

# Survey and Classification of Cooperative Automated Driver Assistance Systems

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**Abstract**—The introduction of dedicated short-range Vehicle-to-Vehicle communication (DSRC) enables the next step in advanced driver assistance systems (ADAS) – the cooperative automated driver assistance systems (CoDAS). Combined with automated functions and even autonomous driving, a host of novel functions become feasible. Some of these – such as platooning – have been in research for decades, while others are not tackled yet. In this paper we give an overview on research on automated cooperative functions, survey conceivable functions and present a way to classify them.

**Keywords**—*ADAS; cooperative vehicles; intelligent vehicles; cooperative driver assistance; CoDAS*

## I. INTRODUCTION

Vehicular communication over dedicated short-range (DSRC) is nearing introduction to the market – just recently GM has announced the introduction for a 2017 Cadillac model [1]. Successful field operational tests as in the US “Safety Pilot” [2] and the European “DRIVE C2X” [3] have shown that the technology is ready and significant improvement to safety and traffic efficiency are to be expected. In parallel, research and development of driver assistance systems has progressed towards more automation, with high-automated driving functions on the horizon for next generation vehicles. Furthermore, research into fully automated and autonomous vehicles has seen a huge boost in these recent years [4].

Between these two dimensions of cooperation and automation spans the field of cooperative driver assistance (CoDAS). While such functions have been investigated for several years, the focus has mostly been on the automation or the function itself, using communication only as a means to enable them. The properties of communication, though, are very unique – distinguishing it from all other perception methods. Most prominently the possibility to receive vehicle intentions and thus to explicitly negotiate a common driving maneuver. We propose to create a generic communication method as an extension of current DSRC to facilitate CoDAS. The requirements for these protocols, though, are highly dependent on the functions to be enabled.

To distinguish communication requirements, a survey of existing functions and subsequently generic functions is necessary. In this work, we present such a survey. We furthermore select criteria to group these functions along their

communications requirements. These are used to identify clusters and thus present a scale for the cooperation dimension, similar to the automation scales recently introduced by NHTSA, BASt and others [5]. In future work, the categories and cluster prototypes identified can be used to create a generic CoDAS protocol.

This paper is structured into six chapters. In chapter two we present existing approaches to CoDAS and list generic functions identified in past and current research. We continue our approaches at identifying theoretically possible CoDAS functions in chapter three. First, we examine functions made possible by adding a cooperative element to existing automated ADAS. Subsequently, we look at the alternative direction: identifying functions possible by adding automation to existing cooperative functions. We conclude chapter three by listing functions not possible with either automation or cooperation alone. In chapter four we present the list of identified functions and properties along which they can be classified. We use these to propose a classification scheme in chapter five. We finish in chapter six with a conclusion and an outlook into further development in this area especially in light of fully automated and autonomous vehicles.

## II. SURVEY OF EXISTING COOPERATIVE AUTOMATED DRIVER ASSISTANCE

In this chapter we provide a survey of cooperative automated functions existing. We ignore any function without both automation and cooperation.

Research from academia and industry has a long history of implementing communication into driver assistance. In particular, first communication was implemented in huge research programs such as Prometheus or PATH. The automated highway system (AHS) in early PATH functions used communication amongst other sensors to enable a fully automated highway [6].

One of the obvious uses of communication is to enhance perception fidelity. Using communication, clear measurements not only of vehicular speed, but also of derivations acceleration and jerks can be transmitted, which normal sensors can only extrapolate. This was used to implement longitudinal vehicle control beyond capabilities of normal sensors in vehicle following situations in several functions. “Platooning” (i.e. permanent longitudinal and lateral control of vehicles to follow

a lead vehicle in close proximity) was implemented in PATH as well as in PROMOTE-CHAUFFEUR [7]. Recently, the SARTRE project has implemented a platooning function based on IEEE 802.11p [8].

Besides platooning, a more loose form of vehicle coupling is being implemented in the Autonet2030 project [9]. This “Convoy” function consists of a group of vehicles travelling in the same direction at similar speeds and uses cooperation to adapt longitudinal and lateral control. Furthermore, a pure longitudinal control is known as “cooperative adaptive cruise control (CACC)”. This has been in research in projects such as the “Connect&Drive” project and the “Grand cooperative driving challenge” [10][11].

In the area of lateral control, communication is used to prevent accidents in conjunction with lane changes and while overtaking. We have presented a “cooperative active blind-spot assistance (CABSA)” function in [12]. Work into “cooperative overtaking assistance (COA)” and “cooperative overtaking collision prevention (COCPP)” has been done in the PRORETA project [13][14].

Finally, a well-known research area is that of intersection collision prevention [15], [16] and automated intersections [17], [18]. In these functions, vehicles (in some instances in cooperation with an infrastructure-based component) negotiate usage of an intersection and try to find and optimize collision-free usage.

### III. SURVEY OF GENERIC CoDAS FUNCTIONS

In this chapter we survey theoretically feasible functions to evaluate properties of CoDAS classes. We specifically do not judge feasibility in this stage.

#### A. Generic CoDAS as a cooperative extension of automation

Since CoDAS is the combination of automation and cooperation in a driver assistance system, generic CoDAS functions can be derived by analyzing current ADAS functions regarding their compatibility to integrate cooperation.

One of the most prevalent ADAS function in current production vehicle is longitudinal control based on headway and speed of vehicles ahead. This function can be used for comfort (adaptive cruise control, ACC) or for safety (frontal collision avoidance, FCA). Both of these functions are obvious candidates for a cooperative variant: communication can provide more precision and higher distance of vehicle tracking compared to any in-vehicle sensor. In a cooperative longitudinal control function, this information can be used two-fold: to improve range for preemptive adaption or to increase fidelity.

In the case of a cooperative vehicle directly ahead, communication can be used to receive low latency high-precision situational information, especially for speed, acceleration or hard-braking situations. This can be used to optimize longitudinal control. This function is well-known as CACC. When considered as a safety-relevant function, it is classified as “cooperative frontal collision avoidance (CFCA)”.

In situations, where cooperative vehicles are present beyond line-of-sight of in-built sensors, the ACC function can

adapt speeds in case of extreme deviations, e.g. with traffic-jams or roadworks ahead. This function has not been discussed in depth so far, but presents an obvious target for a more “intelligent” ACC. Thus, we will refer to it as “iACC”. It differs from CACC in scope – while CACC is a continuous adaptation based on periodic message, the iACC uses event-based messages (not necessarily directly from the vehicle it follows) to adapt to events ahead in a longer timeframe.

The second area of ADAS, which can be optimized with communication is lateral control in lane-changing situations. Current vehicles offer blind-spot collision avoidance (active blind-spot assist, ABSA). Functions, which conduct automated lane changes (lane-change assist, LCA) are under development both as individual functions as well as combined with high-automated driving. Technically, both functions are very similar – identifying the possibility of a safe lane change. Communication in this regard can be useful to identify vehicles out of sensor range and to increase precision of measurements. This can be useful in situations with high differential velocity, e.g. for hard-braking vehicles in the adjacent lane ahead or for quick approaching vehicles out of sensor range (e.g. on unrestricted German highway sections). The corresponding functions are subsequently identified as “cooperative active blind-spot assist (CABSA)” and “cooperative lane change assist (CLCA)”.

Finally, first ADAS functions for intersection collision prevention (ICP) are emerging, e.g. in the “BAS PLUS with Cross-Traffic Assist” function introduced in the 2014 S-Class. Since intersections often feature occlusions by buildings and vegetation, this area is an ideal candidate for communication. The “cooperative intersection collision prevention (CICPP)” thus enhances the ICP function with beyond line-of-sight capabilities.

The next step in ADAS is in level of automation: the introduction of high-automated functions (“pilot” or “chauffeur” functions) on highways is expected in this decade [19], [20], [21]. These other functions are optimal candidates to include event information from cooperative messages, such as traffic hazards, roadworks or average speeds. This function is subsequently referred to as “intelligent Pilot (iPilot)”.

#### B. Generic CoDAS as an automated extension of cooperation

In this section we present an overview of generic functions created by extending cooperative functions with automation. For this paper we surveyed functions implemented in the most recent large-scale FOTs DRIVE C2X and Cooperative Safety Pilot [3][22].

Similarly to the previous section, collision avoidance is an obvious target for CoDAS functions. Safety Pilot and to an extent DRIVE C2X developed and tested functions in the category of FCA, e.g. “emergency electronic brake light” or “traffic-jam ahead warning” (DRIVE C2X) or “frontal collision warning” (Safety Pilot). These functions lend themselves for automation in a CFCA function.

In “Safety-Pilot”, intersection assistance is considered as a safety-related function. To this reasoning, an active intersection collision avoidance is reasonable, as presented in the CICPP

above. In “DRIVE C2X”, however, intersection assistance is considered as a comfort-related vehicle-to-infrastructure function in the “green-light optimized speed advisory function (GLOSA)”. Therefore, traffic lights communicate their signal phase and timing, allowing drivers to approach at an optimized velocity. This function could be integrated with longitudinal control functions (ACC, CACC) to create an “adaptive intersection cruise control (AICC)”, in which the function optimizes velocity when approaching intersections. Similarly, this could be integrated into the “iACC” discussed above.

### C. Novel CoDAS functions

In this section we present a survey of function not feasible without cooperation *and* automation. These functions feature a strong focus on cooperation by means of communication – with explicit transmission of intentions or negotiation of common driving maneuvers. We will denominate functions exhibiting a common automated action in participating vehicles (i.e. joined driving maneuver) as “collaborative” to distinguish from the commonly used adjective “cooperative”.

For the area of lateral control, we identified two function sets: in lane changes with unidirectional traffic flow (highways) a “cooperative lane merge (CLM)” describes a function, in which adjacent vehicles transmit *intentions* on changing lanes to improve merging (e.g. future trajectories). The extension of *negotiating* a lane merge, in which two or more vehicles adapt velocities to allow for an optimized merge is subsequently named the “collaborative lane merge (CILM)”.

For lane change situations with oncoming traffic (overtaking on rural and urban roads) we distinguish between overtaking assistance (to facilitate an efficient overtaking maneuver) and overtaking collision prevention. The “cooperative overtaking assistance (COA)” function consequently utilizes transmitted *intentions* to allow an overtaking maneuver. Again, if vehicles actively *negotiate* common behavior (e.g. oncoming traffic intentionally slowing down to enable the overtaking) in an overtaking maneuver, this function is denominated the “collaborative overtaking assistance (CIOA)”. Conversely, the “cooperative overtaking collision prevention (COCP)” function uses information received by communication to deny or abort an overtaking maneuver. If vehicles negotiate this maneuver (e.g. the overtaken slowing down, whilst the overtaking vehicle accelerates to complete the maneuver in time) this function is referred to as a “collaborative overtaking collision prevention (CIOCP)”.

Finally, in the area of intersections the introduction of collaboration enables two novel function categories. With “collaborative intersection management (CIIM)” we denominate functions, in which two or more vehicles negotiate intersection usage in a common driving maneuver to optimize intersection passing times. These are often referred to as “automated intersection” or “autonomous intersections” [18]. Respectively, we denominate “collaborative intersection collision prevention” functions, which utilize collaborative driving maneuvers to prevent accidents in intersection areas, e.g. due to right-of-way violations. These theoretically feasible functions could be active in the violating vehicle or other

participants and utilize a negotiated common driving maneuver to minimize accident risk and/or to mitigate accidents.

## IV. PROPERTIES OF IDENTIFIED CODAS FUNCTIONS

In total 17 generalized functions have been identified in the previous chapters, as shown in table 1. To understand their relation beyond area of application, we show in this chapter a comparison regarding selected characteristics:

- $p_M$  – function is theoretically possible with existing DSRC *messages* in ETSI ITS G5 or SAE J2735
- $p_P$  – function is theoretically possible with existing DSRC *protocols* in ETSI ITS G5 or SAE J2735
- $c_D$  – direction of communication (U/B) – unilateral, or bilateral communication
- $c_T$  – timeframe of communication (C/E) – continuous or event-driven communication
- $a_S$  – lowest possible automation mode of sender (according to NHTSA level of automation [23])
- $a_R$  – lowest possible automation mode of receiver

The properties have been chosen to find common characteristics beyond scope of application and subsequently to form a classification metric for CoDAS functions. Some of these values are dependent on implementation details. We therefore tried to examine generic functions, as described in the previous chapter.

TABLE I. PROPERTIES OF IDENTIFIED FUNCTIONS

Function	$p_M$	$p_P$	$c_D$	$c_T$	$a_S$	$a_R$
CACC	Y	Y	U	C	0	1
iACC	Y	Y	U	E	0	1
iPilot	Y	Y	U	E	0	2
CABSA	Y	Y	U	C	0	1
CLCA	Y	Y	U	E	0	1
CLM	N	Y	U	E	1	2
CILM	N	N	B	E	2	3
COA	N	Y	U	E	1	2
CIOA	N	N	B	E	2	3
COCP	Y	Y	U	E	0	1
CIOCP	N	N	B	E	2	2
AICC	Y	Y	U	C	0	1
CICP	Y	Y	U	E	0	1
CIIM	N	N	B	E	2	2
CIICP	N	N	B	E	2	2
Convoy	N	Y	U	C	2	2
Platooning	N	N	B	C	2	3

Utilizing these properties, it is possible to cluster the functions. Specifically, we propose to introduce two major distinctions.

**Implicit vs. Explicit:** As seen, a large number of existing ADAS functions can be improved by adding information received over communication to the functions' information sources. Thus, range and detail of perceived information can be improved over traditional sensors. Importantly, the sender does not need to be aware of these functions – the information transfer is implicit. Explicit functions on the other hand work in similar manners, but require a dedicated effort by the sending party for especially this function. While the distinction might seem small, the implications are large. Since any communication is established in standards, each explicit function needs a standardization process to enter into production, while implicit functions can be implemented with current standard DSRC. Therefore, implicit functions in the future will start from an already established penetration, whilst any explicit functions will start with zero penetration. Furthermore, implicit functions can be implemented OEM-specific without need for accord.

**Unilateral vs. Bilateral communication:** The majority of today's DSRC communication is unilateral in nature. Therefore any information transmitted is initiated at a sender either in periodic intervals or on certain events. This also means, that cooperation in the sense of vehicles negotiating and adjusting a common function is impossible. While this limits the kind of cooperation possible using given DSRC communication, it also greatly enhances network usage and limits communication complexity. To allow bilateral communication, simple messages are not sufficient: instead common communication protocols need to be applied, maintained and adapted for functions on all participating vehicles.

## V. A CLASSIFICATION APPROACH

The two categories are partially exclusive: No bilateral cooperation can be implicit, since implicit communication specifically does not specify dedicated communication for a certain function – but bilateral communication only makes sense in dedicated functions. The inversion is also true, no implicit communication can be bilateral – at least on a meaningful level. We therefore propose to distinguish into three categories:

- Unilateral implicit functions
- Unilateral explicit functions and
- Bilateral explicit functions.

We will refer to these levels as *cooperation levels* and propose to utilize them as means of classifying novel CoDAS functions.

The first level of **implicit CoDAS** functions denominates those functions, which use already existing cooperative information (e.g. from standard messages such as “Basic safety message”, “Cooperative awareness message”, “Decentralized environmental notification message” or “Signal-phase and timing message”) to augment already existing ADAS functions. Thus, communication is used to enhance perception

range and fidelity. Implicit functions utilize the *situation* transmitted by other participants.

The second level of **explicit CoDAS** functions are those, that become possible by communication. These functions build upon information delicately transmitted by other vehicles – thus providing an insight into *intentions* of other participants. Therefore, explicit functions have to be integrated into standards and amended to current considered functions in ETSI ITS G5, SAE J2735 and comparable standards. They work, however, on standard network and transport stacks used in today's DSRC and are unilateral in nature.

The third and final level of **collaborative CoDAS** denominates those functions, which are actively intervening in more than one vehicle. These functions are used to perform collaborative driving maneuvers (in literature, the term “cooperative driving maneuver” is commonly used). Therefore, DSRC needs to provide means to propose and negotiate these driving maneuvers between participants. This implies bilateral or multilateral communication means. Current DSRC standards do not provide such capabilities, but they might be possible to append on network or even message level. We initially proposed such an amendment in [24], but will provide an updated version based on the findings presented in this paper. Similar approaches have been presented by Caveney and Dunbar [25] and recently in the Autonet 2030 project [9].

TABLE II. OVERVIEW OF IDENTIFIED FUNCTIONS

Area	Respective ADAS function	Implicit	Explicit	Collaborative
Longitudinal control	ACC	CACC		
		iACC		
Lateral control	ABSA	CABSA		
	LCA	CLCA		
			COA	CIOA
			COCF	CIOCF
Intersection			AICC	CIIM
	ICP		CICP	CIICP
Piloted		iPilot	Convoy	Platooning

In table 2 we present an overview of the surveyed functions along cooperation level and area of operation.

## VI. CONCLUSION AND OUTLOOK

It is evident, that a host of novel functions becomes conceivable by combining automation and cooperation in driver assistance systems and consequently automated driving/autonomous driving. Three properties are found in communication that make these possible:

- Beyond line of sight and range
- Fidelity of situational information transmitted

- Capability to transmit intentions and negotiate future driving maneuvers

To enable a clear-sighted approach to implementing cooperative driver assistance functions (CoDAS) and the necessary DSRC protocols to enable them, it is necessary to first survey and to classify possible functions. In this paper we presented an initial survey based on four categories: existing research and prototypes, augmentation of existing automated functions with communication, augmentation of existing cooperative functions with automation and finally by identifying novel functions only becoming feasible in this novel function class of CoDAS. Overlaps exist between these categories.

We initially classified the functions along their area of operation and proceeded to determine various properties such as automation levels and communication “direction”. Using these properties we were able to identify three basic levels of CoDAS functions: **implicit**, **explicit** and **collaborative**.

We propose to utilize these categories to:

- Classify novel functions and to
- Approach the next generation of DSRC.

We are aware, that no such survey can be exhaustive, as new functions are identified and researched continuously with technological progress. These categories, however, should remain valid and provide initial reference for DSRC implementation. The ongoing work in higher automation and eventually autonomous vehicles can benefit directly from these capabilities, as communication can be used to enable and enhance the various sub-functions of these intelligent vehicles.

In this paper we have not rated functions for feasibility – it is necessary to critically discuss the identified functions in regard to feasibility under open world conditions. Specifically in cooperative functions, the impact of penetration rate, reliability of communication and security & trust issues have to be examined per function.

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