Anticipatory Driving Competence – Motivation, Definition & Modeling

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ABSTRACT
Anticipation of future events is recognized to be a significant element of driver competence. Surely, guiding one's behavior through the anticipation of future traffic states provides potential gains in recognition and reaction times. However, the role of anticipation in driving and ways to support it have not been systematically studied. In this paper, we identify the characteristics of anticipatory driving and provide a working definition. In particular, we distinguish it from overall driving goals such as eco or defensive driving, but rather present it as a high-level competence for efficient positioning of the vehicle to ultimately facilitate these goals. We also argue that anticipation occurs within the context of stereotypical scenarios and provide an initial taxonomy for the identification of such scenarios. We suggest the Decision Ladder as a useful way of modeling anticipatory driving and finally discuss a potential approach for the facilitation of anticipatory driving through skill- and rule-based behavior, which can allow for shortcuts on the Decision Ladder.

Categories and Subject Descriptors
H.1.2 [Models and Principles]: User/Machine Systems – Human factors, Human information processing

H. 5.2. [Information Interfaces and Presentation]: User Interfaces – Theory and methods, Methodology

General Terms
Human Factors, Theory, Performance, Design, Measurement, Standardization.

Keywords
Driver Behavior, Anticipation, Traffic Safety, Fuel Economy, Decision Ladder, Skill-based Behavior, Rule-based Behavior.

AutomotiveUI"'13, October 28-30 2013, Eindhoven, Netherlands.
 ACM 978-1-4503-2478-6/13/10 ...$15.00
http://dx.doi.org/10.1145/2516540.2516579

1. INTRODUCTION
Driving is a challenging task that demands the coordination of motor, perceptual, and cognitive skills. Cognition comes into play as drivers interpret the perceived information and select an action. If the drivers do not perceive a familiar situation, they tend to rely on reacting to events, while upon encountering familiar situations they tend to anticipate what is about to happen next [1]. Being in a reactionary mode requires a given event to have passed already, thereby severely limiting the time a driver has to deal with the event. In contrast, anticipation of the event allows for additional room and time to ensure that disruptions and potential conflicts are minimized.

Facilitating a shift from reactionary to anticipatory driving may help enhance safety, traffic flow, as well as driving economy. Supporting evidence can be found in studies that have investigated the effect of response priming on driving performance, which consistently report better performance if drivers have correct expectations. For example, a simulator experiment investigating response priming on a follow-up lane change request found enhanced reaction times and steering precision with valid primes [2]. Several other studies that have investigated reaction times of car drivers and motorcycle riders in the real word come to similar conclusions: reaction time improves when participants are alerted to, and consequently expect an obstacle in their path [3], [4], [5]. The alignment between the expectation of a specific event and the actual event proves crucial for good performance. Interpreting anticipation as another form of expectation, driving performance can therefore be improved by enabling correct anticipation of upcoming events.

Facilitating anticipation may also prove important in automation design. For example, there will necessarily be a phase when autonomous vehicles will share the road with human drivers. Understanding how competent human drivers are able to interpret traffic situations and anticipate other drivers' behavior can help designers train automation to do the same.

Although the positive role of anticipation is occasionally mentioned in driving research, a systematic analysis has not been performed so far. In this paper, we take a first step towards achieving this goal.

2. DEFINING ANTICIPATORY DRIVING

2.1 Connection to Previous Research
"When you have linked turns, when you exit the corner fast or slow and get to the next one, that's when there's more possibility to pass the rider and ***where you have to understand what the***

***other rider will do**, or how you can pass him. **You have to anticipate this braking** and go faster in the first turn so in the next you can pass him."* This quote (highlighting by authors) is from an interview with Julian Simon, a professional motorcycle racer explaining the importance of anticipating the actions of other riders.

Anticipation is crucial, not only for racing, but for driving in general. It can aid in the realization of various driver goals, such as safe or defensive driving, eco-driving, or efficient driving with respect to a reduction in travelling time. In terms of situation awareness, anticipatory driving would be situated on the third level, the "projection of future status" [6]. Due to the complex reasoning and significant cognitive resources necessary for this level, it is reasonable to assume that novice drivers will lack both the experience and spare cognitive resources needed to successfully drive in an anticipatory manner. In fact, "the inability to predict ahead of time the risks that will appear in the roadway" is identified as the primary cause of fatalities for this group [7]. Further, in a study focusing on hazard recognition in video-recorded scenarios, experienced drivers were found to be significantly more successful in anticipating the conflicts that were about to arise than were novice drivers [8]. While the facilitation of anticipatory driving is important for all drivers, it appears to be particularly important for the group of novice drivers.

The idea of anticipation in driving is frequently found in discussions of driver behavior. In Fuller's risk avoidance model, an attempt at analyzing typical driver behavior in dealing with potentially dangerous situations, a given discriminative stimulus is suggested to have two potential consequences: failure to act on the stimulus, or an anticipatory avoidance response in order to eliminate the potential danger (in the former case, the driver may receive a potential aversive stimulus, which then would force her to either react adequately or crash) [9]. Here, the "integration of features projected into the future" [9, p. 1147] is highlighted to be a desirable behavior with respect to safety. Tanida and Poeppel [1] also identify anticipation as a central concept in driver behavior. However, they take on a different perspective and describe driving as a task that is dominated by anticipatory brain mechanisms (the authors talk about neuronal programs) that deal with familiar stimuli. The authors suggest that these programs are only interrupted when the driver is presented with unfamiliar stimuli, in which case driver behavior functions on a reactionary basis.

Anticipation is also found in models describing the dynamics of traffic and of driver assistance systems. In their traffic flow model, Kesting and Treiber [11] include drivers' anticipation of acceleration patterns of vehicles ahead. Onken [9], on the other hand, looks at how drivers currently react in a particular situation as a way of guiding the development of automated systems. He theorizes about the necessity of knowing how to react in a specific situation, and distinguishes between situations that are familiar to the drivers, and those that are unfamiliar to them. He suggests that high-level, knowledge-based behavior guides decision-making in unfamiliar situations, but talks about skill- and rule-based behaviors as guiding responses in familiar situations. According to Onken, familiar situations are usually "anticipated through expectations" [10, p. 53].

Although anticipation is recognized to be an important element of driving, there appears to be a variation in our understanding of anticipation and a lack of research on how to facilitate it. The rest of our paper will discuss anticipation and suggest a working definition and an approach to help facilitate it.

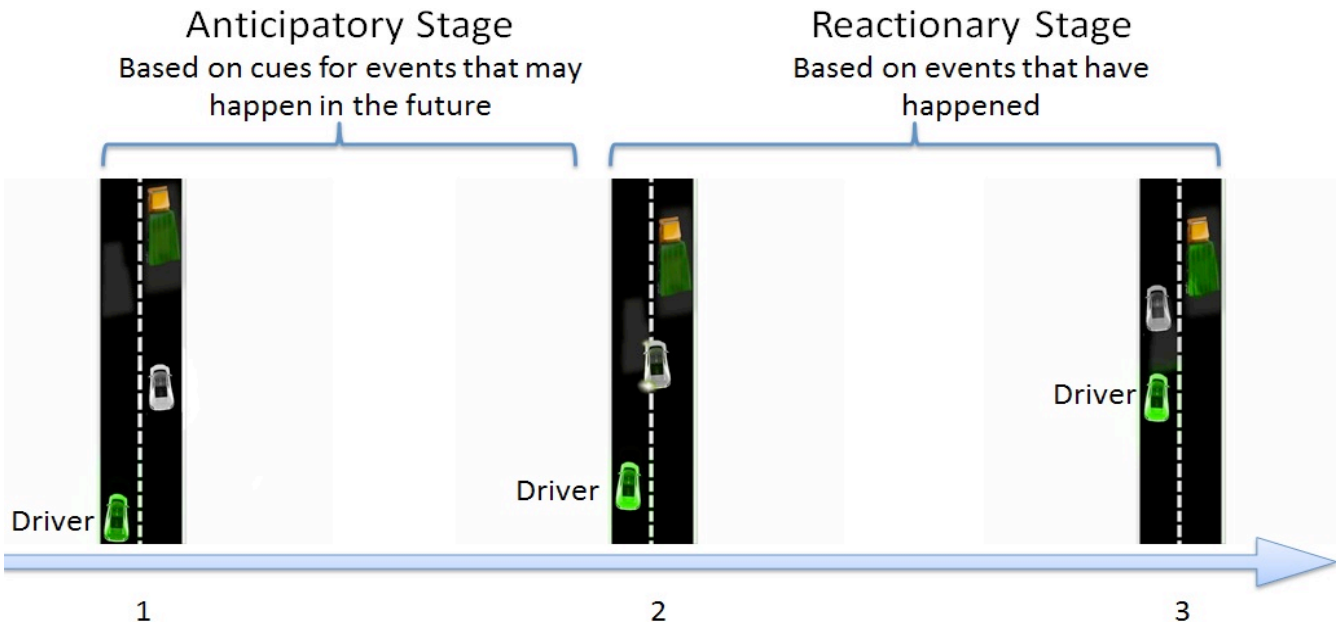

Figure 1: Anticipatory Scenario - A potential headway conflict for the driver, caused by the lane change of a second car that attempts to overtake a vehicle in its own lane

2.2 Definition

An intensional definition becomes satisfactory when it enables accurate identification of all instances of the concept to be defined. It becomes operational when it enables accurate application of the concept, such as to measurement. In this paper, we want to give a first, intensional definition of anticipatory driving.

Anticipatory driving appears to be a relatively straightforward concept upon first glance. An anticipatory driver would be able to identify cues that indicate a potential conflict ahead of time instead of being unaware of upcoming conflicts in traffic, having to wait for them to happen and being left with only reaction as an option. She would consequently be able to take action to avoid conflict. However, when trying to come up with a satisfactory definition, it becomes surprisingly hard to clearly distinguish driver actions that are reactions to events that have already happened from actions that are taken before the event takes place. To explain the challenges, consider the example scenario illustrated in figure 1.

Here, the travelling direction of all vehicles is from the bottom towards the top of the graphic, and we consider the perspective of the green car, which is in the left lane, and is travelling at the highest speed. The grey car is travelling in the right lane, ahead of the green car, and at a slightly lower speed. Finally, the slowest vehicle is a truck travelling in the right lane, ahead of both cars. In this scenario, a potential conflict may occur if the grey car were to change lanes to overtake the truck. Depending on the speed difference and the distance between the two cars, the green car would have to brake to avoid a collision.

From the perspective of the driver of the green car, the anticipation in this scenario would involve the preparation for the grey car changing lanes. Based on the characteristics of the scenario, experienced drivers can identify the likelihood of the car pulling out in front of them, and may therefore take action to avoid potential conflict. A defensive driver would be likely to release the gas pedal, whereas an aggressive driver may accelerate to pass the grey car before it changes lanes. In both cases, an anticipatory action is being taken – the driver of the green car predicts what might happen in the future and reacts with an anticipatory avoidance response appropriate with respect to the driver's goal.

However, in slight variations of the scenario, the recognition of whether or not anticipatory competence is present becomes much harder. Potential challenges are:

1. The non-reactive, anticipatory driver – There is a possibility for a driver to successfully anticipate the potential conflict, but to consciously decide against taking action. While such a driver may still be considered under the "anticipatory" label (or a sub-category of such), the conscious decision against taking action would make it difficult to distinguish this driver from a non-anticipatory one. There would be no observable action as a result of the anticipation.

2. The timing of the anticipatory action – One question that needs to be considered is when anticipatory driving changes to reactive driving. Does action have to be taken before the grey car signals a lane change or initiates one to be recognized as an anticipatory action?

3. The reactivity in anticipation – Even the anticipation of events can be described as a reaction to specific cues. An anticipatory driver could just be considered to react earlier; not to the event itself, but to subtle cues heralding the event. Anticipatory drivers can be interpreted to react to the more subtle stimulus of a particular situation, as opposed to the salient stimulus of a car in their direct travelling path. For example, an increase in the acceleration of the grey car with respect to the acceleration of the truck ahead might be considered as an event to which the driver reacts.

The above example lays out the challenges in creating a satisfactory definition for anticipatory driving. However, there are also certain aspects of anticipatory driving that can be more clearly identified:

1. Anticipatory driving needs to describe a high level competence of cognitive reasoning that serves to facilitate one or more driver goals. Anticipation will increase the useful space in which the drivers can act, as well as the time they have to act, but it will not determine specific actions. The driver will, depending on his personal situation and characteristics, use a behavior to achieve his goal. Consequently, a race car driver may use anticipatory driving to identify the most likely manoeuvers to overtake the driver ahead, while a freight trucker would likely attempt to position his truck to minimize braking or acceleration. In both cases, the competence to anticipate the traffic situation a few seconds ahead aids the drivers in achieving the particular goal they are after. Similarly, the driver of the green car in figure 1 may choose to accelerate past the grey car, or he may release the gas pedal and coast to a slower speed in order to allow the grey car to merge ahead of him. We would see two very different behaviors, but both would be the result of anticipation. Following this rationale, the extent to which anticipatory driving will help achieve short travelling times, improved safety, or fuel efficiency will vary not just because one driver may be able to act early due to anticipation while another only reacts to highly salient events, but also because drivers may have different motivations and goals. Therefore, anticipatory driving can be described as a competence of cognitive reasoning that allows the projection of future traffic states, based on the perception and understanding of the current one. This reasoning process is then followed up with observable, goal-directed behavior that may vary from driver to driver.

2. Anticipatory driving requires stereotypical situations as a basis. It is not clairvoyance, but requires the recognition of distinct traffic setups that have proven to result in potential conflicts. Aiding in anticipatory driving therefore does not require the computation of an infinite number of potential scenarios, but the recognition of stereotypical traffic situations that have a high likelihood of resulting in similar events from one time to another.

3. With respect to the three commonly used levels of driver behavior – strategic, tactical, and operational [12], [13] – anticipatory driving has to take place on a tactical level. Anticipatory driving allows for the recognition of events that are a couple of seconds ahead. The further ahead the event to be anticipated is, the more potential alternatives there are and the more cognitive processing is required. While the strategic level allows for general planning of driving, it does not allow for anticipation of specific events due to near endless possibilities. In contrast, sudden events do not leave enough time for the perception and cognitive processing of complex cues indicative of upcoming scenarios. Thus, on the

operational level, a driver can only be described to be reactive.

4. Anticipatory driving has to describe the competence of correctly interpreting cues for upcoming events, as opposed to a competence focusing on the recognition of particular events. The difference between reactionary and anticipatory action (the third challenge identified above) has to be found in the semiotic status of the observed information. If it is a highly salient, well defined symbol for a conflict, such as the sight of the significantly slower grey car in the left lane, or even the car's signaling of its upcoming lane change, then a driver is merely reacting. Little cognitive effort is necessary here. If, however, the driver picks up on relatively subtle, potentially ambiguous cues, and likely has to connect several of these cues together (in our example the kinds of vehicles, their positions on the highway relative to the driver's own car, the relative speeds between those vehicles), then more than mere reaction to a well defined symbol is happening. Experience and significant cognitive processing are necessary to make sense of these combined cues – the driver is anticipating.

Based on the above discussions, we propose this working definition of anticipatory driving:

Anticipatory driving is a high level cognitive competence that describes the identification of stereotypical traffic situations on a tactical level through the perception of characteristic cues, and thereby allows for the efficient positioning of a vehicle for probable, upcoming changes in traffic.

3. FACILITATING ANTICIPATORY DRIVING

3.1 A Preliminary Taxonomy of Stereotypical Situations

As suggested in our working definition, anticipatory driving involves the identification of stereotypical traffic situations. An understanding of such situations can help researchers investigate to what extent anticipation is utilized by drivers and its effects, as well as develop ways to facilitate it. Facilitation can be in the form of interfaces helping drivers recognize particular situations and suggesting appropriate actions. To this end, a taxonomy can help us systematically identify these stereotypical situations. Guided by the comprehensive task analysis of driving conducted by McKnight and Adams [14], we can categorize these situations based on the type of cues that trigger the driver to recognize the situation:

Natural Environment: Drivers can anticipate upcoming changes in traffic based on changes in the natural environment. For example, lighting conditions can change due to weather or natural vegetation, often resulting in changes to a driver's sight distance. Being conscious of such upcoming phenomena, for example, when approaching a foggy road section or a shady forest road, and adjusting speed accordingly would constitute anticipatory driving. Many other examples, such as changes in vehicle behavior due to rain or snow on roads, or due to the consequences of changes in temperature and road surface friction would fall under this category.

Road Environment/Infrastructure: Drivers can also anticipate changes in traffic based on changes in infrastructure. For example, an anticipatory driver entering a city may alter behavior by being aware of the added risks of reduced visual fields and increasing number of other traffic participants. Many other events can be anticipated based on changes in road infrastructure, such as railroad crossings, road surface, and tight curves in specific locales such as highway ramps. For this category, the desirable actions are often regulated through signage.

Other Traffic Participants: This category deals with the interaction between the driver and the other traffic participants. In the widest sense, animals and even autonomous vehicles can be included here. Due to the difficulty in predicting the actions of other humans, including drivers, pedestrians, and bicyclists, this category likely involves the most complex and interesting situations.

It is important to note that these categories are not mutually exclusive, and anticipatory scenarios can be characterized by cues from several categories. A strip of fog-covered road, for example, has very different implications depending on the amount and kind of other traffic participants present. If such a road is located on a crowded highway, the potential that a driver would need to adjust his driving (or react to a change in the traffic ahead, in case he fails to anticipate) is much higher than if it is located on a straight, empty road section. Furthermore, the categories here are not meant to represent an exhaustive taxonomy – they are merely the highest-level categories for a preliminary taxonomy. Further research is needed to expand this taxonomy and identify useful subcategories.

3.2 Modeling Anticipatory Driving and Goal-Driven Behavior

Another useful way of understanding anticipatory driving and follow-up goal driven behaviors is to model them through the use of Decision Ladders [15], the primary tool of Control Task Analysis [16].

Figure 2 depicts the Decision Ladder for the scenario presented in figure 1. It describes how an anticipatory driver would likely navigate the task. Whereas a usual task analysis centers on the current system state, for the purpose of anticipatory driving we are concerned with a future system state – so with respect to the scenario explained in figure 1, the system state of the Decision Ladder is the future state after the lane change of the grey car.

On the left side, we see the perception and analysis of the situation: from being alerted to the situation by specific triggers and then observing the appropriate traffic participants, to anticipating the probable future traffic state. The right side then describes the decision making process and execution of an appropriate action. It is interesting to note that the distinction between competence and behavior is again helpful. The cognitive competence of anticipating the correct future system state is situated entirely on the left side of the Decision Ladder, whereas the behavior, as characterized by the establishment of an appropriate goal and subsequent implementation of appropriate action, is found on the right side.

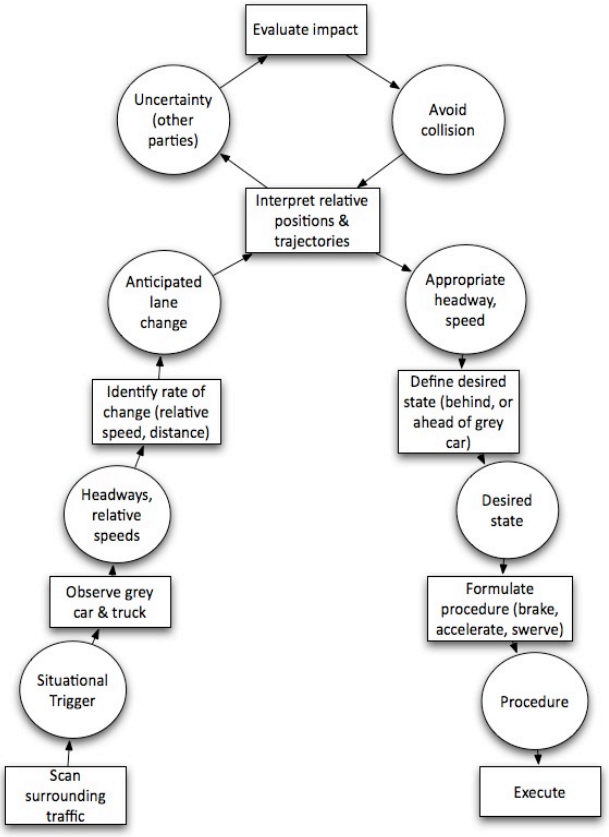

Figure 2: Decision-Ladder for "Conflict after lane change"-Scenario

3.3 Shortcuts for Anticipatory Driving

Decision Ladders uncover potential "shunts" and "leaps" that can be used by drivers to jump from one part of the ladder to another [16]. The goal of an aid designed to facilitate anticipatory driving should be to enable such shortcuts, optimally from the earliest stage of scanning the traffic environment directly to the appropriate action. One way to achieve this goal is by identifying the shortcuts used by anticipatory drivers and the cues triggering use of these shortcuts.

Looking at the Decision Ladder from this perspective, we can interpret the way up the left part of the ladder as one requiring ever-rising cognitive resources and time. Due to inexperience, novice drivers would have to go all the way up the ladder sequentially, and logically deduce the upcoming traffic situation, having to expand considerable amounts of cognitive resources, which are also largely claimed by basic vehicle control and the continued monitoring of the current traffic situation. In contrast, experienced drivers would be more skilled at vehicle control and monitoring, and therefore be able to spare more cognitive resources for anticipation. Furthermore, they would have prior experience with similar situations. This familiarity of a comparable situation would allow the experienced drivers to anticipate the traffic situation much earlier and execute appropriate action earlier as well.

Using Worker Competency analysis, a concept from Cognitive Work Analysis [16], we could describe the way novice drivers arrive at an appropriate action through knowledge-based behavior, and the way experienced drivers arrive at the same action through skill-based behavior [17]. For the purpose of enabling anticipatory driving, knowledge-based behavior is not likely the preferred mode of cognitive processing. We instead advocate for the use of skill-based behavior. Interfaces that aid experienced drivers to trigger an intuitive, experience-based shortcut across the bottom of the Decision Ladder appear promising. Once we understand which time-space cues in the environment enable the skilled anticipatory driver to act in near-automated fashion to avoid upcoming conflict, we can then work on augmented representations of the environment that highlight these exact cues for other experienced drivers.

However, expecting a novice driver to use skill-based behavior appears highly unrealistic. A potential solution may be rule-based behavior, the final element in Rasmussen's taxonomy [17]. Here, the process of arriving at a specific action is neither the cognitive, logical reasoning of knowledge-based behavior, and nor the intrinsic, near automatic triggering of those actions through skill. Instead, these drivers can be aided to ground their actions in pre-defined situational conditions. For example, if a specific traffic situation A is observed, then it will (most likely) lead to particular situation 2 in which action IV is desirable.

To sum up, we suggest that anticipatory driving could be facilitated by enabling shortcuts through the Decision Ladder. These shortcuts can be described in terms of skill- and rule-based behaviors. Consequently, an interface should support skill- and rule based leaps through the Decision Ladder. Figure 3 depicts a task-independent Decision Ladder with possible shortcuts highlighted, inspired by existing work on the theory of interface design [18]. As illustrated, shortcuts on the skill-based level should be expected to jump across the very bottom of the Decision Ladder, while shortcuts on the rule-based level are likely to happen in the middle. Finally, resource-intensive knowledge-based reasoning would be situated towards the top of the ladder.

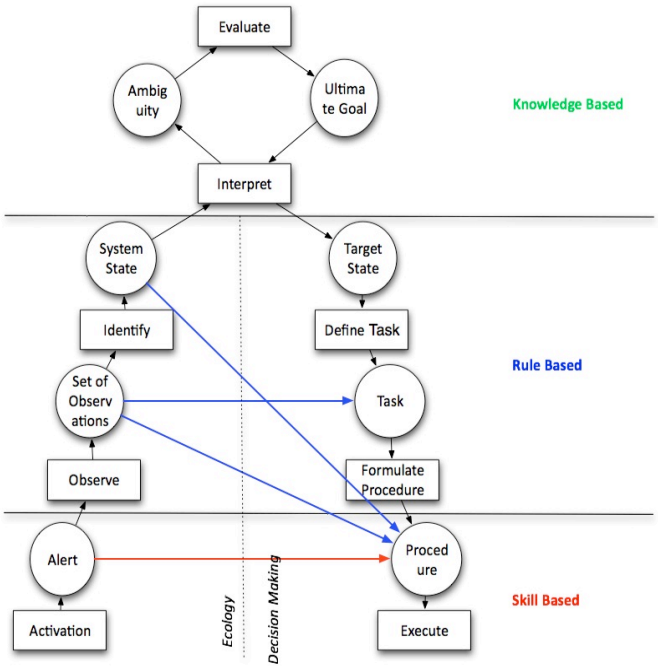

Figure 3: Decision Ladder highlighting skill- and rule-based shortcuts

4. CONCLUSION

In this paper, we discussed the concept of anticipatory driving, and argued for its importance. While being mentioned relatively consistently in driver behavior research and appearing to be a very promising concept to improve driver skills, anticipatory driving has not yet been studied in detail.

We also proposed a working definition of anticipatory driving after a thorough discussion of the challenges involved in coming up with a satisfactory one. We argue that anticipatory driving is a high-level competence as opposed to goal-oriented behavior, is based on stereotypical traffic situations, is situated at the tactical level, and involves the use of subtle cues for the recognition of a stereotypical situation.

The remainder of the paper focused on facilitating anticipatory driving. Using task analysis as a general framework, we proposed Decision Ladders as an appropriate modeling tool which allows for the representation of shortcuts that can be followed by the anticipatory driver. Finally, we suggested that drivers can be guided to exploit these shortcuts in order to facilitate anticipatory driving. By using the skills-, rules- and knowledge taxonomy, we made an attempt to categorize the potential shortcuts, mapping the characteristics of skill- and rule-based behavior to the respective areas in the Decision Ladder.

In future work, we will develop a more detailed taxonomy of potential anticipatory situations. We are also currently in the planning process for an initial simulator experiment, with the goal of exploring whether, and to what extent anticipatory driving is already used by drivers. We hope to be able to identify characteristics of anticipatory drivers (such as high driving experience, for example), and also to develop measures of anticipatory driving. Based on the findings of this experiment, we will then focus on designing aids to facilitate anticipation.

5. ACKNOWLEDGMENTS

The funding for this work was provided by the AUTO21 Network of Centres of Excellence.

6. REFERENCES

[1] Tanida, K.; Poeppel, A. 2006. A hierarchical model of operational anticipation windows in driving an automobile. *Cognitive Processing*. 7, 275–287.

[2] Hofmann, P.; Rinkenauer, G. 2013. Response preparation in a lane change task. *Ergonomics*. 56, 2, 268–281.

[3] Olson, P. L.; Sivak, M. 1986. Perception-response time to unexpected roadway hazards. *Human Factors*. 28, 1, 91–96.

[4] Davoodi, S. R.; Hamid, H.; Pazhouhanfar M.; Muttart, J. W. 2012. Motorcyclist perception response time in stopping sight distance situations. *Safety Science*. 50, 371–377.

[5] Fitch, G. M.; Blanco, M.; Morgan, J. F.; Wharton, A. E. 2010. Driver braking performance to surprise and expected events. In *Proceedings of the Human Factors and Ergonomics Society 54th Annual Meeting*, San Francisco, CA, p. 2076–2080.

[6] Endsley, M. R. 1995. Toward a theory of Situation Awareness in dynamic systems. *Human Factors*. 37, 1, 32–64.

[7] Pollatsek, A.; Narayanaan, V.; Pradhan, A.; Fisher, D.L. 2006. Using eye movements to evaluate a PC-based risk awareness and perception training program on a driving simulator. *Human Factors*. 48, 3, 447–464.

[8] Jackson, L.; Chapman, P.; Crundall, D. 2009. What happens next? Predicting other road users' behaviour as a function of driving experience and processing time. *Ergonomics*. 52, 2, 154–164.

[9] Fuller, R. 1984. „A conceptualization of driver behavior as threat avoidance", *Ergonomics*, 27, 1139–1155.

[10] Onken, R. 1993. „What should the vehicle know about the driver?", In *Driving Future Vehicles*, Parkes, A. M.; Franzen, S., London: Taylor & Francis. 49–67.

[11] Treiber, A.; Kesting, M. 2007. Influence of reaction times and anticipation on the stability of vehicular traffic flow. *Transportation Research Record*, 1999. 23–29.

[12] Michon, J. A. 1985. A critical view of driver behaviour models: What do we know, what should we do? In *Human Behaviour and Traffic Safety*. New York: Plenum Press. 485–520.

[13] Lee J. D.; Strayer, D. L. 2004. Preface to the special section on driver distraction. *Human Factors*. 46, 4, 583–586.

[14] McKnight, A. J.; Adams, B. B. 1970. Driver education task analysis volume I: Task descriptions. Human Resources Research Organization. Alexandria, VA, USA. HumRRO Technical Report 70-103.

[15] Rasmussen, J.; Pejtersen, A. M.; Goodstein, L. P. 1994. *Cognitive Systems Engineering*. New York, NY: Wiley-Interscience.

[16] Vicente, K. J. 1999. *Cognitive Work Analysis: Toward safe, productive, and healthy computer-based work*, Mahwah, N.J.: Lawrence Erlbaum Associates.

[17] Rasmussen, J. 1983. Skills, rules and knowledge: Signals, signs and symbolds, and other disctinctions in Human Performance Models. *IEEE Transactions on Systems, Man and Cybernetics*, 13, 3.

[18] Bennett, K. B.; Flach, J. M. 2011. *Display and interface design - Subtle science, exact art*. Boca Raton, Florida: CRC Press, Taylor & Francis Group.