Collaborative Embedded Systems

CrESt

GEFÖRDERT VOM

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Use Case 1 “Cooperative Vehicle Automation”

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Use Case 1 “Cooperative Vehicle Automation

Project	CrESt	
Responsible	Oliver Kreuzmann	
QA-Responsible	Assystem Germany GmbH	
Authors	Oliver Kreuzmann (Assystem) Dr. Stefan Penz (FEV), Jorge Castillo (FEV), Suryo Buono (Assystem)	
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Abstract

This document handles with the use case study “cooperative vehicle automation” of the CrESt-project. It is designed as an input for the development of the other sub-projects and describes the CACC/Platooning-functionality, a typical collaborative automotive system for multiple vehicle longitudinal control in a real environment. For this case typical challenges for the development, system features, constraints and the realistic use cases of the collaborative system are given. Furthermore, it shows the demonstrator for the automotive use cases of the CrESt-project and which technical aspects and use cases of a collaborative automotive system can be implemented in the demonstrator.

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Introduction and Summary for CrESt-Partners

The main goal of the CrESt project is to investigate and evolve methods, tools and techniques for the development of collaborative embedded systems. In order to anchor the outcomes toward real world applications, several use cases are defined that set a functional context and facilitate the evaluation of the developed methods.

In this document, the use case “Cooperative Vehicle Automation” is described, which should allow several vehicles in a common context to collaboratively reach a common goal, i.e. to drive automatically and closely in one line in order to enhance driver comfort and reduce fuel consumption.

1.1. Motivation and Scope

The automotive industry will be a major driver for collaborative and context aware systems. Up to now, vehicle cruise control systems are limited to isolated control decisions done individually on basis of local sensor data. In the future, vehicle-to-vehicle and vehicle-to-roadside communication technology will enable the cruise control systems to consider not only a vast range of additional context information (e.g. general traffic conditions, dangerous situations ahead etc.), but also to establish effective collaboration between vehicles. In this specific use case, a group of cars that are travelling in the same direction collaboratively and dynamically form a group that can travel safer, more comfortable and more fuel efficient than individual drivers.

1.2. Goals

This use case definition should give the reader an overview of the current state of art in vehicle cruise control systems and provide an outlook on future collaborative enhancements. For these enhancements, models and methods for handling collaboration between vehicles and context-awareness in highly dynamic traffic scenarios are key factors. This document should provide a real-world application context for engineering challenges and discussions with and within the other part projects of CrESt. Moreover, a demonstrator system is described which could be used to implement, validate and evaluate the methods and tools developed by the project.

1.3. Target Audience

This document is targeted to all CrESt partners and part projects that are interested in or working with the use case “Cooperative Vehicle Automation”.

1.4. Document Structure

This document is mainly divided in three parts:

Part one (Chapter two and three) is an introduction into the typical problems of modern automotive engineering and describes how future collaborative systems can support possible solutions. Moreover a little description of former development states for longitudinal vehicle regulation is given.

The second part (chapter four) introduces the development challenges, which are given by the development of collaborative automotive systems in a real environment, especially in terms of customer acceptance. It describes which features and constraints are allocated to collaborative automotive systems and, at the end, realistic use cases for them.

The third and last part (chapter five) describes the demonstrator for the realistic use cases and it constraints compared to a real collaborative automotive system. Finally the document shows how the realistic use cases can be implemented in the demonstrator.

2. Introduction into the use cases

As a part of the CrESt-project, the use cases give an important input for the development of methods and tools for collaborative systems. The Use Case "Cooperative Vehicle Automation" mainly deals with the possibilities of this kind of systems in the road traffic. These contain, besides the passenger traffic, also the daily freight transportation on the street. The collaboration of vehicles allows the optimization of the following, important aspects and problems of modern mobility [1]:

Economy: One of the biggest problems of increasing street traffic is the equally rising number of traffic jams and waiting time at crossroads. Future collaborative systems have the ability to counteract them, especially in the freight transportation. They allow to define a common goal and a solving strategy to reach this goal efficiently for every of the collaborative systems, e.g. reduce the fuel consumption. Furthermore, they can use and share information about traffic and path finding, which can also help to reduce traffic jams.

Safety: There are millions of casualties caused by traffic accidents every year all around the world. Collaborative systems have the ability to reduce this number by using and sharing actual information about relevant traffic environment or potentially dangerous traffic situations like the end of a traffic jam. By sharing this information in real time, an Advanced Driving Assistance System (ADAS) can perform reasonable vehicle actions to avoid accidents of deadly injuries.

Action on Climate: The number of cars running on roads is estimated to be 1.1 billion in 2020. Driving together in a platoon or just getting information about traffic jams can reduce the fuel consumption and therefore the CO^2-, CO- and NOx-pollution.

Saving Time: As described, driving within a group of vehicles may help to reduce or avoid traffic jams. Furthermore, this can help to share information between drivers, preventing stress and time spent on the road.

To give the highest possible input and a good all-around overview, the main part of this document is mainly separated in three chapters. The chapter 4 deals with actual vehicle systems, which allows the vehicle too interact with the direct environment on a low automation level. The chapter 4 shows typical use cases for a theoretical real life usage of a high level collaborative system: the cooperative adaptive cruise control resp. the Platooning (CACC/Platooning). It is assumed, that the necessary environment for such a system already exists and a standard for the communication between the vehicles is defined, which allows the communication between vehicles form different OEM's. The chapter 5 finally deals with the development of a platooning-function in a laboratory environment. This function is allocated to several model vehicles and their use cases are more similar to the real life use cases, but, as described in the chapter, can't simulate all use cases of a real life usage.

3. State of the art of longitudinal vehicle automation

3.1. ACC (Adaptive Cruise Control)

Adaptive Cruise Control (ACC) is an enhancement of conventional cruise control systems that allows the ACC equipped vehicle to follow a forward vehicle at a pre-selected time gap by controlling the engine, power train, and/or service brakes [2]. It means that the ACC is a system requesting the board computers to control the vehicle’s **acceleration** and **deceleration.**

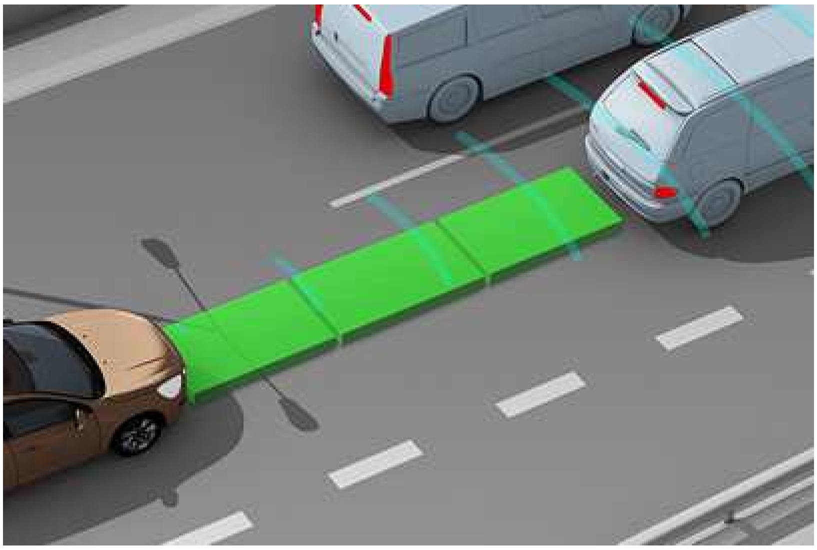

Figure 1: typical ACC Radar range (blue) and the selected time gap (green) [3]

The most common ACC systems generally use automotive **radar systems,** placed in front of the car and/or a **camera** placed at the interior rear mirror. The radar allows to identify obstacles (possible ACC targets) and predicting their speed by sending and receiving radio-waves. This radar usually occupies the band around 77 GHz and works with the frequency modulated continuous wave (FMCW) technique [4]. A first wave is transmitted and a second wave is received in case of an object in front of the vehicle. Both signals are time-delayed and a closed loop control is needed. The camera allows identifying obstacles and making the possible ACC target detected from radar plausible. A camera-only-ACC is an actual research object but not a introduced state of the art.

The ACC increases and reduces the car speed and automatically adjusts the vehicle speed to maintain a safe distance from vehicles ahead. The system may not react to parked, stopped or slow moving vehicles. It alerts an imminent crash and may apply a limited braking but the main responsibility for car steering has the driver.

Some OEMs also recommend not using the ACC in winding roads, hilly roads, city streets or bad weather [5].

3.2. ACC: Full Speed Range (ACC with Enhancements)

This is an enhancement of conventional ACC. Such systems can bring the car to a full stop if the vehicle ahead stops. It may handle itself in a saturated traffic. The vehicle restarts only if the driver pushes the resume button or the gas pedal. It is also known as Stop and Go ACC. Overtaking another vehicle may also be integrated. When the direction indicator is activated; the adaptive cruise control helps to briefly accelerate the car towards the vehicle in front. Some car manufacturers producing a Full Speed Range ACC are e.g. Audi, GMC and Volvo [6] [7] [5].

3.3. CACC (Collaborative Adaptive Cruise Control)

CACC takes cruise control to the next level, enabling vehicles to adjust their speed to the preceding vehicle in their lane with a direct Car2Car-Communication. The CACC system can also respond faster to speed changes by the preceding vehicle and other vehicles farther ahead which are beyond the line of sight. These advancements improve the stability of the traffic flow, increase driver confidence and make it possible to minimize time-gaps for vehicle-following time-gap-regulation possible. Ultimately this results in better use of a **highway’s effective capacity** and **greater fuel efficiency** [8].

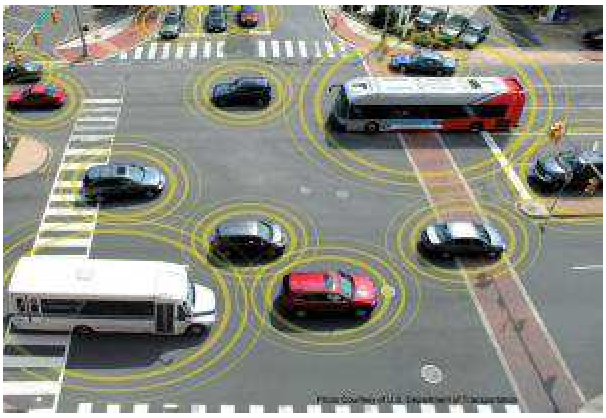

Figure 2: A typical scenario of Car2Car intercommunications on a usual crossroad. [9]

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To optimize the collaborative aspect, the CACC may be observing the following common-driving targets:

- same destination
- partially the same destination
- support in driving an unknown road/ destination
- desired and steady cruising speed
- reduce fuel and time consumption

4. Realistic Use Cases for “CACC/Platooning”

CACC/Platooning takes CACC to the next level by using wireless communication to exchange acceleration data and other relevant information with a **significant number of vehicles** travelling in a platoon formation with a common goal. This communication allows the decrease of time gaps between the platoon vehicles and leads to an increase of the fuel consumption- and street utilization efficiency. The CACC/Platooning fits the goal and need of a collaborative function, a CrESt-function.

4.1. Engineering Challenges

For the development of a CACC/Platooning-System, the following engineering challenges have to be attended:

The **interface** between driver and system is a core topic. Unlike to the other use cases of the CrESt-Project, the CACC/Platooning-function for traffic-assignment is depending on customer acceptance, so the comprehension of the driver for the behavior of the vehicle on a high automation level is absolutely necessary. An example: because of the highly dynamic nature of platooning, the vehicle needs to make real time adjustments to keep the safety and comfort, and when necessary the vehicle also needs to send notifications (e.g. when destination of the platoon doesn’t match the destination of the driver) and alarms (by emergency situations). When the interface doesn’t communicate this information and work autonomously, the driver will not trust the function and don’t use it. Therefore the function should be able to show and receive information to/from the driver. Moreover, the interface should be able to communicate on real time and present information with a high quality level. The interface should produce visual and audible signals to inform the driver about changes regarding the platoon.

Of Course, this interface only can influence the platoon in an appropriate way. A “platoon-Regulation”-Change-Request by a platoon vehicle may not violate any platoon-directives, which influence the effectiveness or safety of the other platoon-members.

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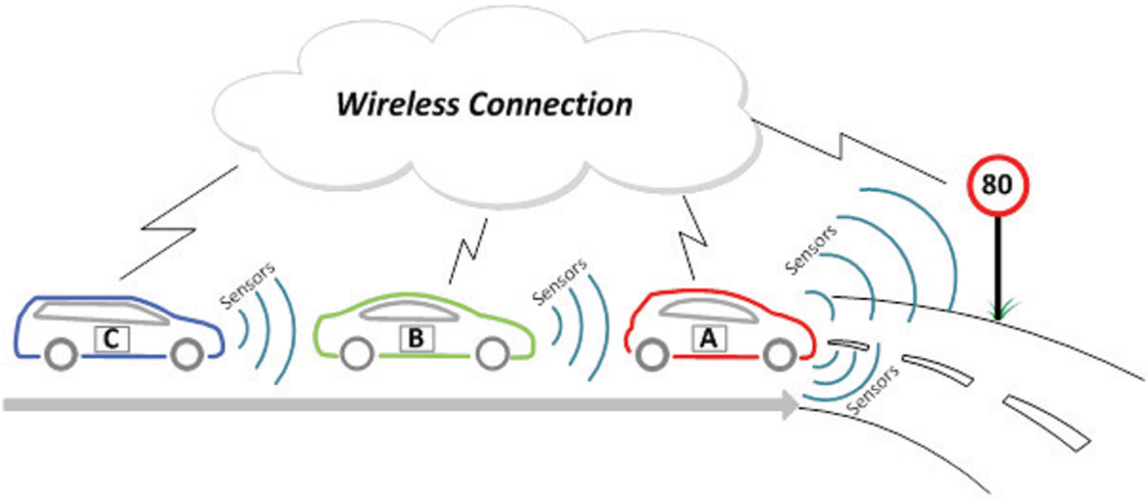
Figure 3: possible Comm.-interface between platoon and driver for CACC/Platooning [10]

The **interconnection** between potential platoon vehicles must use a wireless communication. This interconnection must be defined by a universal communication protocol, which can be used by every OEM who wants to develop a CACC/Platooning-function. This communication protocol has to define mainly:

- the most efficient network topology, depending on the structure of the platoon,
- the information, which has to transmit for platoon-regulation- and platoon-membership-Requests
- the compliance of the control-tolerance-time for the platoon regulation and the platoon directives, if this time outruns,
- the treatment of errors, caused by failures within the platoon-communication



The **Platoon Control Unit (PCU)** should be present at each vehicle and should be interconnected with the on-board control units. The ACC Control Unit can provide the PCU in a public vehicle. This unit should handle or control:

- the driver’s input: creation of platoon, vehicle speed, destination, etc.
- requests of platoon members
- Functions derived by the use cases (e.g. join platoon, leave platoon etc.)
- providing a high quality information to the ACC mounted on the car

The **diversity of vehicles** in a platoon has to be considered by the CACC/Platooning-Functionality. Heavy trucks obviously have different characteristics than fast sport cars which as well have different properties than fuel efficient sub-compact cars. For example, driving at higher speeds might be suitable for sport cars, but might lead to uncomfortable and inefficient driving in a lower powered car. Therefore, the driver should always be aware about the platoon’s driving strategy.

One major engineering challenge in the development of collaborative systems like CACC/Platooning is the **verification and validation** of the complete “system of systems". Current testing procedures for automotive embedded systems assume that all functionality can be tested within the system boundary of a single vehicle. In collaborative environment, an open group of actors (e.g. vehicles, roadside equipment etc.) interacting dynamically and context-aware has to be considered for testing as well. Therefore, new testing methods and simulation environments have to be developed in order to ensure high software quality and functional safety.

4.2. Platooning features

In the following, the basic functions of managing and controlling a platoon will be introduced. We will use the following abbreviations for different vehicle roles in a platooning system:

Term	Meaning
LV	Lead Vehicle leads the platoon.
FV	Follower Vehicle is any vehicle following a LV, therefore it may not be a LV.
PLV	Potential Leading Vehicle is a vehicle requesting to lead the potential platoon. Afterwards it becomes a LV or FV when the platoon is consolidated.

PFV	Potential Following Vehicle is a vehicle requesting to be a FV when a platoon is consolidated.

Most of the collaborative aspects of the CACC/Platooning functionality occur when it comes to building up a platoon. Before any automated vehicle control can start, the vehicles, and maybe their drivers, have to know each other and agree on a common driving strategy. During this phase, several aspects have to be considered:

- The vehicles need to be in a close range, so that a platoon can physically be built up. Therefore, the platoon management system needs to be aware about the physical location, speed and direction of each vehicle. At least, the vehicles need to be aware about other CACC capable vehicles and cars in their immediate vicinity.
- The vehicles (or their drivers) need to have a common driving direction. In the best case, the platoon management system would know the complete routes that the participating vehicles are about to travel.
- The vehicles (or their drivers) should have a common or at least similar driving characteristic or goal. A truck platoon that wants to drive as economically and safe as possible might not be acceptable for a driver of a powerful car who wants to travel much faster. Other drivers might not be willing to accept a very close distance to the surrounding vehicles, which is necessary to maximize the fuel savings. Such driving characteristics have to be negotiated between the participants.
- The vehicles (and their drivers) need to agree on their roles in a platoon. A Lead Vehicle (LV) has to be select, all other platoon members will be assigned the role of a Follower Vehicle (FV). Either role might not be acceptable for some drivers.

Presumably, there are a lot more aspects and parameters that have to be considered or negotiated during the build-up phase of a platoon. A collaborative platoon management system has to be flexible enough to cope with such diverse information. The actual operative actions like “Create Platoon” or “Join Platoon” described below cannot start before the participants have collaboratively agreed on a platoon participation.

4.3. Platooning Constraints

In order to reduce the complexity coming from cross-traffic, pedestrians, traffic lights etc., the platooning functionality is currently assumed to be limited to highway scenarios.

If the number of vehicles in a platoon increases, several issues can occur especially considering interaction with other traffic that is not part of the platoon. For example, a very long platoon of trucks could hinder a car to enter a highway by not giving enough room at the highway entrance. Therefore, it has to be assumed that a platoon is reasonably limited in length.

Considering the SAE Automation Table [11], the LV should be monitored by the driver, L1 or L2. The FV may have a Full Automation level (L5), inherent to the CACC platoon system.

All drivers (LV or FV) are assumed to be able to take over control of their vehicle within a reasonable short time.

The vehicles communicate by a wireless connection. A loss of communication between the vehicles requires the vehicles to immediately increase the inter-vehicular distance which in turn can lead to dissolving the complete platoon (functional degradation strategy). Obviously, this problem has to be considered in real-world applications.

Functional safety is of utmost importance in all CACC systems. Safety critical situations can occur. The platoon should inform opportunely to the vehicles involved and take the decisions needed (e.g. degradation or platoon leaving).

4.4. Realistic Use Cases

In order to investigate the approach in collaborative vehicle Automation, the following real user’s cases are proposed to be developed:

4.4.1. Create or Join a platoon:

A vehicle driver desires to create a platoon and uses a defined technology to define a platoon proposal. This vehicle drives on the highway and emits continuously a signal to others vehicles which wants to join the platoon. Another vehicle gets the request and accepts the proposal. After the acceptation, both vehicles start the platoon verification, which includes the platoon role allocation (PLV_1 and PFV_1). During the verification, the vehicles avoiding automatically that other PFV_x get connected at the same time. The PFV_1 should join the PLV_1 longitudinally from rear. Both vehicles speed should manually be synchronized to proceed the car’s pairing. When the verification is closed and the platoon is created, the PLV_1 becomes LV_1 and the PFV_1 becomes FV_1.

In the meantime, the Platoon Proposal remains active and requests continuously whether other cars want to join the platoon. A PFV_2 gets the request and accepts the proposal. So the already existing platoon will receive another FV. It should also join from the rear of the platoon, in other words behind the FV_1. The PFV_2 should pair with the FV_1 or the LV_1, depending on the platoon network topology. Once the pairing is finished and the platoon regulation works, the platoon join is closed. The PFV_2 becomes FV_2.

Hint: For the platoon creation, at least two vehicles are necessary. The join could only being done if already one platoon creation is performed.

4.4.2. Leave or dissolve a platoon:

A platoon is already defined and an FV_x wants to leave the formation. Therefore the PV informs the LV about the leaving intention. The intention may be considered when the FV driver takes the steering wheel control, push the brake/accelerator pedal, using the indicator light or a vehicle diagnostic error is reported. In case of an unwanted driver action, aborting of the leave is possible by informing the LV of this desire. It is not mandatory to have an authorization from LV to FV to leave the platoon. If several FVs are paired to the platoon, the arising gap will be closed by the following FVs.

Furthermore the platoon must be dissolvable. It is mandatory to have an approval from all the FV cars to dissolve the platoon even if that may involve the FVs in a wrong target or taking another highway. In this case, the FVs have to leave the platoon. If only two Vehicles are in a platoon and one vehicle wants to leave the platoon, the platoon dissolves automatically.

4.4.3. Change lane

A platoon is already defined and a road work is introduced on the way. The LV decides to change the lane and should forward this information to the others vehicles. The FVs receive the information and also decide to change the traffic lane. However if one of the FVs detect an object on the side, they should communicate this and abort the change with leaving the platoon.

4.4.4. Platoon Fusion

In some situations, it might make sense to join two or more independent car platoons into a single one. A typical reason for fusing two platoons is to raise the highway’s effective capacity, e.g. five vehicles follow one leader instead of two leaders with different regulation. This is called platoon fusion. The separated platoons have to agree on the fusion.

If a maximum number of cars are defined for a platoon, this number has to be considered. For example, if the maximum platoon length is defined as 7 cars and two platoons of length 4 are going to fusion, the concept has to define how to deal with the situation.

4.4.5. Platoon Splitting

An already defined platoon (at least one LV and three FVs) should exist. In several situations, it is necessary to split the platoon in two or more smaller platoons. For example, at a motorway junction, some cars decide to go straight ahead and others want to leave to the other motorway. It might also make sense to split a platoon with different vehicle types into more homogeneous platoons, e.g. one platoon with only cars and one platoon with only trucks, so that the car platoon is able to go faster. Nevertheless, the platoon splitting includes that every new platoon from the old platoon has to verify a new LV and his PVs with all platoon verification sub use cases.

5. Functional Use Cases

The former chapter handles the challenges and use cases, which have to be accepted for the development of a collaborative automotive system. This chapter gives an overview of the actual development of a CACC/Platooning-functionality, which is implemented in the automotive demonstrator for the CrESt-project, the VeloxCar-Project.

5.1. Overview Demonstrator “VeloxCar”

The VeloxCar is a project for the research and development of autonomous driving vehicles (ADV). Especially the further development of ADV-related functions like CACC for longitudinal control, lane keeping for lateral control or full automated parking assistance are the capital themes of the VeloxCar-Project. In context of the CrESt-project, the VeloxCar is a demonstrator for a collaborative system network via Car2Car-communication and CACC/Platooning-functionality.

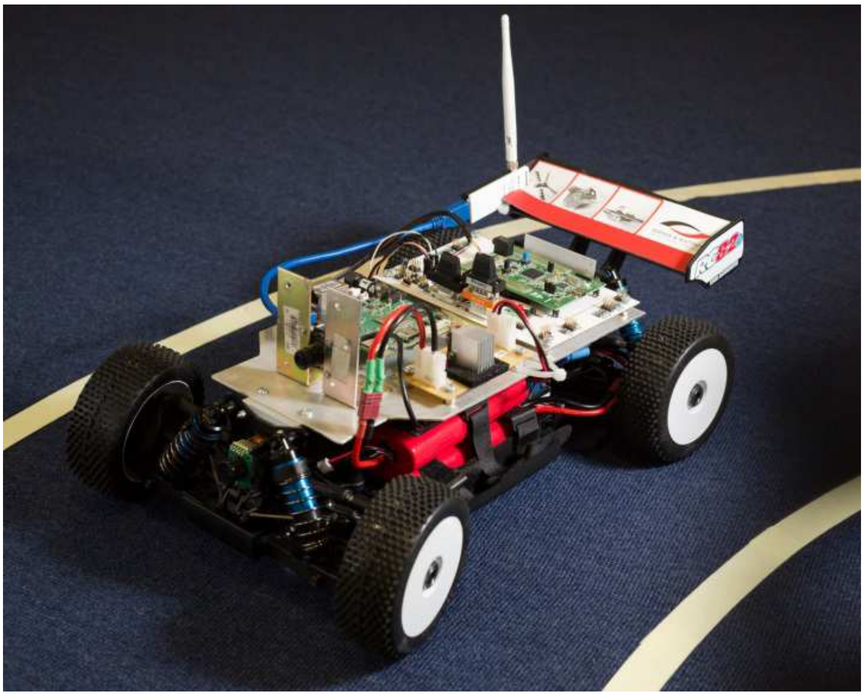


Figure 4: one of the VeloxCar model vehicles

The technical focus of the VeloxCar-project are the four experimental model vehicle in scale 1:8, which are able to drive autonomously in a laboratory environment. This environment is designed to simulate the drive of vehicles on a freeway. Of course, the laboratory environment and the model vehicles cannot reproduce this case exactly, so the following points distinguish the former showed “freeway” use cases and the “laboratory” use cases:

- Realistic driving conditions, e.g.:
  - Environment lighting conditions (e.g. sunlight, mirroring surfaces)
  - vehicle dynamics (model vehicles vs. Motor vehicles)
  - vehicle speed (the model vehicles max. speed is 10 km/h)
  - underground surfaces (laboratory ground vs. road surface)
- A limited number of simulated platoons (maximum are 2 platoons)
- vehicles can only join or leave the platoon as the last or first vehicle in the platoon
- Actually, the laboratory environment only simulates an one-lane-freeway,
- The CACC/Platooning-function is designed for full-speed-range (FSR-CACC/platooning)
- The model cars don’t use the IEEE 802.11p-WiFi-communication standard for car2car-connection, which is recommend in real life usage
- The model vehicles don’t have drivers, only an operator who controls the vehicles via radio remote control

Figure 5 shows the actual system context of the VeloxCar-Platoon in the case of full automation. As it shown, the platoon is self-regularized, that means the operator of the platoon cannot control a single vehicle of the platoon. In a fully autonomous state, the only planned control variable is the platoon speed, but the actual control variables “under development” are described in 5.2.2. Furthermore, he is able to order a joining- or leaving-procedure for a vehicle to the platoon.

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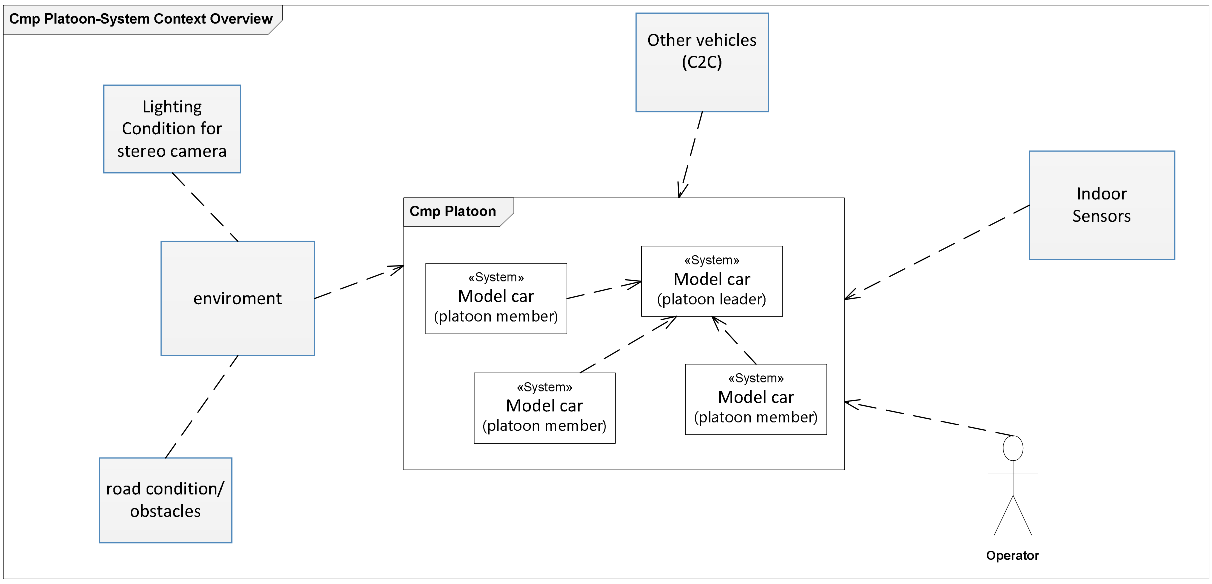

Figure 5 SysML System Context Diagram

5.2. The SysML Use Case Diagrams

5.2.1. Definitions

The Use Cases of the CACC/Platooning-function of the VeloxCar-Project are designed with the modeling language “SysML”. In the context of the VeloxCar-project, the CACC/Platooning-function creates a platoon as a System of Systems (SoS), as it is defined in the CrESt-project, with a main-function and several sub-functions, which are distributed on and executed by the system participants (the vehicles). To create a fully flexible SoS, every defined sub-function must be usable by every system participants. This is an important condition to be able to provide running-time-changes of the platoon structure.

Vehicles in a platoon can occupy one of the following roles, with little changes due to the definition in subchapter 4.2:

The **LV** (**lead vehicle)** guides the platoon and organizes its structure during the whole lifetime of the platoon,

A **FV** (**follower vehicle)** drives in the platoon behind the LV and regulates its own speed by the regulation commands of the leader vehicle. If only one follower vehicle is in the platoon, he is the first follower. If the platoon has more than one follower vehicle, the first follower is the predecessor of the second follower etc.

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As the definition of the platoon roles shows, every platoon has only one leader, but several followers. Figure 6 shows the naming conventions of a platoon with two and with three vehicles.

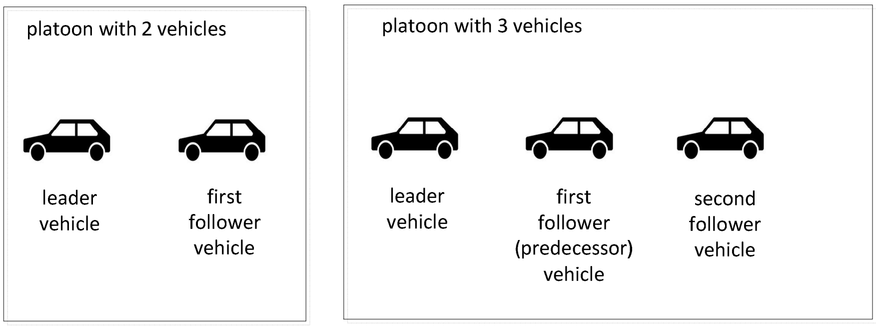

Figure 6 platoon naming conventions

In the following sub chapters, all dashed use cases are possible use cases for the VeloxCar, but will not be implemented in the next releases.

5.2.2. Main Use Case “Platoon Regulation”

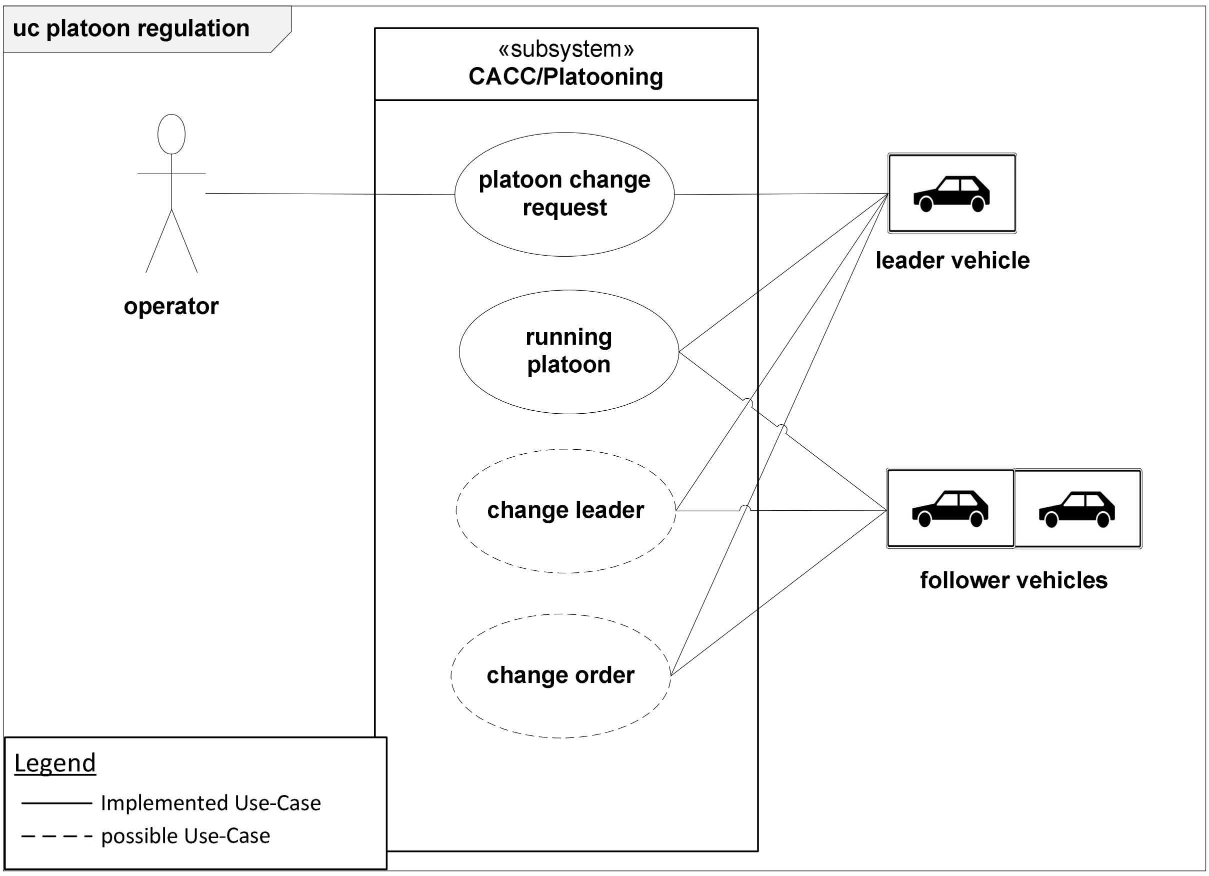

Figure 7 Use Case “Platoon Regulation‘

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The use case “Platoon Regulation” includes all sub use cases, which handles the regulation of the platoon itself. The following sub use cases are included:

The sub use case **“Platoon Change Request”** concerns all control possibilities of the platoon by the operator. These possibilities are an open list, but the following control mechanisms are essential for the operation of the platoon:

- Set the target speed
- Set the minimum time gap between the vehicles
- Set the target order of the vehicles in the platoon

If a Change Request is received, the LV handles necessary activities in the following sub use cases.

The sub use case **“running platoon”** concerns the acceleration regulation of the platoon and the execution of the “Platoon change requests” between the leader vehicle and the following vehicles regarding the platoon regulation. Furthermore, this sub use case defines the platoon-controller-type and the communication-protocol of the platoon. For the VeloxCar, the platoon is organized in a star network.

The sub use case **“change leader”** concerns the possibility to change the leader vehicle without the platoon leaving of the old or platoon joining of a new leader vehicle by the instruction of the operator.

The sub use case **“change platoon order**” concerns the possibility to change the order of the platoon without the platoon joining of new or the platoon leaving of old follower vehicles by the instruction of the leader.

5.2.3. Main use case “platoon membership”

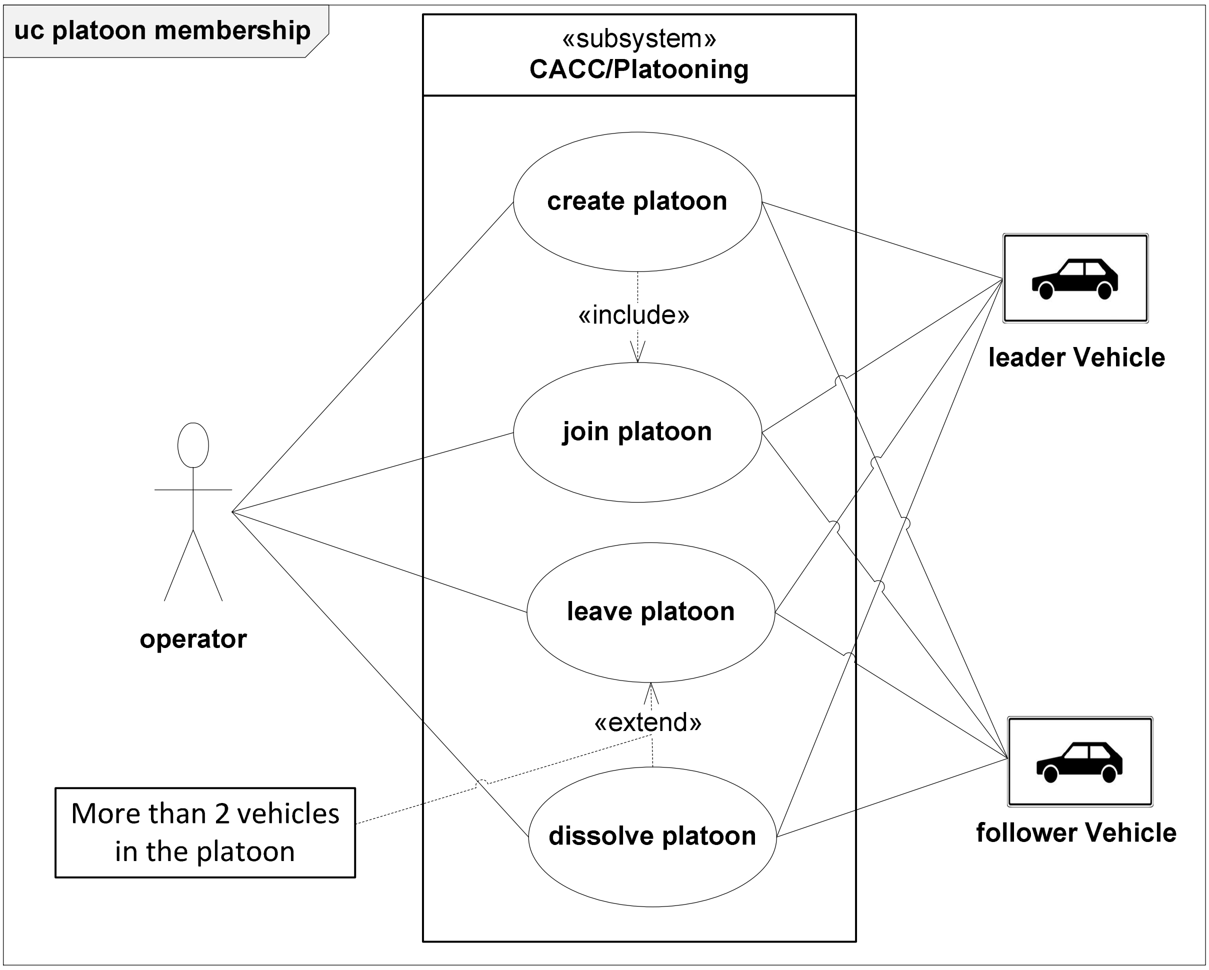

Figure 8 use cases “platoon membership”

The Main use case “Platoon Membership” shows how the platoon arranges the membership of a FV. These sub use cases base on the realistic use cases in 4.4.1 and 4.4.2 and are explained in a more detailed way below and in the following sub-chapters.

- **create platoon:** describes the buildup of a platoon. It is assumed that up to this point no platoon exists. Exactly two vehicles have to exchange their data and handle the platoon verification to fulfill these sub use case. If at least two vehicles have successfully established WLAN communication and the follower follows the leader, one speaks by definition of a platoon within this document.

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- **join platoon:** It assumes the existence of a platoon with at least two vehicles. For each additional vehicle that would like to join the platoon, the use case join platoon occurs.
- **leave platoon:** describes the leaving of a vehicle of the existing platoon. Furthermore, a platoon length of at least three vehicles is defined by definition for leaving a platoon.
- **dissolve platoon:** describes the dissolution of the platoon. If a platoon with only two vehicles and one of the members intend to leave the platoon, the entire platoon will be dissolved.

5.2.4. Sub Use Case ‘Create Platoon’

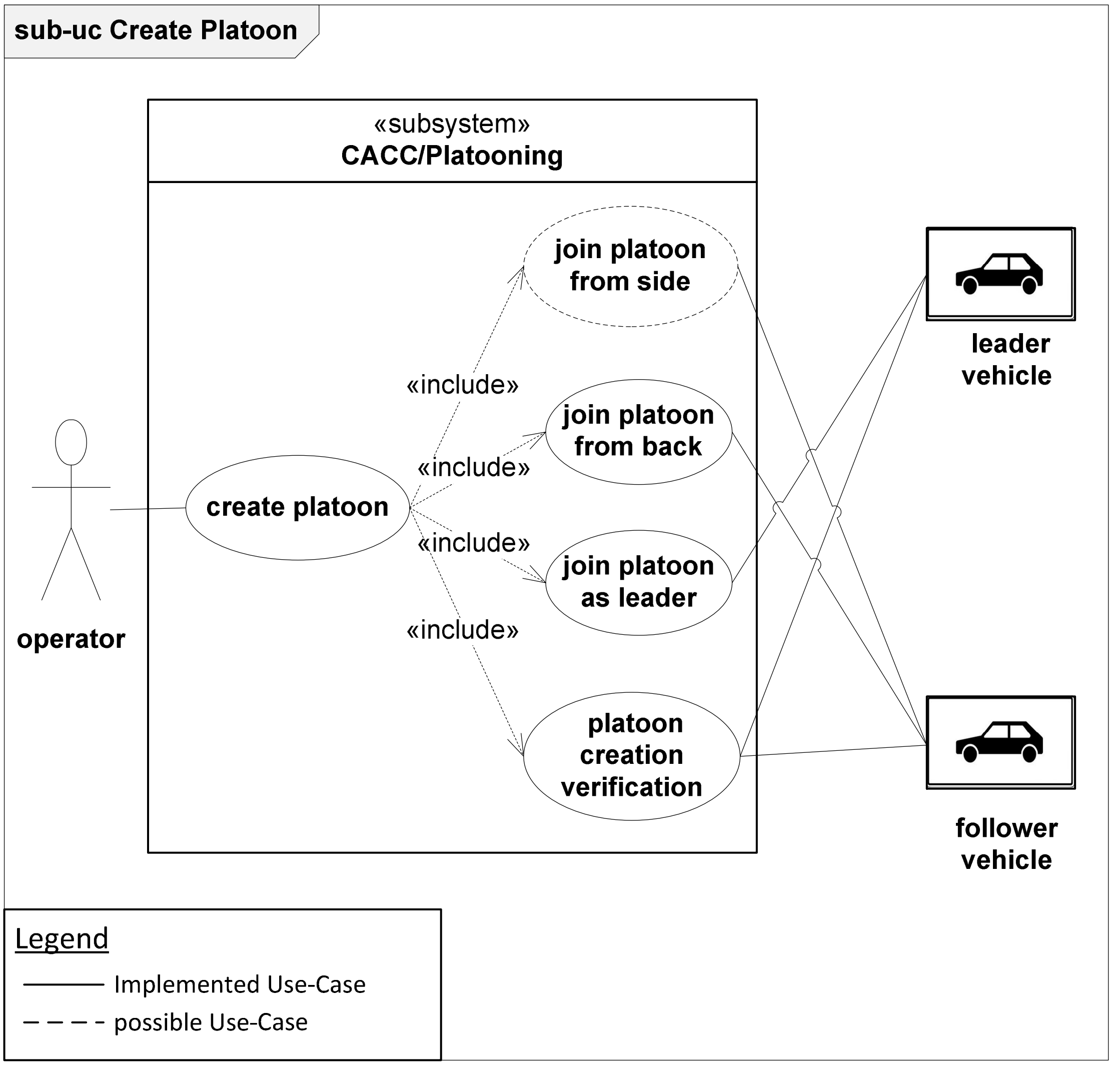

Figure 9 use case “create platoon”

Use Case 1 “Cooperative Vehicle Automation

Figure 9 shows the extension of the use case “create platoon”. The sub-use-case “platoon creation verification” deals with reviewing the conditions necessary to create a platoon. A further investigative aspect within this application is the identification of the FV and the LV by previously defined conditions. This is why only two vehicles can use the “platoon creation verification”. After the allocation of the roles to the vehicles, the allocated leader joins the platoon as LV (“join platoon as leader”) and the allocated follower vehicle joins the platoon as FV (“join platoon from back”). Should another vehicle try to join the platoon as FV during the verification, he has to wait until the platoon creation is completed. With regard to the application case “join platoon from side”, a lane change maneuver is necessary, so that at the end of the maneuvers the follow-up and guiding vehicle travel within one lane. As described in the introduction of the VeloxCar, the sub use case “join platoon from side” is not implemented, but will be defined in the conception for future developments.

5.2.5. Sub Use Case ‘Join Platoon’

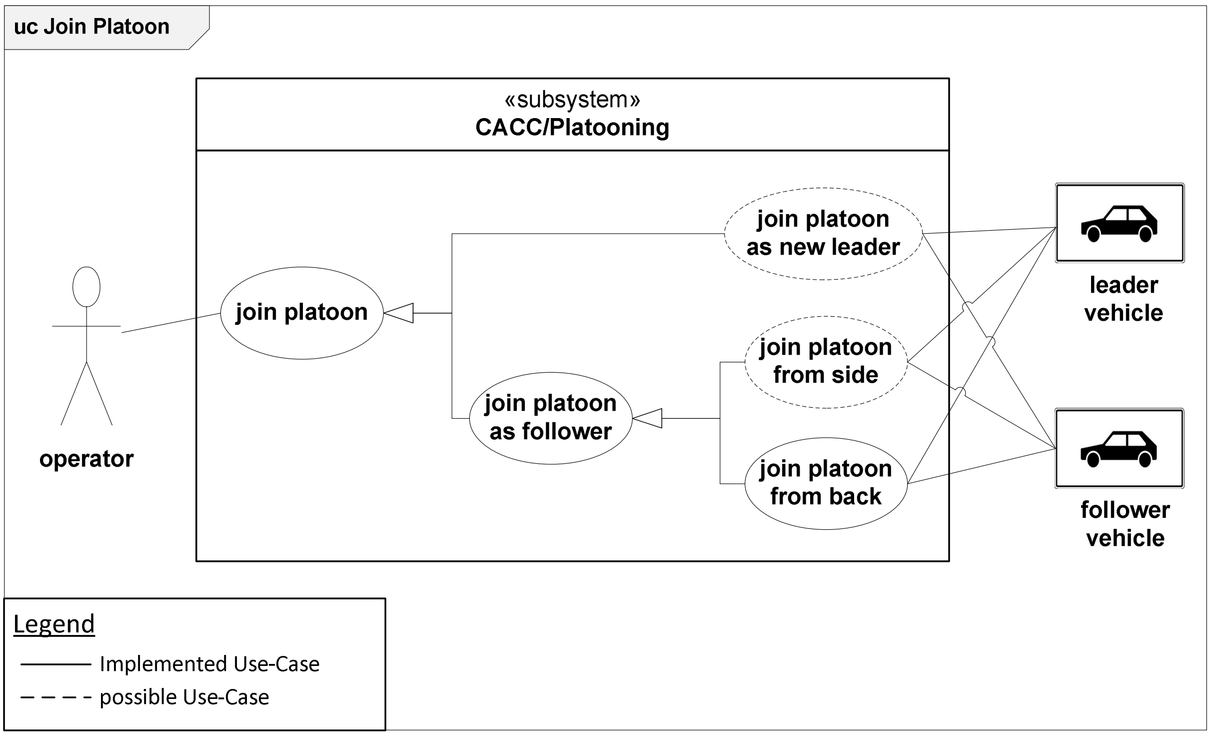

Figure 10 use case “join platoon”

Figure 10 shows the sub use case “join platoon”. It is divided into two further sub-use cases. “join platoon as new leader” describes the connection of a new vehicle to the top of the platoon. It implies that the vehicle becomes the LV. Any other vehicle that wishes to connect to the platoon at the end or side of the column will meet the application "join platoon as follower". The sub use cases in Figure 10 have a "generalized" relationship among each other. The generalization specifies a general application and get specified by further application cases. For example, “join platoon” is an abstract application. The generalized applications “join platoon as new leader” and “join platoon as follower” describe the concrete variants of the abstract use case “join platoon”. The same applies to the applications “join platoon from side” and “join platoon from back”, which are generalizations from another application (see Figure 10).

5.2.6. Sub Use Case ‘Leave Platoon’

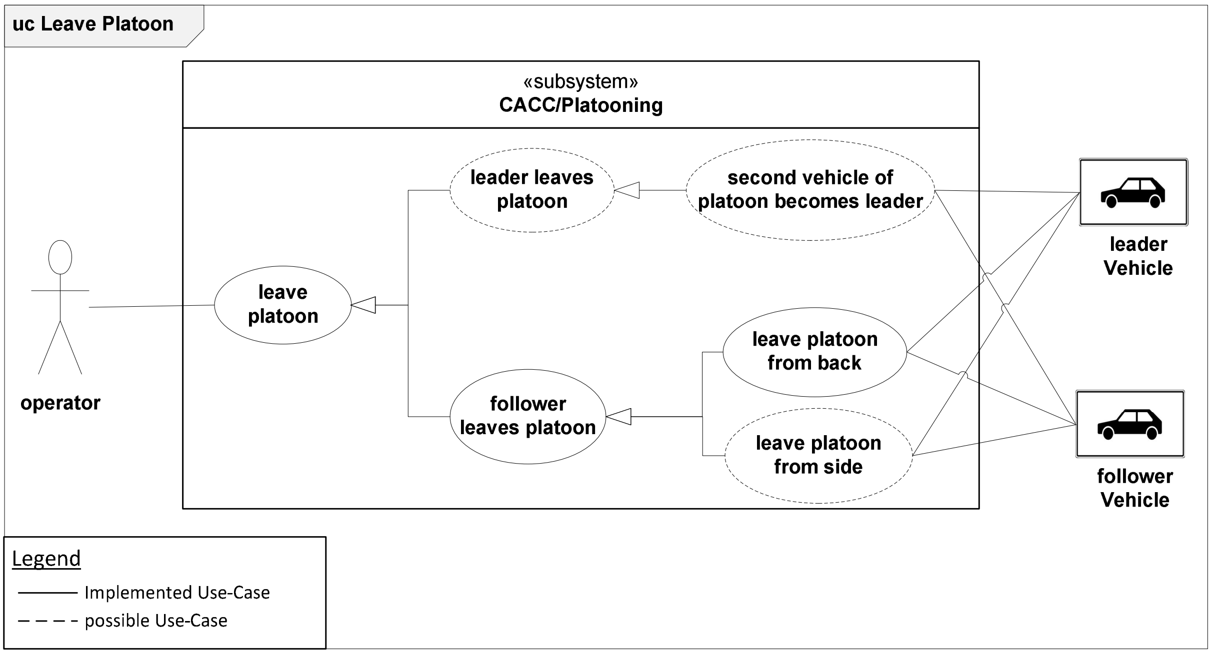

Figure 11 use case “leave platoon‘

The use case “leave platoon”, in Figure 11, describes the leaving of a vehicle from the platoon. This maneuver can be performed by the LV or by one of the FVs. In the sub use case “leader leaves platoon”, the old LV get replaced by the first FV becoming the new LV. In the sub use case “follower leaves platoon”, the FV can leave the platoon to the back or to the side. On which way the vehicle should leave the platoon has to be defined by the operator. All sub use cases are generalized in the use case “leave platoon”.

5.2.7. Sub Use Case ‘Dissolve Platoon’

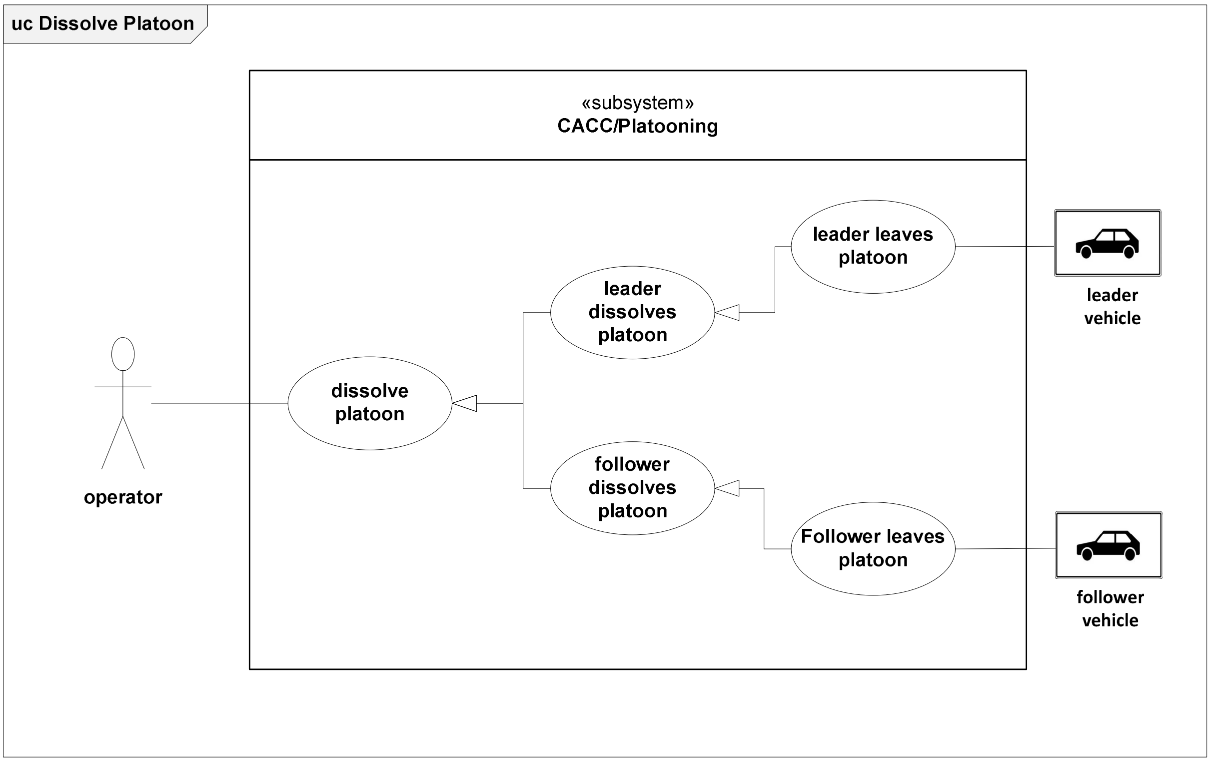

Figure 12 use case “dissolve platoon”

The application “Dissolve Platoon” describes the dissolution of the platoon. The pre-requisite of this use case is an existing platoon via the use case “create platoon”. It can be triggered by the operator if only two vehicles remain in the platoon by leaving one of the last vehicles via “leader leaves platoon” or “follower leaves platoon”. This is established by the platoon minimum number of two vehicles. A general platoon dissolution with more than 2 vehicles is not planned for this CACC/Platooning-functionality.

5.3. Main Use Case “Platoon interactions”

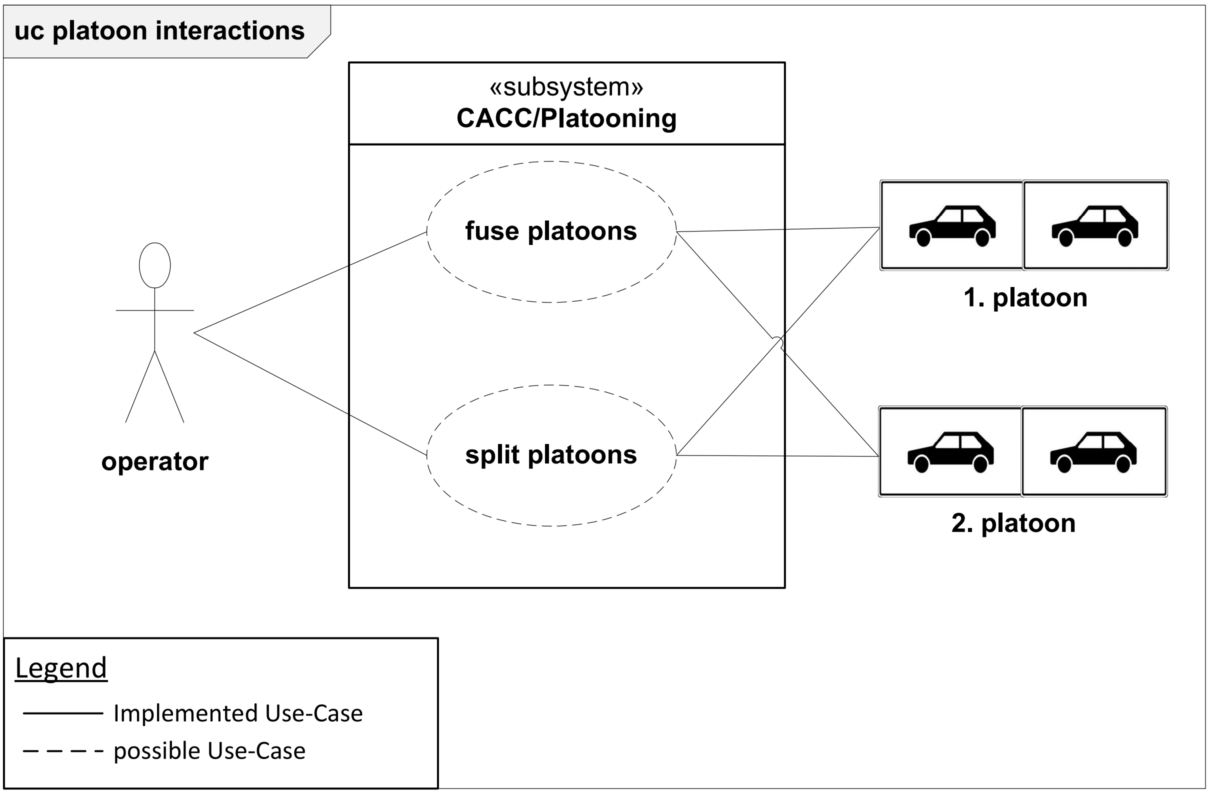

Figure 13 use case “platoon interactions”

The use cases of the platoon interaction define all sub use cases, which allows the platoon to interact with other platoons. At the current development, the sub use cases “fuse platoons” und “split platoon” are the only ways of platoons to interact together. Because of the current state of the development, these use cases will not be a focus for the VeloxCar.

6. Summary

The development of a cooperative system like the CACC/Platooning-function for vehicle automation leads to several possibilities to raise the efficiency of the daily street traffic, which can be:

- Less traffic jams,
- Less vehicle accidents,
- Higher fuel efficiency of platoon members,
- Saved time,

But this causes a lot of challenges, which the developer has to accept. The realistic and functional use cases “Cooperative Vehicle Automation” gives a good overview, which problems have to be solved in the first instance.

At first, the real use cases describe some of the challenges for the development of real CACC/Platooning-functions for the freeway. These can be summarized as follows:

- The definition of Human-Machine-interfaces and the customer acceptance,
- The communication of information between the different CACC/Platooning-PCUs,
- The ability of a vehicle to take every role in a platoon and to operate safely in every platoon transition (Create/Dissolve, Join/Leave)
- Suitable verification and validation methods for CACC/Platooning function

The VeloxCar-demonstrators, which are developed for the CrESt-project, are ready to implement the CACC/Platooning-functionality and allow the development of use cases with a more technical view.

Use Case 1 “Cooperative Vehicle Automation

In the context of the functional use cases, the challenges for the development can be summarized as follows:

- Conception, implementation and validation of diff. platooning controller-types,
- The platoon-regulation.-concept and its quality, especially the safety and reliability
- The platoon-communication-concept and its quality, especially the security
- The definition of actions for all platoon-membership use-cases without harming the safety of the platoon members
- The definition of adapted requirements for engineering methods and tools for collaborated Car2Car- and Car2X-using-functionalities.

Use Case 1 “Cooperative Vehicle Automation

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7. Reviews

#	Reviewer	Chapter	Description	Decision
1	Alexander Becker (As-system)	All	Complete Review with Word-comments	Review comments analyzed and included
2	Bai Yu (Assystem)	All	Complete Review with Word-comments	Review comments analyzed and included
3	Christian Granrath (RWTH)	All	Complete Review with Word-comments	Review comments analyzed and included
4	Christoph Schulze (FEV)	All	Complete Review (Email comments)	Review comments analyzed and included
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