvin and Saad (2000) stress the importance of investigating the potential impact of new support systems being developed in car driving. Harbluk, Noy and Matthews (1999) also remark that ADAS could result in fundamental changes in the nature of driving with possible adverse effects. The HASTE project, which focused on In Vehicle Information Systems, has also acknowledged that methodologies to assess safety implications of these systems are still lacking (Carsten and Brookhuis, 2005). In the present article, we will illustrate the importance of taking road users' expectations into account when developing ADAS by focusing on the interaction aspect in driving.

Time is often a limiting factor in the decision making process in interaction situations. Take, for example, an intersection with two road users approaching each other from different directions and at some point in time 'competing' for the same road space at the same time. In this case, conferring with other road users about who will take which action is not possible. However, it is necessary for at least one of the road users to take some kind of action within seconds to prevent a collision. Despite this, situations like these rarely develop into an accident. Thus, it seems plausible that drivers must have some kind of expectation of what is about to happen in the next moments in order to be able to react in time. In a later section of this article we will go deeper into the role and content of these expectations.

In order to be able to make any predictions about the impact of ADAS on driving behaviour in interaction situations a thorough insight into the interaction process is needed. Current ADAS concepts have mostly neglected the interaction aspect of the driving task. These may lead to unexpected driver behaviour and to unforeseen and dangerous responses by surrounding road users. As these systems are expected to have a special impact on driver behaviour in terms of, for example, the speed practised and/ or the safety margins adopted in car-following situations, they will change drivers' behaviour and may thus alter the way they usually interact with other road users. Therefore, a deeper insight into interaction behaviour in traffic is urgently needed to provide more extensive and safer design criteria.

In this article, we will discuss problems that have occurred with currently available ADAS in further detail to illustrate the need for research on understanding the driving behaviour ADAS intends to support. As this article is focused on the interaction aspect of the driving task, we will discuss the concept of expectancy which is assumed to be a key concept in understanding interaction behaviour in traffic. Subsequently, an experiment will be discussed which aimed at identifying aspects of expectations that drivers involved in interaction have. Based on these results, speculations are made about future ADAS functionalities that aim to support drivers during interactions.

2. Problems with currently available ADAS

Many of the ADAS developments are led by car manufacturers, since ADAS provides them with marketing opportunities. The first preliminary ADAS' that may influence interaction behaviour, are already available on the market. For example, a distance keeping device known as Adaptive Cruise Control (ACC) was first introduced to luxury vehicles and has now also become available on middle class vehicles. During the development of ACC it was regarded as a tool with the potential to increase traffic safety. However, ACC is currently marketed as a convenience system rather than a safety aid. According to some authors (Marsh, 2003) this is done out of fear of potential lawsuits following accidents. The ACC applications that have been introduced often still have imperfections. For example, the current ACC devices allow the user to operate the system under conditions for which they were not designed. All ACC devices are only operable at speeds above either 30 or 40 km/h. According to the manuals (e.g., BMW, 2002 for more details; Mercedes Benz, undated; Nissan, undated) the systems should be used on straight roads where traffic is moving relatively smoothly and a steady speed can be maintained for a prolonged period. Moreover, the systems should not be switched on in city driving or under adverse weather conditions. However, the system can also be operated outside these restricted design conditions. Use of the system in conditions for which it was not initially designed could, in turn, lead to unsafe driving situations.

A study by Jagtman and Wiersma (2003) illustrated the discrepancies between intended/foreseen effects and unintended/unforeseen effects and showed that the use of an ACC device could lead to unexpected behaviour of the device and the driver. In this study, some test drives in everyday traffic with an ACC device available on the market implemented in a showroom vehicle showed that the user is confronted with many inadequacies of the first generation ACC devices. These problems can be divided into three areas, as shown in table 1.

Table 1. Categories of problems with first generation ACC devices

	Inadequacies
1	Known but accepted shortcomings of the ACC systems
2	Experiences that differ from pre-introduction studies
3	Unknown and unexpected behaviour of the device and the driver

An example of the first category is the problem that the ACC device can be switched on in conditions in which it should not be operated. Although the driver probably knows that the ACC device is only active at speeds above either 30 or 40 km/h, the way the ACC device actually operates, might still come as a surprise to the user. For example, when a preceding vehicle approaches a traffic jam or a red traffic light, the driver of the following vehicle will reduce speed and come to a standstill. A car with an ACC device, however, will not support the vehicle to come to a full stop when approaching obstacles at low speeds, but will switch off. Another disturbing experience is the acceleration of the vehicle in curves which occurred especially in urban areas. This is caused by the fact that the vehicle in front goes out of range of the detector, which only looks straight ahead. Consequently, the ACC device decides to accelerate to the preset speed.

With respect to the second category of problems, the reaction of ACC users when driving with the ACC device available on the market sometimes differs from simulation studies. For example, a study of Hoedemaekers (1999) showed that drivers with an ACC tended to overtake more and keep to the left lane more in a motorway environment. Also, they attempted to maintain their desired speed. However, during the test drives, Jagtman and Wiersma experienced a tendency to stay behind the vehicle in front, because the ACC was functioning almost unnoticed. In other words, the ACC driver did not notice that she/he was actually driving slower than the pre-set cruise speed. This has a positive effect on traffic: it is quieter, more environmentally friendly, and safer. The difference may be the result of different settings of the implemented ACC's from the one tested in the research mentioned.

In one situation during the test drives, the driver was confronted with behaviour of the ACC device that was opposite to what the human driver would do. The ACC user experienced a sudden acceleration when a vehicle with a higher speed merged in the gap between the ACC vehicle and the vehicle it was following (see, Jagtman and Wiersma, 2003 for more details). A normal driver would have released the accelerator to increase the gap with a sudden new vehicle suddenly appearing in front. These experiences showed that there are safety concerns, at least in unexpected situations or by operating the device outside its designed limitations. It is unknown how these experiences influence safety. Are they only temporarily disturbing for the ADAS-users? Can such ADAS related problems influence other road users or have an effect on the local traffic process?

The possibility of systems getting into operational modes different from their intentions is a recognised phenomenon in safety science. System process models (e.g., Hale and Glendon, 1987; Kjellén and Larsson, 1981; MacDonald, 1972) describe a sequence in which a traffic system may shift away from the intended or normal process in a series of steps which finally lead, if uncorrected, to accidents. These models distinguish a normal or intended process with in-built hazards kept under control by preventive barriers or procedures. Since traffic systems are constantly changing they may at some point get into a deviation, which is defined as a stage outside the defined intended process or states. Deviations may be the result of failures of the control measures, unintended use of them, or unanticipated side effects of them, which can have effects on safety. As deviations are stages outside the defined control boundaries of the intended operation, the risks are increased. However, the traffic system can still return or be returned to its intended operation. Many deviations in traffic that could potentially develop into an accident are solved by participants involved in the traffic process before they actually have time to develop into an accident. Since road users often have to decide on multiple actions within seconds, road users need to anticipate specific events in the near future in order to cope with the situation in time. To do this, they need to continuously make assumptions about the traffic situations they will encounter in their near future. These assumptions about the future can also be referred to as expectations about the situations road users will encounter while participating in traffic. Since road users are able to solve most of the deviations in the current traffic system (even without being equipped with ADAS), having these expectations seems to be quite a robust coping strategy. ADAS should therefore be developed in line with road users' expectations in order not to interfere with the effective way human drivers currently interact with each other.

3. The concept of expectancy in interaction situations in traffic

In a study into the information processing of drivers involved in interaction situations, a model has been formulated (2004) which is based on Endsley's Situation Awareness (SA) model (1995) and Wickens' model of Information Processing (2000). In this model (figure 1) two kinds of expectancy are distinguished; 'long term' and 'short term' expectancies. Long term expectancies are derived from the driver's mental model of the situation and are thus based mainly on experience and education. An example of a long term expectation is the expectation that road users on a motorway will all drive in the same direction. This expectation is so powerful that phantom drivers are often not 'seen' because drivers believe that they simply cannot be confronted with counter traffic. Subsequently, short term expectancies are based on these long term expectancies and include information from the situation at that particular point in time. An example of such an expectancy is the expectation that another road user will be at a certain position in the next few moments. It should be noted that although both long and short term expectancies are based on mental models, they are distinctly different from mental models. An expectancy is focused on a specific aspect of a situation in the future, whereas a mental model is less specific than (especially short term) expectancies and includes more than just an extrapolation of the current situation to the future.

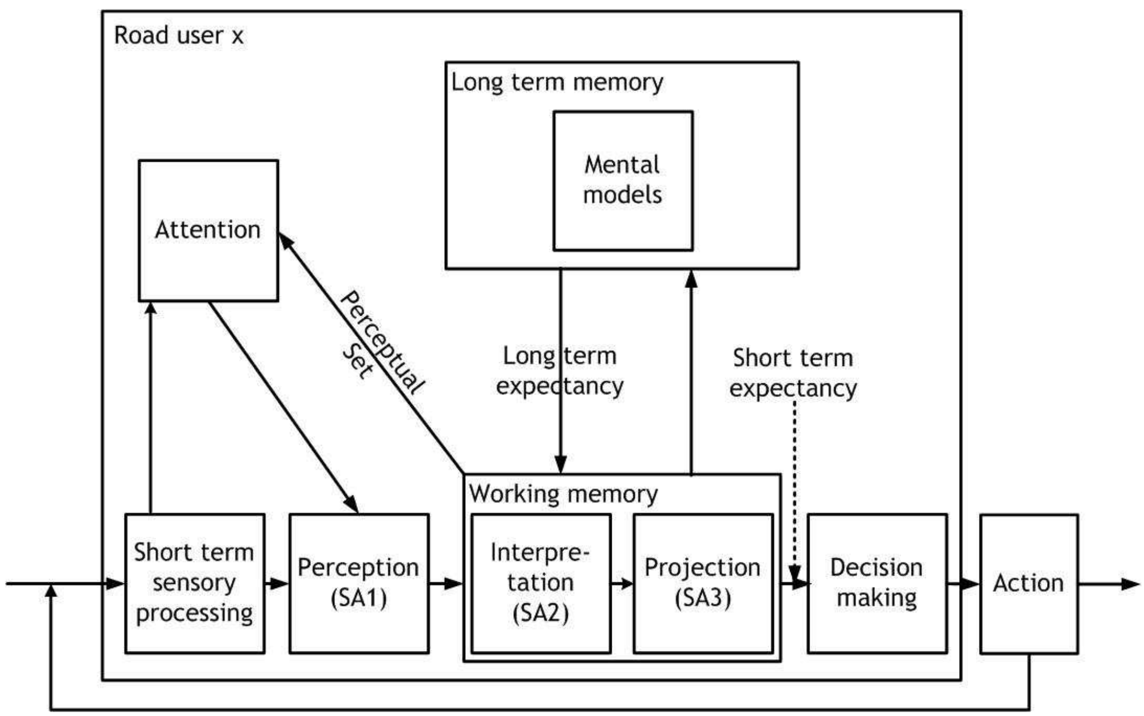

Figure 1. Information processing in driving (Houtenbos et al., 2004)

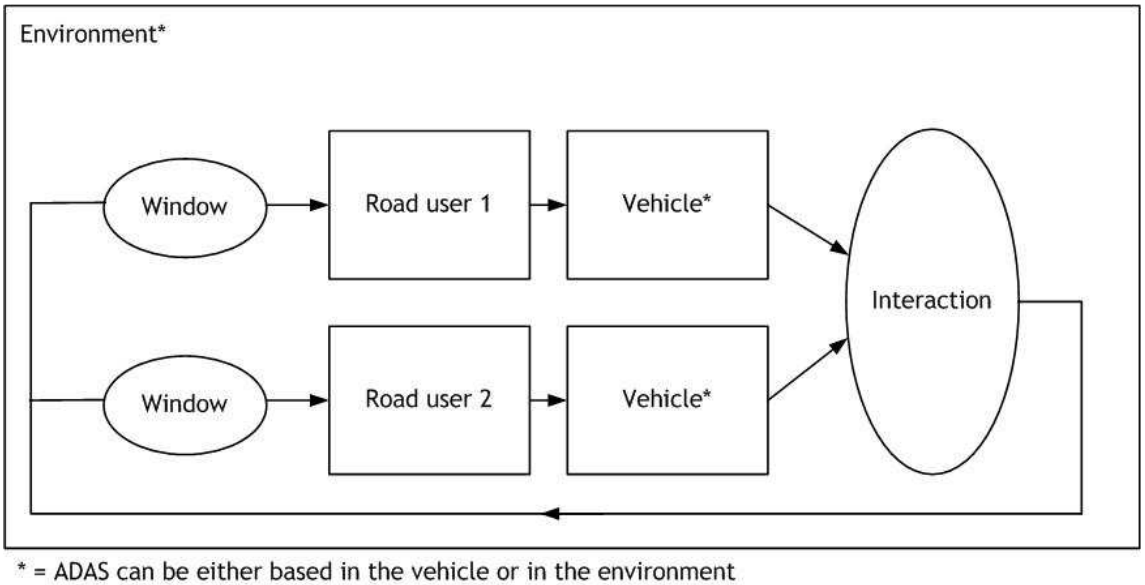

Figure 2. Interaction in driving (Houtenbos et al., 2004)

Figure 2 shows a model of an interaction situation. The main idea of this model is that several road users perceive the environment through a 'window' which induces a filtered perception of the environment. Subsequently the road users react through their vehicle to the situation they have perceived. Although only two road users are presented here, it is possible to add more road users. In this model, ADAS is represented by an asterisk in the vehicle and environment boxes as ADAS may or may not be present in either the road users' vehicles and/or in the environment.

Although it is not necessary for road users to have exactly the same expectations, it is however important that these expectancies do not conflict. This notion should be kept in mind when designing ADAS' that aim to support interaction behaviour. It is important for the sake of traffic safety, that car drivers using ADAS do not contradict the expectations that other road users have. However, this might occur as behaviour of drivers using ADAS might seem unfamiliar to other road users.

4. Identifying aspects included in expectations of interaction situations

In a first attempt to achieve a better understanding of interaction behaviour in traffic, an explorative study has been performed (Houtenbos, Hagenzieker, Wieringa, and Hale, 2005a, 2005b). This study will only be briefly reported here; more details will be published elsewhere (Houtenbos, Hagenzieker, Wieringa, and Hale, *[in prep]*). In order to investigate which parameters could be identified in (short-term) expectancies of interactions an experiment was designed in which participants responded to photographs of interaction situations. The technique used to obtain the 'expectancies' from respondents was an adapted version of the concept mapping technique as discussed by Jackson and Trochim (2002).

The stimuli for the experiment were developed by recording video fragments from within a moving car using a video camera. These recordings were then extracted and searched for interaction situations. Interaction situations were defined as situations in which some kind of decision regarding the course of the situation needed to be made by any of the interaction partners. Eventually, 17 interaction situations were found and still pictures were extracted from the video fragments for use as stimuli in the experiment. The still pictures were then rated on 6 aspects in order to assess the complexity of the situation. For example: 'the number of interaction partners' and 'the number of branches of the intersection'. In complex situations, it is hypothesized that more information needs to be taken into account to formulate an adequate expectation. Thus, it is assumed that the more complex a situation, the more difficult it will be for drivers in interaction situations to react in time.

In order to achieve a set of stimuli which varied in complexity, pictures were selected based on the rated complexity aspects. Pictures of situations where a roundabout was involved were also excluded from the final set of pictures. This exclusion was based on the fact that a still picture made on a roundabout does not display the roundabout features clearly enough. Consequently, respondents are not able to tell that the picture is made on a roundabout and will not be able to judge the situation in the correct context. The same problem occurs with pictures of a situation in which a traffic light is involved but is not to be found in the still picture. This could lead respondents to judge the situation as if there were no traffic lights at all. Figure 3 shows one of the pictures included in the experiment.

Figure 3. Example of a stimulus used in the experiment

The experiments started with a concept generation stage in which 20 respondents were presented with the ten selected photographs of interaction situations on a website and asked to respond to the following two questions: (1) "What do you expect will happen?" and (2) "Why do you expect that?". Respondents typed their answers in a text box below each photograph and were not limited in the length of their answers.

Subsequently, we transformed their responses into 'if.. , then..' statements. A random selection of 100 of these statements was given back to two groups of 10 respondents who participated in the previous concept generation stage. The selection of statements was made by randomly selecting 1 statement per respondent per picture which resulted in a collection of 100 statements per group of 10 respondents. The size of the respondent groups was based on the recommendations by Jackson and Trochim (2002) in their article on concept mapping. Respondents were asked to sort the statements according to their own judgment considering their similarity. Subsequently, each pile of statements was named by the respondent to reflect the contents of that particular pile. The concept sorting task took respondents about one hour.

For each respondent group, the results for each subject were entered into SPSS. A HOMALS Analysis (Homogeneity Analysis by Means of Alternating the Least Squares) was performed to discover which were the important clusters of expectations and how they were categorised by the respondents. The HOMALS technique resulted in a visualisation of the way statements were sorted by the group of respondents. Statements that were sorted together by many respondents were placed closer together in the HOMALS solution than statements that were rarely sorted in the same pile. It should be stressed that the HOMALS approach is mainly used for explorative research. Although no hypotheses were tested here, the results of this HOMALS analysis will, however, enable us to formulate hypotheses that can be tested in further research.

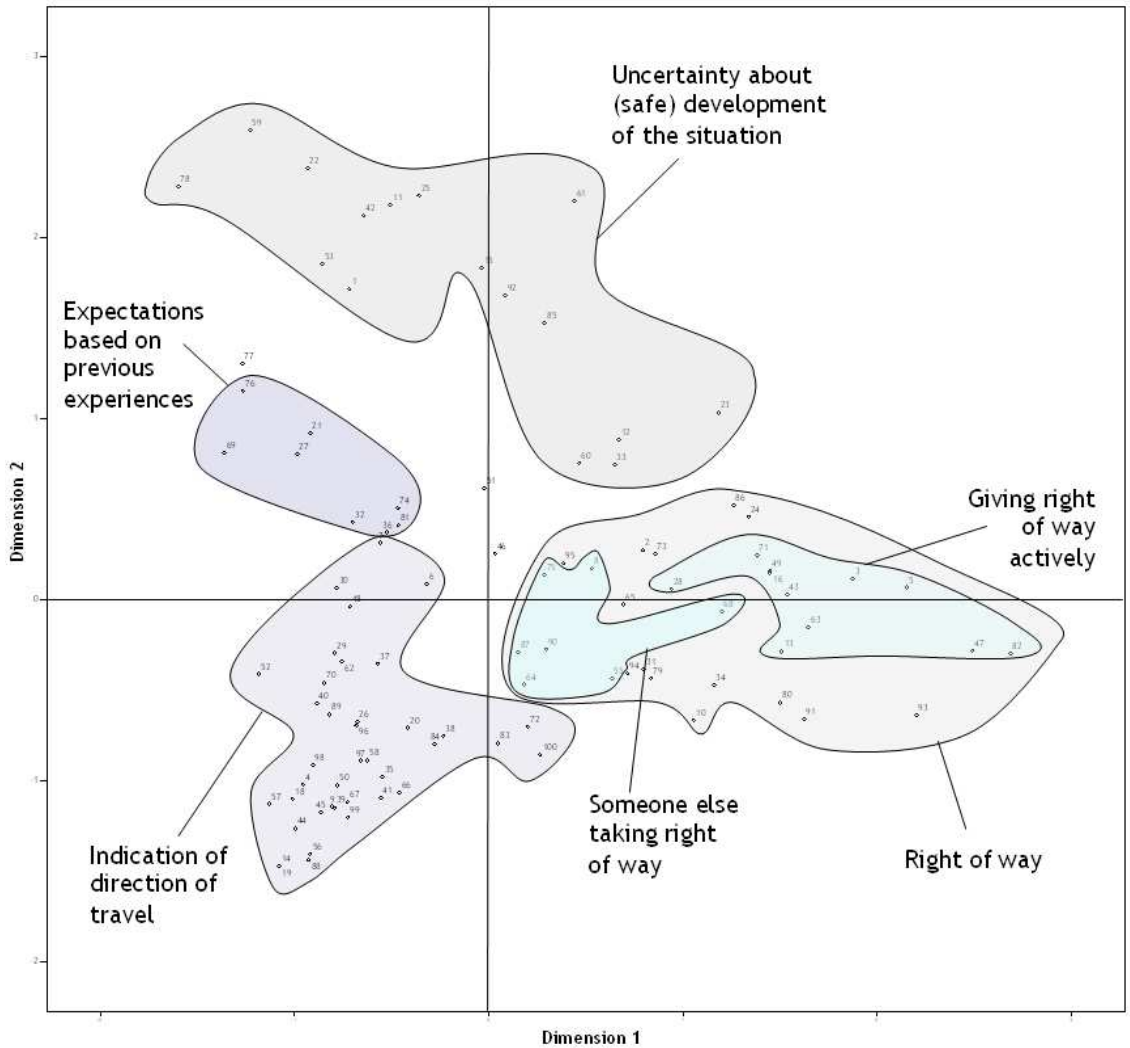

Figure 4. HOMALS Solution of the first respondent group

In total, 20 respondents (divided into two groups of 10 respondents) sorted statements which were based on the answers given by their own group of 10 respondents in the concept generation stage. The analysis of the sorting results of the first respondent group resulted in several meaningful clusters. We distinguished these clusters by reading all statements in the solution and determining similarities between the statements that were close together. The main similarity per cluster can be found in the cluster-labels in figure 4. This figure shows the HOMALS solution of the first respondent group. In the solution of the second respondent group, roughly the same clusters could be distinguished, which suggests that the concept mapping technique is relatively reliable.

The cluster, '*right of way*', unsurprisingly surfaced as an important aspect of expectations of interactions. Within this cluster, it seems that another distinction is possibly present between 'actively giving right of way' and 'someone else taking right of way'. If so, this distinction provides an idea for an interesting hypothesis: in situations where the driver actively gives right of way to another road user, it seems that the driver perceives himself relatively in control of the situation. Could it be that in situations where another road user 'takes' right of way, the locus of control is not perceived within the driver, and is therefore more difficult to manage? In order to be able to test this hypothesis it is necessary to identify the difference between these two behaviours. However, this appears to be a rather difficult task. Could it be that the difference is to be found in the subjective perception of the driver in such a situation? For example, the behaviour of a driver who is *given* right of way may appear to another road user as if this driver has *taken* right of way.

Another hypothesis is induced by the cluster of statements addressing '*uncertainty about (safe) development of the situation*'. Having an expectation of the situation which is about to happen is a way of coping with the limited amount of time available. Thus, being uncertain of the way the situation will develop could increase the risk of the situation developing dangerously, as there is less time to choose an adequate action. Again, it is necessary to define uncertainty before we will be able to test a hypothesis that includes this concept. Perhaps uncertainty could be defined as considering several options concerning the development of the situation, but not yet having decided what is actually happening or going to happen.

Another distinct cluster included statements that addressed *'indication of direction of travel'*, which could also be expected. A road user indicating which way he is going enables another road user involved in the interaction to form a more accurate expectation about what will happen and thus decrease uncertainty about the way the situation will develop.

The final cluster, which was not that large, included statements which addressed *'expectations based on previous experiences'*. The statements in this cluster correspond with the long term expectancies as mentioned in the model in figure 4.

5. Discussion: Preliminary directions for generic ADAS developments

The results of the explorative concept mapping experiment are only the beginning of trying to understand the mechanism of road users' expectations in interaction situations. The results allowed us to formulate hypotheses which will be tested in future experiments. Also, the role of complexity will be further investigated. Further understanding of the difference between actually giving right of way and someone else taking right of way and of the impact of uncertainty are needed. Moreover, we should study the relative importance of these aspects as part of the driving task and of participating in traffic as a whole. However, these first results provide us with the opportunity to go back to the possibilities of ADAS to support drivers in interaction situations. What kinds of directions for ADAS developments might be of interest? And which concerns can already be addressed?

The experiment focused on intersections. Based on the first cluster 'right of way' we can conclude that the expectations in interactions include the outcome of a decision that determines who has right of way. Based on this cluster, an 'intersection-ADAS' could perhaps include assistance with this decision and determine who has right of way in the approaching interaction situation. However, further research is required to identify the difference between the two aspects found in this cluster: actively giving right of way versus someone else taking right of way. What implications does this distinction have for road users receiving assistance from an 'intersection-ADAS'? If one interaction partner gives the other right of way there should be no conflict as long as the other will take it. A problem occurs if both interaction partners take it, which could result in a crash. On the other hand, if both partners give right of way, then the traffic stops and a new situation arises. In this case, more communication needs to take place to resolve the impasse (e.g., waving on, flashing lights, hooting). This could subsequently lead to a misunderstanding and result in a slow-motion crash as each partner gives and then takes right of way alternatively. Perhaps ADAS could play a role in resolving situations like these by deciding which of the partners will go first and instructing the partners involved in the interaction.

If the other distinct cluster 'uncertainty about (safe) development of the situation' is also included, we can indicate additional directions for an 'intersection-ADAS'. An ADAS which would include information about relevant road users, could be a way of decreasing uncertainty about the way the situation will develop. This functionality brings us to some interesting questions. First of all, we should define 'relevant' road users. Are these road users who could be involved in the approaching interaction or only road users that are already involved? Is it even possible to find one unambiguous criterion to decide who are relevant road users and who are not? It becomes even more complicated if we try to formulate a definition which can be used in ADAS. Are relevant road users all road users the system can detect within a certain range from the ADAS user (if necessary speed dependent)? And, if the ADAS should always detect all relevant participants, how should the system deal with detection problems, for instance detecting more participants than are actually present (see e.g., Lehto, Papastavrou, Ranney, and Simmons, 2000 for false alarms versus misses in an ADAS device)?

With respect to uncertainty we should moreover question the *implementation strategy* of such ADAS devices. What if there is a *mixture* of vehicles with an 'intersection-ADAS'? How to deal with pedestrians and cyclists, who cannot be equipped with such a device? Since the aim of ADAS applications is to assist drivers and not to fully automate (parts) of the traffic system, the behaviour of users of an 'intersection-ADAS' should preferably correspond to users without this ADAS. Otherwise the presence of such systems might increase uncertainty for the other, non-ADAS using, motorised road users and all vulnerable road users.

A parallel can be drawn with the results of various experiments with Intelligent Speed Adaptation (ISA). ISA is primarily developed to support users in towns, residential areas and other sensitive environments where speed bumps are currently used. This area of use is similar to the area of use of an 'intersection-ADAS' (still to be developed). Experiments have shown that uncertainties can most effectively be reduced if an ISA provides some sort of active support and if the system is mandatory (e.g., Biding and Lind, 2002; O. Carsten and Fowkes, 1998). The support and implementation strategies can significantly reduce the variation in speeds and increase the predictability of the (maximum) speed driven by an ISA user. In group-discussions on similarities in expectations after introduction of ISA (see, Jagtman, 2004) the mixture of ISA and non-ISA vehicles was addressed. The main opinion seemed to be that ISA in a mixture of traffic would probably not reduce uncertainty, unless perhaps it is indicated that a given vehicle is ISA-equipped.

6. Conclusion

This article addressed road users' expectations in relation to the developments of ADAS. Although technology produces more and more opportunities to provide road users with all sorts of information or even to actively support parts of the driving task, we still do not have

a clear understanding of the ADAS related needs of an interacting driver. In particular, the mechanism whereby road users are able to avoid accidents by compensating for each other's behaviour is not yet thoroughly understood. By investigating interaction behaviour, ADAS can be adapted to support the driver with more difficult aspects of the interaction process.
All in all, the results of the concept mapping study so far have elicited many interesting questions which will be elaborated on in future studies. This will eventually enable us to identify the direction that (future) ADAS will need to follow in order to optimally support the 'interacting driver' from a safety point of view. In a follow-up experiment, the method will also be used in a similar experiment using dynamic stimuli to assess the impact of dynamic information versus static information. Subsequently, an experiment using an interactive driving simulator will be designed to test the hypotheses that were derived from the results of these previous experiments. Eventually, this will help us to identify criteria ADAS should meet in order to optimally support a driver in their interaction task at intersections.

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