2015 IEEE 18th International Conference on Intelligent Transportation Systems

Structuring Cooperative Behavior Planning Implementations for Automated Driving

Simon Ulbrich, Simon Grossjohann, Christian Appelt, Kai Homeier, Jens Rieken, and Markus Maurer

***Abstract*— Cooperative behavior planning for automated vehicles is getting more and more attention in the research community. This paper introduces two dimensions to structure cooperative driving tasks. The authors suggest to distinguish driving tasks by the used communication channels and by the hierarchical level of cooperative skills and abilities. In this manner, this paper presents the cooperative behavior skills of "Jack", our automated vehicle driving from Stanford to Las Vegas in January 2015.**

I. INTRODUCTION

The issue of cooperative driving and behavior planning has recently become a trending topic in the automated driving research community. While it is already hard to come up with a definition of what cooperative behavior or cooperative driving actually is, it is even harder to contrast it against what was done in previous decades in the field of tactical driving behavior planning.

In this paper, the authors develop a structure to classify cooperative driving tasks. On the one hand, an essential difference for cooperative driving tasks is the communication or awareness channel being used. On the other hand, the level of cooperative behavior skills and abilities may differ. Based on this, the authors develop a matrix to organize and cluster cooperative driving behavior tasks.

We pinpoint the challenges for cooperative driving due to the limited availability of appropriate communication and awareness channels. Moreover, we derive scenarios for cooperative behavior planning. Based on this, we discuss the cooperative behavior skills implemented in "Jack", our automated vehicle driving from Stanford to Las Vegas for this year's Consumer Electronics Show.

This paper is structured as follows: In section II, we review already existing definitions for cooperative behavior planning in automated driving and introduce the aspect of the employed communication channel. Based on this, the authors develop our so called cooperation matrix to cluster common cooperative behavior planning tasks in section III. Based on a survey in section IV, the authors present the cooperative behavior skills of Jack in section V. Last of all, section VI finalizes this paper with conclusions and a research outlook.

S. Ulbrich and M. Maurer are with the Institute of Control Engineering, Technische Universität Braunschweig, 38092 Braunschweig, Germany {ulbrich, rieken, maurer}@ifr.ing.tu-bs.de

S. Grossjohann, C. Appelt and K. Homeier are with the Volkswagen Group Research, Berliner Ring 2, 38440 Wolfsburg, Germany {simon.grossjohann, christian.appelt, kai.homeier}@volkswagen.de

II. RELATED WORK AND TERMINOLOGY

In robotics, the idea of cooperative behavior planning has been addressed and reviewed in many publications already, compare e.g. [1], [2], [3], [4].

In psychology, Spieß [5] defines cooperation as a form of societal collaboration between persons, groups and institutions, or respectively as social interaction. Spieß stresses that cooperation entails conscious and planned acting, as well as processes of mutual coordination about specific objectives. Cooperation premises on fair conditions of collaboration and reciprocity.

Cao et al. [1] defines "[...] a multiple-robot system displays cooperative behavior if, due to some underlying mechanism (i.e., the mechanism of cooperation), there is an increase in the total utility of the system." According to Franklin's broad definition of cooperation in [6], a multi-agent system is *independent* if each agent pursues its own agenda independently from others. Agents are called *discrete* if the agendas of both agents do not bear any relationship with each other. Anyhow, from an observer's point of view, agents can cooperate with no intention of doing so. If every agent is simply carrying out its individual behavior without the specific intention of cooperation, some *emergent cooperation* may still become visible for an outside observer.

Apart from independent multi-agent systems, Franklin [6] identifies *cooperative systems* as those in which the agendas of the agents explicitly include cooperation with other agents. He further differentiates between *deliberative* and *negotiating communicative* and *non-communicative* systems. Communicative multi-agent systems are intentionally sending and receiving signals from other agents and jointly plan their actions, or even compete for resources. Non-communicative agents coordinate their cooperative activity by observing and reacting to the behavior of others.

Norman uses a much sharper definition of cooperation in [6]. He defines that cooperating means "to act with another or others for a common purpose and for common benefit". This definition embraces three aspects. The aspect of *acting together*, a *common purpose* and a *common benefit*.

The DFG priority program proposal [7, p. 5] differentiates between using *implicit* cooperation *only* and using *implicit together with explicit* cooperation. The program proposal avoids a clear definition of explicit and implicit cooperation. Rather more, it illustrates the differentiation by two examples: According to [7, p. 1] explicit maneuver coordination allows to plan driving trajectories within safety critical margins, for which human drivers are not able to do the same because of their limited communication and reaction

978-1-4673-6596-3/15 $31.00 © 2015 IEEE
DOI 10.1109/ITSC.2015.349

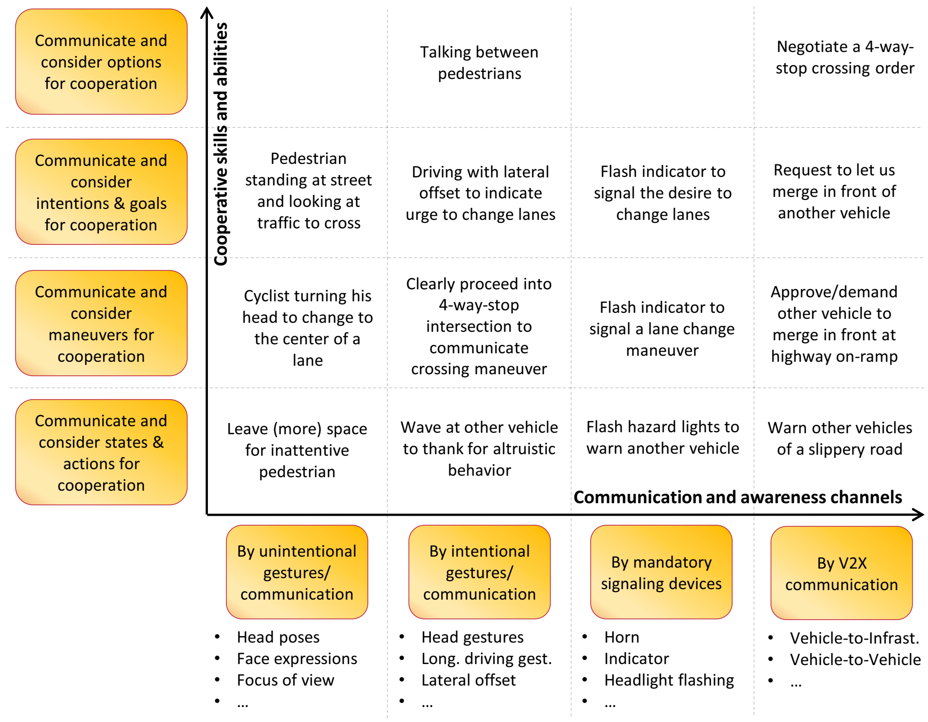


Fig. 1. Examples for cooperative behavior planning tasks classified by communication channel and necessary cooperative skills and abilities

abilities. Hence, explicit cooperation seems to necessitate explicit communication. For implicit cooperation a merge situation is discussed, where the drivers' head poses or even the lateral offsets within a lane are used to negotiate the merging process. In [8], our team pointed out that V2X-communication is just a particular communication channel among other channels that have been used long before like indicators, flashing headlights or a signal horn. No conclusive decision has yet been made, e.g., if those signaling devices should be considered as explicit or implicit communication. Similarly, Sawade and Radusch [9] differentiate between implicit, explicit, and collaborative cooperative driver assistance systems. The latter are assumed to "actively interfere in two or more vehicles at the same time" and to "negotiate".

Düring and Pascheka [10] clarified that agents are not *cooperative* per se, but *cooperative* is rather an attribute to an agent's behavior. They define "cooperative behavior with respect to [another] agent [...] and with respect to a total utility function [...], if by choosing this behavior [the first] agent [...] knowingly and willingly increases the total utility [...] in a coupled situation, compared to a reference utility." They assume that knowingly and willingly shall imply more cooperative behavior than just what the agent is *forced* to do "by legislation or physical laws".

III. COOPERATION MATRIX

Figure 1 illustrates different levels of skills and abilities and existing communication channels to address these. It lists common examples for these situations in daily driving. It differentiates disparate channels of communication and awareness and different levels of cooperative skills and abilities.

A. *COMMUNICATION AND AWARENESS CHANNELS*

As pointed out before, different communication and awareness channels exist. Apart from technical channels like a V2X-communication interface, a standard vehicle already has by traffic laws mandatory signaling devices for communication. Moreover, intentional gestures like longitudinal driving maneuvers, hand gestures or even a driver's hand gestures might be used. Technically challenging but still a viable mode of communication are unintentional gestures. All communication channels can be used to receive or transmit information. E.g. we can intentionally use indicator flashing to communicate an intention and/or be able to perceive the indicator flashing of other vehicles. If the receiving part dominates the usage of the channel it may be more intuitive to call it an awareness channel. All channels necessitate a detection and tracking of objects to cooperate with.

B. *COOPERATIVE SKILLS AND ABILITIES*

Any kind of cooperative multi-agent systems in the scheme of Franklin in [6] require certain cooperative skills and abilities, e.g. regarding perception, reasoning or communication. These skills and abilities enable cooperation on different hierarchical levels and allow different scopes of optimization and altruism as pointed out above.

According to Häcker [11] an ability is defined as the entirety of conditions which are necessary to deliver a performance. In contrast, Heuer [12] defines a skill as performance in a particular task, which results for humans from the background of task-unspecific abilities by training.

Cooperative skills and abilities are to a certain extend hierarchically distinguished.

C. EXAMPLES OF COOPERATIVE BEHAVIOR

On a very basic abstraction level, cooperation can be achieved by the communication and consideration of states and actions for cooperative driving behavior. A possible state to be communicated could be an intervention of the Electronic Stability Control (ESC) system of a vehicle. A possible action to be communicated could be a braking action. The next level does not address single actions or states, but rather tactical maneuvers. A maneuver entails a sequence of actions and states. Maneuvers, which are to be executed are motivated by intentions and goals. Thus, an even higher abstraction level is to communicate and consider intentions of other vehicles even before they are substantiated into executable maneuvers. An example for such an intention could be a bus at the roadside communicating its merge intention and an altruistic automated vehicle which brakes a bit for the bus and communicates that it will let the bus merge back into the traffic. If the skills and abilities are limited to the communication and consideration of intentions and goals, decisions need to be made locally by each *deliberative agent* (cf. [6]). Vice versa, for *negotiating multi-agent systems* it is necessary to communicate (inquire and answer) and consider *options* for behavior alternatives. It is necessary to negotiate by exchanging information about costs of potential behavior options (intentions, goals, maneuvers, actions). This allows to achieve solutions closer to the true overall system optimum with still independent agents. As an example for this, it could be beneficial for a bus to communicate via V2X high costs for the behavior option of not letting it merge in front of an automated vehicle because the bus is behind it's schedule. It is to be noted, that this communication about options does rarely happen in today's traffic. On the one hand, because typical traffic participants do not have a communication channel with a suitable bandwidth (shouting between fast moving vehicles, that one is behind its schedule is rarely seen). On the other hand, this level of cooperation requires honest behavior. An individual agent gains personal benefit from communicating wrong behavior option costs. Without a mechanism (e.g., a system of trust) to penalize such selfishness, cooperation on such a high abstraction level might not work at all.

D. THE CHALLENGE FOR COOPERATIVE BEHAVIOR PLANNING IN TODAYS AUTOMATED VEHICLES

Figure 1 provides a scheme to substantiate the vague term of "cooperation". Yet, figure 1 also illustrates one of todays main challenges for cooperative behavior planning in automated driving. In the very right it lists possible cooperation scenarios using V2X-communication. But, since V2X-communication as of 2015 is not widely available, it is at best an additional channel to improve comfort. Anyhow, cooperative automated driving needs to work safely also without this channel.

On the other end of the axis of communication and awareness channels, is the communication by intended and unintended gestures. Using these channels imposes high perception requirements, which are currently not fully met. As of 2015, it is already challenging to perceive lanes and decently sized objects like cars or trucks reliably. Identifying the driver in a tracked car is at the forefront of research. Estimating his head pose or hand signals seems far out of reach for reliable use for today's cooperative, automated vehicles. The same holds true -although to a smaller extend- for detecting indicators, brake lights or a headlight flashing.

In essence, cooperative automated driving is limited to very few situations, for which communication and awareness channels exist in today's automated vehicles. For many of those, it is rather a matter of taste to call them *cooperative behavior* or just regular automated driving. E.g., aborting an already initiated lane change maneuver due to suddenly perceiving a vehicle on the neighbor lane could be considered a cooperative maneuver to prevent discomfort or stress for the other vehicle, but it could also just be called a necessary basic feature of a lane change planning module.

IV. SURVEY OF PUBLISHED IMPLEMENTATIONS

Nakamura et al. [13] propose a general concept for vehicle-to-vehicle and vehicle-to-infrastructure communication in automated driving. They see applications in warnings for dangers ahead, emergency notifications, driver information about surrounding vehicles and collision prevention systems.

Longitudinal behavior planning for automated vehicles has been the main focus of the Grand Cooperative Driving Challenge held in 2011 [14]. It stimulated a lot of research around longitudinal behavior planning and vehicle control with V2X-communication, e.g., regarding string stability, fuel consumption minimization and platooning.

However, as todays availability of V2X-communication partners on a regular stretch of highway or in urban areas is close to zero, the focus for the remainder of this survey is directed to cooperative behavior without V2X-communication.

Milanes et al. [15] demonstrate a similar system as above, where they compare a series production ACC-system and a cooperative ACC-system optimized for vehicles cutting in and out closely in front of the test vehicle (cf. SC 6 in table I; "SC" = Scenario) without V2X-communication. Similarly, Freyer et al. [16] try to improve the ACC behavior in scenarios as in SC 6 and SC 9 in table I, by incorporating a situation analysis and a behavior prediction of the lane changing behavior of other traffic participants.

In simulated environments, the development of car-following models for behavior simulation has been a focus of research for several decades. Literature is vast and has extensively been reviewed by, e.g., [17], [18], [19]. Extensions of these models exist to address lane changing and gap selection aspects, in which cooperative behavior is a central topic. Gipps [20] proposes a framework for lane change decision making in sub-urban driving situations (cf. SC 1). Hidas [21, p. 366] and [22] analyzes that merging situations are just a special case of lane changing, because a (ramp) lane ends or is blocked. Particularly but not limited to these situations, he proposes an improved lane change model. If a lane change is necessary but not feasible the merging vehicle will determine a best possible merge acceleration to make the traffic situation more favorable for lane changes. If no gap seems suitable for a lane change it will pick the most behind gap and thus decelerate (cf. SC 5). Moreover, he implements some kind of cooperative behavior for other vehicles to clear a lane for a merging vehicle (cf. SC 7).

Ruf et al. [23] develop the SPARC framework for behavior planning and addressed scenario SC 10 and SC 13. The prediction model is separated from the reward model. So far it is applied on perfect, simulated data but seem to scale well with real, uncertain sensor data.

Among the core issues for cooperative behavior planning is an appropriate situation assessment. Schubert et al. [24] use a Bayesian network for situation assessment and decision making for lane changes (cf. SC 1). Deceleration to safety time (DST) is used as a central criterion for lane change situation assessment.

Reichel et al. [25] present an approach for situation aspect modeling and situation assessment for merging situations as in scenario SC 9. Frese [26] develops a framework for the planning of cooperative driving maneuvers for automated vehicles. He addresses how to determine cooperative groups and how to modify the trajectory planning to cooperate with other vehicles. His evaluations are based on a simulation environment. He assumes a communication channel to communicate vehicle state variables and maneuvers. Sivaraman et al. [27] demonstrate an assistance system for lane changes to address the scenarios SC 1 and SC 5. Schwarting et al. [28] propose a system to consider costs of other vehicles in a cooperative group and tests the approach in a simulation environment and *offline* with recorded data form an automated vehicle driving on a highway.

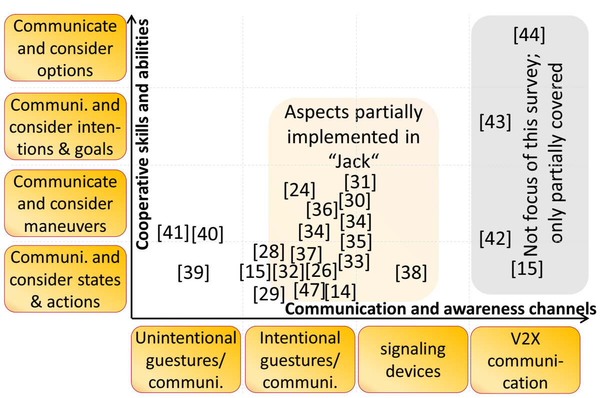


Fig. 2. Literature clustered in the matrix

In the DARPA Urban Challenge, the scenarios SC 1, SC 10 and SC 13 have been addressed by many teams. Exemplary implementations can be found in [29], [30].

Ardelt et al. [31], [32] present BMW's approaches for the scenario SC 1 in its *ConnectedDrive*-project, focused on highly automated driving on highways.

Team Autonomous from FU Berlin [33] demonstrates the handling of traffic lights/intersections (cf. SC 12, SC 13), obstacle avoidance/passing (cf. SC 10) and according to [33, p. 72] some briefly mentioned lane change implementation (cf. SC 1). Ulbrich et al. [34], [35] demonstrate the handling of lane changes in automated driving in urban areas (cf. SC 1). In their PROUD demonstration, Broggi et al. [36] have addressed cooperative behavior at crosswalks (cf. SC 11), traffic lights/intersections (cf. SC 12) and merging/yielding at intersections and roundabouts (cf. SC 13). Daimler and the KIT [37] demonstrated the handling of yielding and merging at roundabouts (cf. SC 13), traffic lights/intersections (cf. SC 12), pedestrians (cf. SC 11), obstructing objects (cf. SC 10) [38] in their Bertha-Benz automated driving tour.

In the remainder of this section, we present some papers not addressing cooperative behavior as a whole, but which are focusing on certain key aspects that will help to implement cooperative behavior in future. Fröhlich et al. [39] present an approach for turn signal recognition in the frequency domain. Klöden [40], Schmidt et al. [41] and Keller et al. [42] address the perception of head poses and crossing intentions for pedestrians crossing a street. They use unintended gestures for this.

Awal et al. [43] use an V2X-communication based approach to coordinate highway merge situations (cf. SC 6, SC 7), where one vehicle is selected as a group leader for a cooperative group. The group leader receives *state information* and calculates/communicates a cost-optimal choreography for the cooperative group to cross the intersection. Makarem et al. [44] simulate a V2X-Communication based approach for vehicles to cross intersections without traffic lights by a decentralized model-predictive control approach (cf. SC 13). They assume the communication of *states* and *intentions*. Similarly, de Campos et al. [45] present a decentralized approach for unsignalized intersection crossing for automated vehicles with V2X-communication. They assume the exchange of *attraction sets* for behavior *options*, thus allowing a *negotiation of policies* between vehicles.

Figure 2 tries to group some of the references in this paper in the matrix from figure 1. Many publications span over several aspects. Anyhow, for the sake of readability, publications are shown as one point rather than a spanning area. Focus of todays not-V2X-communication research is the communication and consideration of states, actions and maneuvers by intentional gestures. Many publications use signaling devices to broadcast information. Only few to receive information. Higher levels of cooperative behavior are currently mainly tested in simulations which assume a V2X-like communication channel.

V. IMPLEMENTATIONS IN "JACK"

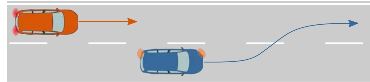
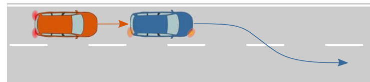
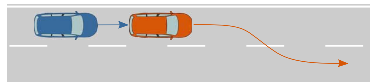
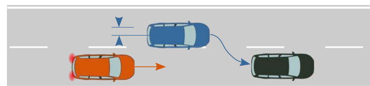
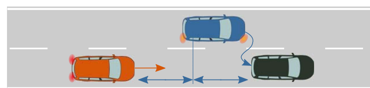
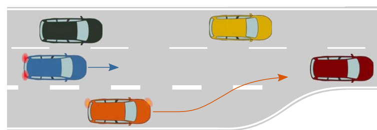
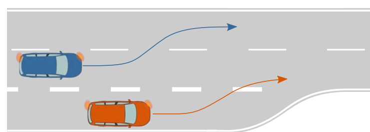
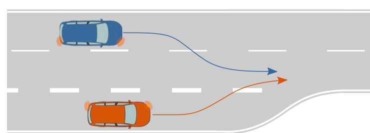
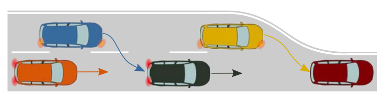
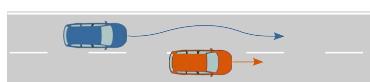
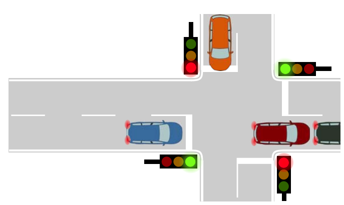
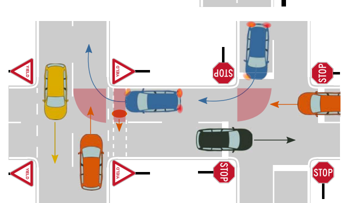
In January 2015, our team presented "Jack", the *Audi A7 piloted driving concept* vehicle for automated driving, at the Consumer Electronics Show 2015 in the US[1] and in February on a German highway to the media[2]. For this, the vehicle drove a stretch of 550 miles on a highway from Stanford to

[1] http://www.audi.com/content/com/brand/en/vorsprung_durch_technik/content/2014/10/piloted-driving.html

[2] http://www.stern.de/auto/news/jack-das-selbstfahrende-auto-von-audi-erstmals-auf-einer-deutschen-autobahn-2174446.html

TABLE I

SCENARIOS NECESSITATING COOPERATIVE BEHAVIOR (EGO VEHICLE=BLUE OR ORANGE) AND BEING ADDRESSED BY WHOM

Nr.	Scenario	Illustration	Addressed by publication	Addressed by "Jack"
SC 1	Considering (dis-)comfort costs for rear vehicles		[20], [24], [31], [32], [34], [35], [27], [29], [30], [33]	✓
SC 2	Giving way to pressing rear vehicles			✓
SC 3	Requesting cooperation of slow front vehicle ("tailgating"). May not be legal			✗
SC 4	Squeezing into gaps by lateral offsets to the lane center			✓
SC 5	Squeezing into gaps by longitudinal adjustment to gaps and usage of the indicator		[21], [22], [27]	✓
SC 6	Letting vehicles merge in front if their lane or on-ramp ends soon, or if they enter the traffic from a bus stop or parking space		[43], [15], [16]	✓
SC 7	Clearing a lane for vehicles if their lane or on-ramp ends soon, or if they enter the traffic from a bus stop or parking space		[22], [43]	✓
SC 8	Not changing to a lane on which another vehicle is about to merge to			✓
SC 9	Dedicated handling of zipper method merging where the automated vehicle merges or let merge		[25], [16]	✓/✗
SC 10	Off-centered driving to leave space for obstructing objects		[23], [37], [29], [30], [33], [38]	✓
SC 11	Letting a pedestrian pass, who has just entered the road. Possibly -but not limited to- crosswalks		[36], [37]	✗
SC 12	Not entering an intersection/conflict area, if it cannot be cleared and cross-traffic will be obstructed		[33], [36], [37]	✗
SC 13	Yielding and merging to another lane. This subsumes 4-way stops, roundabouts, pedestrian and bike lanes, etc. Conflict areas highlighted in red		[23], [33], [36], [37], [44], [45], [29], [30]	✗

Las Vegas and around Braunschweig, Germany. To achieve this, it was necessary to implement several cooperative behavior skills.

Table I shows a non-conclusive list of scenarios and conjoined cooperative behavior. Most of the scenarios need to be considered from both the blue vehicle's, but also the orange vehicle's, point of view.

Many of the maneuvers are by some extend linked to lane changes. Lane changes are of particular importance as they often necessitate cooperative behavior or are at least vastly simplified by this. Moreover, one should note, that traffic regulations explicitly dictate cooperation in some of these scenarios.

Fig. 3. "Jack", our *Audi A7 piloted driving concept* vehicle

The automated vehicle is able to perform lane changes while considering the costs of discomfort for other vehicles (cf. SC 1). Moreover, it is able to give way to other vehicles tailgating the automated vehicle (cf. SC 2). This is particularly relevant for automated driving on German highways, where overtaking on the right is not allowed. The opposite scenario, to tailgate a slow vehicle to request its cooperation to clear the lane (cf. SC 3) is technically feasible to implement but will conflict with traffic regulations and has therefore not been implemented.

To enable lane changes in dense traffic, it is necessary not just to wait until a decently sized gap appears, but also to cooperatively "open up" gaps for lane changes. To achieve this, the automated vehicle is able to perform off-centered driving (cf. SC 4) and a longitudinal adjustment to the center of a gap and activating the indicator (cf. SC 5).

At highway entrance ramps, some degree of cooperation is often expected by other traffic participants. In particular if a truck is merging onto the highway it will expect cooperative behavior of regular vehicles. The scenarios SC 6 to SC 8 illustrate three aspects of these situations. First, the automated vehicle will open up a gap in front of it in order to let vehicles merge in front (cf. SC 6). Secondly, it will avoid changing onto the rightmost lane of a highway if a merging vehicle may also be changing to that lane (cf. SC 8). Thirdly, depending on the accuracy of perception and a-priori map data, it will clear a lane for merging traffic by a lane change (cf. SC 9).

A zipper-method merging as in scenario SC 9 has not dedicatedly been implemented, but is partly covered by the cooperative behavior in the earlier mentioned scenarios already. However, no dedicated counting of other vehicles to determine their order of merging has been demonstrated. If a vehicle insists to move before the automated vehicle it will be tolerated no matter if it is its turn or not.

Scenario SC 10 illustrates cooperative, off-centered driving for maintaining comfortable lateral distances towards other objects. This has initially been implemented as a part of the trajectory planning for collision avoidance but also serves the purpose of cooperation on the tactical behavior level.

Cooperative behavior as in scenarios SC 11 to SC 13 have not yet been demonstrated to the public and are not relevant for the domain of highways that has been demonstrated for the CES 2015 show case.

Implementation details of the cooperative, tactical behavior planning go beyond the scope of this paper. Parts of them are presented in Ulbrich & Maurer [46], [47].

VI. CONCLUSIONS

In this paper, we reviewed definitions and concepts for cooperation in tactical behavior planning for automated vehicles. We pinpointed a possible differentiation by communication and awareness channels and the orthogonal dimension of cooperative behavior skills and abilities. Based on this, we identified the challenge for cooperative tactical behavior planning for today's automated vehicles imposed by the limitations of available communication channels. Nonetheless, we identified a list of scenarios for cooperative behavior planning being addressable with today's automated vehicles already. Here we presented what has been implemented in the *Audi A7 piloted driving concept* vehicle driving automated from Stanford to Las Vegas.

So far, the list of scenarios is not yet complete. The authors expect more scenarios especially in the urban domain. The authors surveyed several publications. However, the matrix in figure 2 as well as the list of scenarios demonstrate several gaps, which haven't been addressed yet. This publication is limited to just naming these scenarios and fields. It opens a big field of application development to actually implement them facilitating different channels of communication.

REFERENCES

[1] Y. U. Cao, A. S. Fukunaga, and A. Kahng, "Cooperative Mobile Robotics: Antecedents and Directions," *Autonomous Robots*, vol. 4, no. 1, pp. 7–27, Mar. 1997.

[2] L. E. Parker, "Current research in multirobot systems," *Artificial Life and Robotics*, vol. 7, no. 1-2, pp. 1–5, Mar. 2003.

[3] Y. Mohan and S. Ponnambalam, "An extensive review of research in swarm robotics," in *World Congress on Nature Biologically Inspired Computing, 2009. NaBIC 2009*, Dec. 2009, pp. 140–145.

[4] M. Brambilla, E. Ferrante, M. Birattari, and M. Dorigo, "Swarm robotics: a review from the swarm engineering perspective," *Swarm Intelligence*, vol. 7, no. 1, pp. 1–41, Mar. 2013.

[5] E. Spieß, "Kooperation," in *Dorsch Lexikon der Psychologie*, M. A. Wirtz, Ed. Verlag Hans Huber, 2014, [accessed on 04.01.2015]. [Online]. Available: https://portal.hogrefe.com/dorsch/kooperation/

[6] J. E. Doran, S. Franklin, N. R. Jennings, and T. J. Norman, "On cooperation in multi-agent systems," *The Knowledge Engineering Review*, vol. 12, no. 03, pp. 309–314, 1997.

[7] C. Stiller, W. Burgard, B. Deml, L. Eckstein, F. Flemisch, F. Köster, M. Maurer, and G. Wanielik, "Kooperativ interagierende Automobile," Deutsche Forschungsgemeinschaft (DFG), Tech. Rep., 2013. [Online]. Available: http://www.mrt.kit.edu/spp1835/download/spp1835.pdf

[8] R. Matthaei, A. Reschka, J. Rieken, F. Dierkes, S. Ulbrich, and M. Maurer, "Autonomes Fahren," in *Handbuch Fahrerassistenzsysteme: Grundlagen, Komponenten und Systeme für aktive Sicherheit und Komfort*, 3rd ed., H. Winner, S. Hakuli, F. Lotz, and C. Singer, Eds. Springer, 2015.

[9] O. Sawade and I. Radusch, "A Selection Process for Next Generation Cooperative Driver Assistance Systems," in *20th ITS World Congress*, Japan, 2013.

[10] M. During and P. Pascheka, "Cooperative decentralized decision making for conflict resolution among autonomous agents," in *Proc., 2014 IEEE Int. Symposium on Innovations in Intelligent Systems and Applications (INISTA)*, June 2014, pp. 154–161.

[11] H. Häcker, "Fähigkeiten," in *Dorsch Lexikon der Psychologie*, M. A. Wirtz, Ed. Verlag Hans Huber, 2015, [accessed on 04.01.2015]. [Online]. Available: https://portal.hogrefe.com/dorsch/faehigkeit/

[12] H. Heuer, "Fertigkeiten," in *Dorsch Lexikon der Psychologie*, M. A. Wirtz, Ed. Verlag Hans Huber, 2015, [accessed on 04.01.2015]. [Online]. Available: https://portal.hogrefe.com/dorsch/fertigkeit/

[13] M. Nakamura, H. Kawashima, T. Yoshikai, and K. Aoki, "Road-vehicle cooperation driving system," in *Proc. of Vehicle Navigation and Information Systems Conference*. IEEE, 1994, pp. 425–430.

[14] J. Ploeg, S. Shladover, H. Nijmeijer, and N. van de Wouw, "Introduction to the Special Issue on the 2011 Grand Cooperative Driving Challenge," *IEEE Transactions on Intelligent Transportation Systems*, vol. 13, no. 3, pp. 989–993, Sept. 2012.

[15] V. Milanes, S. Shladover, J. Spring, C. Nowakowski, H. Kawazoe, and M. Nakamura, "Cooperative Adaptive Cruise Control in Real Traffic Situations," *IEEE Transactions on Intelligent Transportation Systems*, vol. 15, no. 1, pp. 296–305, Feb. 2014.

[16] J. Freyer, B. Deml, M. Maurer, and B. Farber, "ACC with enhanced situation awareness to reduce behavior adaptations in lane change situations," in *IEEE Intelligent Vehicles Symposium*, June 2007, pp. 999–1004.

[17] T. Muller and H. van Zuylen, "A Driving Behavior Model for Microscopic Online Simulation based on Remote Sensing and Equipped Vehicle Data," in *Transportation Research Board Annual Meeting*, Washington, DC, 2006, p. w/o page numbers.

[18] T. Toledo, "Integrated Driving Behavior Modeling," Dissertation, MIT, 2003.

[19] V. Kanagaraj, G. Asaithambi, C. H. N. Kumar, K. K. Srinivasan, and R. Sivanandan, "Evaluation of Different Vehicle Following Models Under Mixed Traffic Conditions," *Procedia - Social and Behavioral Sciences*, vol. 104, pp. 390–401, Dec. 2013.

[20] P. Gipps, "A model for the structure of lane-changing decisions," *Transportation Research Part B: Methodological*, vol. 20, no. 5, pp. 403–414, Oct. 1986.

[21] P. Hidas, "Modelling lane changing and merging in microscopic traffic simulation," *Transportation Research Part C: Emerging Technologies*, vol. 10, no. 56, pp. 351–371, Oct. 2002.

[22] P. Hidas, "Modelling vehicle interactions in microscopic simulation of merging and weaving," *Transportation Research Part C: Emerging Technologies*, vol. 13, no. 1, pp. 37–62, Feb. 2005.

[23] M. Ruf, J. R. Ziehn, D. Willersinn, B. Rosenhahn, J. Beyerer, and H. Gotzig, "A Continuous Approach to Autonomous Driving," in *Proc. of the Conference on Vehicle and Infrastructure Safety Improvement in Adverse Conditions and Night Driving (VISION 2014)*, Versailles, France, Dec. 2014.

[24] R. Schubert, K. Schulze, and G. Wanielik, "Situation Assessment for Automatic Lane-Change Maneuvers," *IEEE Transactions on Intelligent Transportation Systems*, vol. 11, no. 3, pp. 607–616, Sept. 2010.

[25] M. Reichel, M. Botsch, R. Rauschecker, K. Siedersberger, and M. Maurer, "Situation aspect modelling and classification using the Scenario Based Random Forest algorithm for convoy merging situations," in *13th International IEEE Conference on Intelligent Transportation Systems*. Madeira, Portugal: IEEE, 2010, pp. 360–366.

[26] C. Frese, "Planung kooperativer Fahrmanöver für kognitive Automobile," Ph.D. dissertation, Karlsruher Institut für Technologie, 2012.

[27] S. Sivaraman and M. M. Trivedi, "Dynamic Probabilistic Drivability Maps for Lane Change and Merge Driver Assistance," *IEEE Transactions on Intelligent Transportation Systems*, vol. 15, no. 5, pp. 2063–2073, Oct. 2014.

[28] W. Schwarting and P. Pascheka, "Recursive conflict resolution for cooperative motion planning in dynamic highway traffic," in *17th Int. Conference on Intelligent Transportation Systems (ITSC)*, Oct. 2014, pp. 1039–1044.

[29] M. Montemerlo, J. Becker, S. Bhat, H. Dahlkamp, D. Dolgov, S. Ettinger, D. Haehnel, *et al.*, "Junior: The Stanford Entry in the Urban Challenge," *Journal of Field Robotics*, vol. 25, no. 9, pp. 569–597, Sept. 2008.

[30] C. Urmson, J. Anhalt, D. Bagnell, C. Baker, R. Bittner, M. N. Clark, J. Dolan, *et al.*, "Autonomous Driving in Urban Environments : Boss and the Urban Challenge," *Journal of Field Robotics*, vol. 25, no. 8, pp. 425–466, 2008.

[31] M. Ardelt and P. Waldmann, "Hybrides Steuerungs- und Regelungskonzept für das hochautomatisierte Fahren auf Autobahnen," *at - Automatisierungstechnik Methoden und Anwendungen der Steuerungs-, Regelungs- und Informationstechnik*, vol. 59, no. 12, pp. 738–750, 2011.

[32] M. Ardelt, C. Coester, and N. Kaempchen, "Highly Automated Driving on Freeways in Real Traffic Using a Probabilistic Framework," *IEEE Transactions on Intelligent Transportation Systems*, vol. 13, no. 4, pp. 1576–1585, Dec. 2012.

[33] M. Wang, T. Ganjineh, and R. Rojas, "Action annotated trajectory generation for autonomous maneuvers on structured road networks," in *5th International Conference on Automation, Robotics and Applications*. Wellington, New Zealand: IEEE, Dec. 2011, pp. 67–72.

[34] S. Ulbrich and M. Maurer, "Probabilistic online POMDP decision making for lane changes in fully automated driving," in *Proc. of the 16th Int. IEEE Conference on Intelligent Transportation Systems (ITSC 2013)*, The Hague, Netherlands, Oct. 2013, pp. 2063–2067.

[35] S. Ulbrich and M. Maurer, "Evaluation einer taktischen Verhaltensentscheidungsfindung für Fahrstreifenwechsel beim vollautomatisierten Fahren in Städten," in *9. Workshop Fahrerassistenzsysteme FAS 2014*, B. Färber, Ed., Walting, 2014, pp. 147–158.

[36] A. Broggi, P. Cerri, S. Debattisti, M. Laghi, P. Medici, M. Panciroli, and A. Prioletti, "PROUD-Public road urban driverless test: Architecture and results," in *Intelligent Vehicles Symposium Proceedings, 2014 IEEE*, June 2014, pp. 648–654.

[37] J. Ziegler, P. Bender, M. Schreiber, H. Lategahn, T. Strauss, C. Stiller, T. Dang, *et al.*, "Making Bertha Drive - An Autonomous Journey on a Historic Route," *IEEE Intelligent Transportation Systems Magazine*, vol. 6, no. 2, pp. 8–20, 2014.

[38] J. Ziegler, P. Bender, T. Dang, and C. Stiller, "Trajectory planning for Bertha - A local, continuous method," in *Intelligent Vehicles Symposium Proceedings, 2014 IEEE*, June 2014, pp. 450–457.

[39] B. Fröhlich, M. Enzweiler, and U. Franke, "Will this car change the lane? - Turn signal recognition in the frequency domain," in *Intelligent Vehicles Symposium Proceedings, 2014 IEEE*, June 2014, pp. 37–42.

[40] H. Klöden, "Potenzial der Kopfposenerkennung zur Absichtsvorhersage von Fußgängern im urbanen Verkehr," in *9. Workshop Fahrerassistenzsysteme FAS 2014*, Walting, 2014, pp. 67–78.

[41] S. Schmidt and B. Färber, "Pedestrians at the kerb Recognising the action intentions of humans," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 12, no. 4, pp. 300–310, July 2009.

[42] C. G. Keller, C. Hermes, and D. M. Gavrila, "Will the Pedestrian Cross? Probabilistic Path Prediction Based on Learned Motion Features," in *Pattern Recognition, Lecture Notes in Computer Science*, ser. Lecture Notes in Computer Science, R. Mester and M. Felsberg, Eds. Springer Berlin Heidelberg, Jan. 2011, pp. 386–395.

[43] T. Awal, L. Kulik, and K. Ramamohanrao, "Optimal traffic merging strategy for communication- and sensor-enabled vehicles," in *Proc. 16th Int. IEEE Conference on Intelligent Transportation Systems (ITSC 2013)*, Oct. 2013, pp. 1468–1474.

[44] L. Makarem, D. Gillet, and S. Member, "Model predictive coordination of autonomous vehicles crossing intersections," in *16th International IEEE Conference on Intelligent Transportation Systems (ITSC 2013)*, 2013, pp. 1799–1804.

[45] G. R. de Campos, P. Falcone, and J. Sjoberg, "Autonomous cooperative driving: A velocity-based negotiation approach for intersection crossing," in *16th Int. IEEE Conference on Intelligent Transportation Systems (ITSC 2013)*. IEEE, Oct. 2013, pp. 1456–1461.

[46] S. Ulbrich and M. Maurer, "Towards tactical behavior planning for lane changes in automated driving," in *18th Int. IEEE Conference on Intelligent Transportation Systems (ITSC 2015)*, Gran Canaria, Spain, Sept 2015, accepted.

[47] S. Ulbrich and M. Maurer, "Situation Assessment in Lane Change Behavior Planning for Automated Vehicles," in *18th Int. IEEE Conference on Intelligent Transportation Systems (ITSC 2015)*, Gran Canaria, Spain, Sept 2015, accepted.