Systematic Derivation of Use Case Clusters for a Generalized Low-Speed Automated Driving Function

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Abstract: One approach for the introduction of SAE Level 3+ Automated Driving are low-speed driving functions due to a reduced risk associated with them. In this paper, a systematic methodology to derive use cases and use case clusters for low-speed applications of Automated Driving (AD), which can be potentially fulfilled by a generalized low-speed function architecture, is described and applied. The use case clusters are defined according to a classification of the derived use cases in the dimensions of safety and technical capabilities. Thereby, the results of this paper simplify the definition of the ODD as well as the functional requirements and architecture for the future development of low-speed AD functions.

Keywords: Automated Driving, Low-Speed Functions, Use Cases, Requirements, Operational Design Domain

1 Introduction and State of the Art

The field of Automated Driving (AD) has evolved substantially during the last years. A major challenge in this field is the introduction of AD functions with functionality according to SAE Levels 3 and 4 [1] into the existing traffic [2]. One approach to face this challenge, e.g. presented by Bolle et al. [3], is the restriction of use cases for AD. Low-speed AD applications seem very suitable in this context because of a simple fail-safe strategy. Due to the low kinetic energy and the resulting low braking distance the overall risk is highly reduced [2]. Furthermore, low-speed AD applications have minor technical requirements on the perception, prediction, and planning horizon of the AD system [3]. Thereby, low-speed AD functions come along with a reduced effort for the technical development and the safety approval, enabling an earlier market introduction and serving as a basis for introducing AD functions with a more complex Operational Design Domain (ODD). One piece of evidence for that is that the worldwide first regulatory-approved AD function according to SAE level 4, an Automated Valet Parking (AVP) system in a car park at the Stuttgart airport [4], is a low-speed application. Another example that underlines the relevance of speed limitation for the approval of AD functions is the recent introduction of the first internationally approved SAE Level 3 system, the *Drive Pilot* by Mercedes-Benz. Its ODD is limited to highway drives under further conditions, but only to maximum speeds of 60 km/h [5].

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A second motivation for low-speed AD functions is that they have the potential to increase the comfort and efficiency of daily life in the near future. The aforementioned use case of AVP offers several benefits like the reduction of vehicle damages [6], the increase of time and energy efficiency for searching a parking space [7], and the possibility for High Density Parking (HDP) [6]. AVP is currently the most popular and evolved application for low-speed AD functions, as evidenced by the fact that there are regulatory documents and standards in development and release, as a technical requirements catalog for AVP published by the Kraftfahrt-Bundesamt [8] and two ISO standards under development (ISO 23374-1 [9], ISO 12768 [10]), which focus on AVP and possible extensions. As the scope of ISO 12768 shows, AVP can also be extended to use cases like automated charging (*Automated Valet Charging*, AVC), e.g. [11] and [12], or washing (*Automated Valet Washing*, AVW), e.g. [13]. Beyond that, low-speed shuttle applications are already in the focus of research and industry for longer than 20 years [14]. Low-speed shuttle services seem beneficial especially for industrial applications, where goods, persons, or the vehicle itself (see e.g. pilot project *Automatisiertes Fahren im Werk* (AFW) by BMW [15]) are transported on a fixed route from a starting point to a certain destination.

To summarize, there are a lot of different perspectives and stakeholders, like society, OEM, and vehicle owners, that have an interest in low-speed AD functions. It therefore is desirable to expand the potential of low-speed AD functions by exploiting further use cases, e.g. also in the regular road traffic. Till now there exist only a few approaches to holistically consider use cases and scenarios of low-speed AD functions. At this point, ISO 22737 ("Low-speed automated driving (LSAD) systems for predefined routes") [16] should be mentioned, which defines overall system, safety, and performance requirements for low-speed applications on predefined routes. However, neither specific use cases nor the important aspect of technical requirements, e.g. the necessary sensor setup, are considered.

In order to close this gap in the field of AD in low-speed applications, in the scope of the public-founded project AUTOtech.*agil* [17] one goal is to develop a generalized AD function for low-speeds ("Generalized Low-Speed Function", GLSF), which uses a dedicated short-range sensor setup as well as own perception and planning modules. This driving function shall cover as many different use cases and scenarios in the low-speed range as possible with one generic architecture. In the context of a modular platform architecture of automated vehicles, as realized in the project UNICAR*agil* [18], the GLSF as one unique function can thus be implemented in different vehicle concepts (e.g. private-owned vehicle vs. cargo shuttle).

As a starting point for the specification of the function's requirements and architecture, it is necessary to define the use cases to be implemented and the ODD under consideration. To select the use cases, it is necessary to look for common features in possible use cases for low-speed AD functions. For this purpose, this paper presents a methodology for the systematic derivation of use case clusters for low-speed AD functions. This enables to frame the scope of a generalized low-speed AD function and its required capabilities, which will in the future be used to derive its architecture as well as its functional and technical requirements.

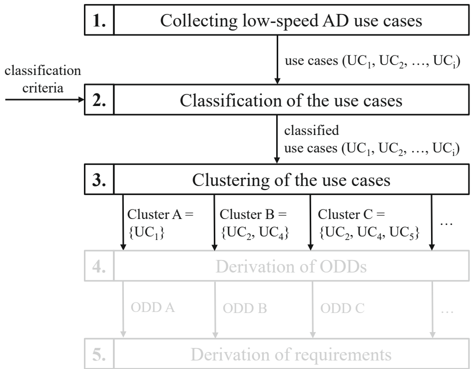

Figure 1: Methodology for the derivation of use case clusters for low-speed AD functions

2 Structure and Methodology

The applied methodology for the systematic derivation of the use case clusters for low-speed AD functions is shown in Figure 1. This methodology also defines the structure of this paper.

In the first step, described in Section 3, possible use cases and scenarios for low-speed AD functions are collected by considering two approaches – a *Stakeholder-Based Approach* and a *Velocity-Based Approach*. Subsequently, the found use cases are evaluated based on classification criteria. Therefore, in Section 4, classification criteria in two categories, covering the aspects of safety and technical capabilities, are first described and afterwards applied to the collected use cases. Based on this, the use cases are grouped into individual clusters that have common features regarding the evaluation of the individual criteria, which is described in Section 5. The identified clusters represent groups of use cases that each share common characteristics with respect to the evaluation criteria and therefore have the potential to be implemented through a generalized functional architecture. Subsequently, ODDs and requirements for specific applications can be derived from the single clusters. However, the latter mentioned two steps are not in the scope of this paper, but part of the development of the GLSF in the Project AUTOtech.*agil*.

3 Collection of Low-Speed AD Use Cases

Two approaches are followed to collect possible use cases for low-speed AD functions as completely as possible. As a basis for the collection, the following constraints on low-speed AD functions are assumed to achieve the goal of a generalized low-speed AD function: The low-speed AD function represents a separate driving mode of the automated vehicle (AV), which is entered either from manual driving or from another AD mode. Thus, the low-speed AD function can be implemented both in SAE Level 3 and Level 4 systems. Consequently, there may or may not be occupants in the vehicle. Furthermore, only use cases are considered where the driving task is limited to transport on paved roads.

3.1 Stakeholder-Based Approach

In the first approach, the *Stakeholder-Based Approach*, different stakeholders are considered by investigating their possible needs and advantages regarding low-speed AD functions. In doing so, the following stakeholders are identified.

Firstly, a *vehicle owner* in the sense of a user of a private-owned vehicle, who is interested in the automation of challenging and annoying driving activities in the low-speed range. This results e.g. in *Pilot Services*, where the vehicle conditionally takes over the driving task (e.g. in a congestion). Furthermore, the use case group of *Automated Valet Services*, where the vehicle is automatically parked (AVP), charged (AVC), or washed (AVW), is of interest for the *vehicle owner*. Another stakeholder interested in this is a *municipality* (e.g. a city) that benefits from an efficient usage of the available parking space and reduced individual traffic for searching a parking spot.

A further stakeholder is summarized by the term *industry* and is aimed at all industrial applications, which automate activities that were previously carried out by humans. This results in the use case group of *Shuttle Services*, in which various entities are automatically transported from a defined starting point to a defined destination. Conceivable is the transport of people (*Group Shuttle*) or freight (*Cargo Shuttle*), for example on a large company site. Especially the *Group Shuttle* meets additionally the demands of a stakeholder *Commercial Operator*, which represents an entity managing a defined institution (e.g. airport, shopping centre, exhibition). Furthermore, the transport of the vehicle itself from the end of production line at the assembly plant to the transfer place is very resource-intensive and thus another use case for a low-speed AD function (*Self-Transportation Shuttle*), which is of special interest for the stakeholder *OEM*.

Another stakeholder is the *Automated Driving System (ADS)*, a central functional component in the AV that manages and ensures its correct and efficient functioning. In the case that the low-speed AD function represents a separate driving mode besides a main AD function, the following interests of the ADS in a low-speed AD function arise: Firstly, in the event of a degradation of the main AD system, the low-speed AD function can act as a fallback layer to bring the vehicle to a safe state. Furthermore, the low-speed AD function may have better characteristics in terms of maneuvering accuracy and energy consumption than the main AD system, so a change to the low-speed AD function may be reasonable in certain situations.

3.2 Velocity-Based Approach

In the second approach, the *Velocity-Based Approach*, possible use cases are collected considering all situations in road traffic where the vehicle's speed is below a threshold speed $v_{\max}$. In general, the particular value of $v_{\max}$ for low-speed AD functions is open. In this paper, a threshold speed $v_{\max}$ of 25 km/h is assumed, since a speed of 30 km/h already includes a high proportion of public road traffic, such as residential areas and main roads with reduced speed. In this case, the low-speed AD functions would not be distinguished from general AD functions for urban traffic.

The consideration of a threshold speed provides a variety of road traffic situations that can be classified into five groups, distinguished by the condition that induces the low-speed driving below the threshold speed. First, low-speed driving *induced by traffic,* e.g. congestion or right-of-way situations. Secondly, low-speed driving *induced by traffic* *regulations*, which is dependant on the respective national road traffic regulations. In this work, the German Road Traffic Regulations (StVO) [19] are considered, resulting in situations such as driving through a traffic-calmed area (ger.: *Verkehrsberuhigter Bereich*). Thirdly, situations where low-speed driving is necessary due to a *scenery induced condition*, e.g. driving through a narrow street segment or manoeuvring into a parking lot. Fourthly, low-speed driving is necessary due to a *vehicle state induced condition*, such as a degradation of components of the AD system (see Stakeholder *ADS* in section 3.1). Fifth, the need of driving slowly due to a *vehicle load induced condition*, such as the transport of standing people. This situation can be linked directly to the use case *Group Shuttle* in section 3.1.

3.3 Summary and Functional Description

In summary, the found use cases can be divided into three overarching groups, as shown in Figure 2. Firstly, the **Pilot Services**, which refer to low-speed driving in public road traffic (e.g. congestion). This group is characterized by a frequent and condition-dependent transfer between „regular driving“ (other AD-mode or manual driving) and the low-speed use case. Furthermore, the possible environment of the use cases in this group can be a high number of road types with an unlimited variety of other road users. The second group are the **Automated Valet Services**, where the vehicle performs a certain service (parking, charging, washing) by AD in SAE Level 4 after the control was handed over to the Automated Driving System (ADS) at a defined drop-off zone and all occupants have left the vehicle. The drop-off zone can be either at the border of the area of the service (*internal drop-off*) or at an external place (e.g. airport terminal) (*external drop-off*). **Shuttle Services** represent the third group, which include the transfer of certain entities (people, freight, vehicle itself) from a defined starting point to a defined destination. In contrast to the Group *Pilot Services*, the groups *Automated Valet Services* and *Shuttle Services* are conducted by driving low speeds in delimited areas, which is

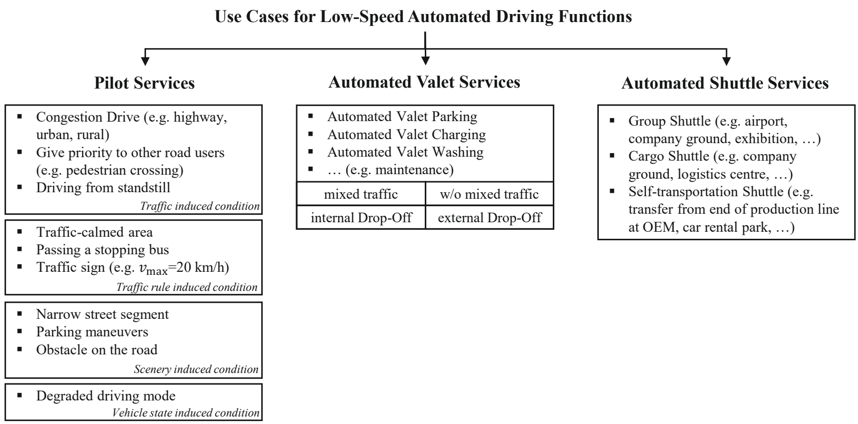

Figure 2: Overview of low-speed AD use cases

characterized by a well defined, e.g. position dependent, transfer into the low-speed use case. The environmental conditions and possible other road users are limited and can be predefined for the specific use case.

As a necessary prerequisite for the classification of the collected use cases (see Chapter 4), they are specified in two steps. First, all use cases whose functional characteristics may be included in another use case, are gathered together with the corresponding use case (e.g. *give priority to other road users* may be included in *urban congestion drive*). Second, for each use case a functional description is given. If necessary for the classification, constraints regarding the functional scope as well as the ODD of the corresponding use case are specified. The functional descriptions of the use cases considered in the following are given in Table 1. Each use case is identified with an ID (UC_X).

Use Case ID	Use Case	Functional description
$\text{UC}_{1.1}$ (AVP) $\text{UC}_{1.2}$ (AVC) $\text{UC}_{1.3}$ (AVW)	Automated Valet Service (Parking/Charging/Washing) *w/o mixed traffic*; *internal drop-off*	The vehicle performs a certain service (parking, charging, washing, etc.) by Level 4 AD after control was handed over and all occupants have left the vehicle at a defined drop-off zone. Vehicle returns to defined pick-up zone after completing the service respectively upon user request. Pick-up/ drop-off zone can be *internal* (pick-up/ drop-off zone at border of area of the service) or *external* (pick-up/ drop-off zone outside of area of the service), which includes low-speed AD in public traffic to the area of the service. Inside the area of the service there either may only be AD vehicles (*w/o mixed traffic*) or people as well as manual driven cars (*with mixed traffic*) present.
$\text{UC}_{2.1}$ (AVP) $\text{UC}_{2.2}$ (AVC) $\text{UC}_{2.3}$ (AVW)	Automated Valet Service (Parking/Charging/Washing) *with mixed traffic*; *internal drop-off*	
$\text{UC}_{3.1}$ (AVP) $\text{UC}_{3.2}$ (AVC) $\text{UC}_{3.3}$ (AVW)	Automated Valet Service (Parking/Charging/Washing) *with mixed traffic*; *external drop-off*	
UC_4	Group Shuttle	Vehicle transfers certain entities (*Group Shuttle*: Sitting and standing people; *Cargo Shuttle*: Freight; *Self-transportation Shuttle*: Vehicle itself from end of production line at assembly plant to transfer place) from a defined starting point A to a defined ending point B by Level 4 AD. *Constraint*: Vehicle drives in delimited area (e.g. industrial site) between starting point and ending point; Only few instructed persons have access to transportation area (employees); No requirements to complex driving operations (e.g. parking maneuvers).
UC_5	Cargo Shuttle	
UC_6	Self-Transportation Shuttle	
UC_7	Parking Maneuver Assist	Function parks vehicle fully automated into a parking lot.
UC_8	Narrow Segment Drive	Function takes over driving task for driving slowly through a narrow road segment with limited length (e.g. narrow underpass).
UC_9	Traffic-Calmed Area Drive	Function takes over driving task in while driving through a traffic-calmed area (dt.: *Verkehrsberuhigter Bereich*).
UC_{10}	Congestion Pilot (Urban)	Function takes over full driving task in urban area or on highway whenever a congestion is present and driven speed is below v_{max}. *Constraints*: The AV will follow the vehicle ahead and execute no lane changes; Right of way is given by priority road or by traffic light (Congestion Pilot (urban)).
UC_{11}	Congestion Pilot (Highway)	
UC_{12}	Speed Limit Drive	Function takes over full driving task whenever a speed limit below v_{max} is present (e.g. 20 km/h or 10 km/h).
UC_{13}	Standstill Release	Function safeguards the start of a Level 4 AV in public road traffic until a threshold speed (e.g. 10 km/h) is reached by perceiving the environment with a near-field sensor module. *Constraints*: Function acts as a sense-only function.
UC_{14}	Degraded Driving Mode	Function takes over driving task whenever a degradation of the regular architecture is detected and a minimal risk condition must be established *Constraints*: Function takes over below v_{max} (vehicle brakes until v_{max} is reached); Path of minimal risk maneuver is predefined (Function safeguards the predefined path); Environment is urban or highway with regular traffic and VRUs.

Table 1: Functional description of the low-speed AD use cases considered in this paper

4 Classification of the Use Cases

The goal of developing a generalized low-speed function implies that the requirements for the different use cases are completely fulfilled in one function. In addition to functional and technical requirements, the automotive industry places demands on safety, specifically defined by ISO 26262 (Functional Safety) [20] and ISO 21448 (SOTIF) [21]. Both set requirements depending on the risks associated with a function, e.g. expressed by an ASIL (automotive safety integrity level) in ISO 26262. Due to the diversity of the identified use cases, for example regarding the complexity of the driving task or the accessibility of the environment for other road users, different risk and respective safety requirements and also different levels of required functional capabilities are expected. To be able to find intersections regarding the relevant requirements within the use cases, classification criteria are defined and assessed in the categories *safety requirements* and *technical capabilities*.

4.1 Safety Requirements

Under the aspect of safety, the risk associated with the execution of the use case with an AD function is assessed, to provide a tendency for the level of safety integrity requirements that will arise. This is important as it can be unfavorable to summarize a use case with low safety integrity requirements with a use case of high safety integrity requirements in one function. According to the state of the art, common risk parameters from ISO 26262 [20] are applied to evaluate the risk of a functional failure in the system. Since the specific architecture of the function is not yet known, however, the failure of safety-related components is not assessed explicitly. Rather, assuming any functional problem that causes a hazardous behaviour of the vehicle, the probability and severity of a collision is evaluated by using the following criteria:

- **Severity**: evaluating whether a collision is severe for a human life. This depends on whether the AV is occupied by humans as well as the type of other road including *unoccupied vehicles*, *occupied vehicles* and *vulnerable road users (VRU)*. Also, the maximum driving speed of the use case is considered, as e.g. driving with 10 km/h while parking leads to less harm than driving towards the end of a congestion with 25 km/h.
- **Exposure**: evaluating the presence of other road users, which depends on the traffic situation in the operative environment and can reach from *no other road users* over *occasional other road users* to *frequent traffic*.
- **Controllability:** evaluating the capabilities of the ego driver or other road users to react to the hazardous situation, e.g. with braking or with an evasive maneuver. This depends on the one hand on the possibility of the AV's occupants to manually control the vehicle, which is for example not possible in a group shuttle. On the other hand, available reaction times might differ depending on the use case.

Each criterion is evaluated on an ordinal scale including *low*, *medium* and *high*, leading to a corresponding final safety requirement level.[1]

4.2 Technical Capabilities

The technical complexity for the realization of the function is evaluated by examining the required functional capabilities for the subfunctions of *sense*, *plan* and *act*. Since the functions are not yet fully technically defined, simplified assumptions are made. It thereby is assumed that the control and actuation stage is part of a common AV architecture, so that the low-speed function architecture is limited to the sensing and planning

[1]It should be noted that these levels are not intended for deriving an ASIL rating, even if the same criteria are used for evaluation, but are only intended to establish comparability among the use cases.

level. Nevertheless, different use cases place different requirements on the precision of the executed trajectory, which is evaluated under the point *act*. Furthermore, it is assumed that a mission and/or route planning is also part of a central instance in the vehicle.

The classification of the required capabilities represents an estimate of the minimum technically necessary to accomplish the specific driving task, to keep the complexity level of the functions as low as possible. The following criteria are classified:

- **Sense capabilities**: classifying the required sensor field of views (FOV) in the direction (*front, sides, rear*) and distance (by means of *maximum speed*), required sensing quantities (*object size, position, relative speed*), object types or infrastructure elements to detect (e.g. *vehicles, pedestrians, cyclists, lane markings, traffic signs*) and level of perception (*only detection* or *classification*).

- **Plan capabilities**: classifying the stages or types of planning that are required to accomplish the AD task as well as the planning environment, as both can require different planning algorithms. The values include *behavior prediction*, *behavior planning*, *path and trajectory planning* and *parking maneuver planning.* The environment is distinguished between *structured*, *semi-structured* and *unstructured.*

- **Act capabilities**: classifying requirements in precisely following a planned path or goal position from *low* to *high*, as for example an AVC use case will place higher requirements on a final position precision than a Group Shuttle.

4.3 Exemplary Application

The classification of the use cases towards the aforementioned requirements is exemplarily shown for $UC_{1.1}$ (*AVP w/o mixed traffic*), UC_4 (*Group Shuttle*), UC_9 (*Traffic-Calmed Area*) and UC_{10} (*Congestion Pilot (urban)*) in Table 2. The classification of all use cases considered in this paper is given in the Appendix (Table 4 and Table 5).

$UC_{1.1}$ is a use case with low safety requirements, which results from the low driving speeds of max. 12 km/h [9] as well as the fact that without mixed traffic no people are involved, neither in the vehicle nor in the environment. The perception requirements are therefore limited towards other vehicles and scenery elements. Assuming that the vehicle requires at least a continuous free space detection and can wait until a path is cleared, no classification or prediction of other objects is required.

UC_4 is evaluated with medium safety requirements, which is determined by the fact that standing persons can be inside the vehicle. Besides the increased safety level, the technical complexity is even lower than for $UC_{1.1}$, as no additional parking maneuver planner is required and the precision requirements are lower.

UC_9 is also a medium safety use case. One major difference from the previous use cases is that the ODD includes public roads. This means that the variety of other road users in the environment increases, yet a traffic-calmed area is only sparsely frequented and the driving speed is even limited to walking speed. The requirements for perception are increasing with regard to objects to be detected. An extreme example here is a ball that suddenly rolls onto the street and can be an indication of children playing. In addition, it is assumed that an object classification in this use case is needed as, in contrast to $UC_{1.1}$ and UC_4, there are pedestrians in the environment to which the vehicle should keep a larger safety distance than to scenery elements. Besides that, traffic-calmed areas still constitute an unstructured environment without lanes, traffic signs or right-of-way rules.

UC_{10}, the congestion pilot in urban environments, results in high safety requirements, which is due to the increased speed up to 25 km/h as well as frequent traffic in the surrounding area. It is assumed, for example, a main road with several successive traffic lights or road works that cause traffic jams. In addition to following a vehicle in front, the vehicle must therefore be able to perceive traffic control elements on the route, such as stopping at a traffic light or giving priority to pedestrians at a crosswalk. This results in additional perception tasks. Due to the increased maximum speed, the sensor field of view must be increased. Furthermore, a structured planning environment is present here in contrast to the other use cases.

		$UC_{1.1}$ *AVP w/o mixed traffic, internal drop-off*	**UC_4** *Group Shuttle*	**UC_9** *Traffic-Calmed Area Drive*	**UC_{10}** *Congestion Pilot (urban)*
Safety Requirements	**Severity**	low (unoccupied vehicles)	medium (occupied vehicles, standing passengers)	medium (occupied vehicles, VRU, very low speed)	high (occupied vehicles, VRU, higher speed)
	Exposure	low (occasional other road users)	low (delimited area with occasional other road users)	low (occasional other road users)	high (frequent traffic in a congestion)
	Controllability	low (no human inside car)	low (no control elements in vehicle)	L3: medium (very low speed) L4: low (no intervention possible)	L3: low (small gaps → low time to react) L4: low (no intervention possible)
	Safety level	low	medium	medium	high
Technical Requirements	**Sensor FOV**	front, sides, rear (very small blind zone req.)	front, sides (no lane changes, no backward driving)	front, sides (no lane changes, no backward driving)	front, sides (no lane changes, no backward driving)
	Sensing distance → max. speed	12 km/h	12 km/h	7-8 km/h "walking speed"	25 km/h
	Objects to detect	scenery obstacles, vehicles in path (ahead, oncoming or crossing), empty parking space	scenery obstacles, vehicles in path, pedestrians (employees)	scenery obstacles, vehicles, pedestrians, cyclists & MVs ahead or oncoming or crossing, play tools like ball	scenery obstacles, vehicles, pedestrians, cyclists & MVs ahead or oncoming or crossing, lanes, traffic signs
	Sensing quantities	ego position, size and relative position of relevant objects	ego position, size and relative position of relevant objects	ego position, size and relative position of relevant objects	ego position, size and relative position and speed of relevant objects, lanes, traffic sign
	Object classification	no	no	yes (e.g. to keep more safety buffer towards pedestrians)	yes (e.g. giving priority to pedestrians)
	Prediction	no (vehicle will wait until path is cleared)	no (vehicle will wait until path is cleared)	no (vehicle will wait until path is cleared)	no (vehicle will wait until path is cleared)
	Planning task	path & trajectory, parking	path & trajectory	path & trajectory	path & trajectory
	Planning environment	unstructured / semi structured	semi-structured	unstructured / semi structured	structured
	Precision req.	high req.	low req.	low req.	low req.

Table 2: Application of the classification scheme to selected low-speed AD use cases

5 Clustering of the Use Cases

The clustering process searches for overlaps in the safety and technical requirements, classified according to the procedure described above. This can result in smaller use case clusters with a low requirements threshold or high but very specific requirements, as well as larger use case clusters that cover simple and complex use cases. This reveals different possibilities of a GLSF, depending on the maximum safety or technical complexity level that is chosen.

The starting point for the clustering are all use cases with a low safety level and matching, low technical requirements, which then form the first "elementary" clusters.

Afterwards, the thresholds in the dimensions of safety and technical capabilities are incrementally increased and partly overlaps to existing clusters are searched, expanding previous clusters. Thereby, further "elementary" clusters with higher requirement levels that have no overlaps to other previous clusters are identified as well.

5.1 Exemplary Application

To demonstrate the methodology outlined above, it is performed exemplarily and a resulting set of related use case clusters is described. This yields the use case clusters A.0, A.1, A.2 and A.3, whose properties are shown in Table 3 for a better understanding of the following.

ID	Use Case Cluster	Use Cases	Properties
A.0	Valet Services w/o mixed traffic	AVP/AVC/AVW *w/o mixed traffic*	**Safety requirements**: low **Technical properties**: max. 12 km/h; 360° perception required; delimited un-/semi-structured environment; parking maneuvers required
A.1	Valet and Shuttle Services w/o human transport	A.0; Cargo Shuttle; Self-Transportation Shuttle	**Safety requirements**: low **Technical properties**: see A.0; detection of humans required (rare presence of humans)
A.2	Valet and Shuttle Services with human transport	A.1; Group-Shuttle; AVP/AVC/AVW *with mixed traffic*; Parking Maneuver Assist	**Safety requirements**: medium **Technical properties**: see A.1; increased requirements to object detection capabilities (e.g. object classification) and response time (frequent presence of humans in direct surrounding possible)
A.3	Valet and Shuttle Services with low-speed public traffic extension	A.2; Traffic-Calmed Area Drive; Narrow Segment Drive; Standstill Release	**Safety requirements**: medium **Technical properties**: see A.2; extension to public traffic in semi-structured environment (*Traffic-Calmed Area*)

Table 3: Extract of derived low-speed AD use case clusters

For the first cluster, use cases with low safety requirements and similar low technical requirements are aggregated from all classified low-speed AD use cases (see Tables 4 and 5, Appendix). Thereby, the "elementary" cluster A.0 (*Valet Services w/o mixed traffic*) is obtained, which includes the three valet services AVP, AVC, and AVW under the boundary condition *no mixed traffic* ($UC_{1.1}$, $UC_{1.2}$, $UC_{1.3}$). Due to the lack of human presence in the ODD of the use cases, all three use cases have low safety requirements. Furthermore, the technical requirements are almost equivalent due to the functional similarity of the three use cases. Therefore a cluster is formed. The technical characteristics of cluster A.0 are shown in Table 3. By increasing the technical requirements while keeping the safety requirements constant, cluster A.1 (*Valet and Shuttle Services w/o human transport*) is formed. In addition to the use cases from cluster A.0, this includes the use cases *Cargo Shuttle* and *Self-Transportation Shuttle* (UC_5, UC_6). In this case, the increase in technical requirements is due to the need for a detection of humans in the environment. The remaining technical requirements for the added use cases are already covered in cluster A.0. After the increase of the technical requirements, an increase of the safety requirements to the level *medium* takes place with the technical requirements remaining as constant as possible, resulting in cluster A.2 (*Valet and Shuttle Services with human transport*). The increased safety requirements here result from the transportation of people in the AD vehicle in the use case Group Shuttle (UC_4), which otherwise has no further technical requirements compared to the previous cluster A.1. The increase in safety requirements as well as the already existing technical requirements further enable the addition of the use case group of valet services with mixed traffic ($UC_{2.1}$, $UC_{2.2}$, $UC_{2.3}$), which in turn results in slightly increased technical requirements (object detection and classification). Due to the necessary safety requirements and technical requirements, the addition of the use case *Parking Maneuver Assist* (UC_7) is also possible. In the last step, the technical requirements are further increased while the safety requirements remain the same. This results in cluster A.3 (*Valet and Shuttle Service with low-speed public traffic extension*), in which the use cases *Traffic-Calmed Area Drive* (UC_9), *Narrow Segment Drive* (UC_8) and *Standstill Release* (UC_{13}) are added. The technical requirements increase due to the extension of the use cases to public road applications, which has an impact on the necessary perception and planning capabilities.

In summary, cluster group A (A.0 to A.3) covers all low-speed AD use cases in delimited areas that are characterized by the same maximum speed of 12 km/h and a similar planning task. Cluster A.3 also extends to use cases on public road traffic with the same maximum speed and still limited technical requirements (e.g. no lane detection necessary).

The complete overview of the defined use case clusters is shown in the appendix (Table 6). In addition to the cluster group A, four further cluster groups were defined. Cluster groups B and C each form subsets of the already described group A. To be highlighted is cluster group D (D.0 to D.2), which is characterized by high safety requirements and technical properties that diverge from cluster group A (e.g. increased maximum speed, behavior planning, traffic sign and lane detection) resulting from applications in public road traffic. The mentioned differences entail that the use cases from cluster group D cannot be combined directly with the use cases from cluster group A. A special case is the use case of Valet Services with external drop-off ($UC_{3.1}$, $UC_{3.2}$, $UC_{3.3}$), whose technical requirements include all technical requirements of the remaining use cases due to the ODD, which includes both public road traffic and delimited areas. This results in use case cluster E (*Holistic low-speed function*), which includes all use cases defined in this paper. If all vehicle concepts of the disruptive modular platform architecture of the UNICAR.*agil* project (private vehicle, taxi, group shuttle, cargo shuttle) [18] were to be considered in one function, cluster E would be the starting point of development.

5.2 General Findings

In addition to the clusters itself, further conclusions can be drawn from the classification and clustering process: It is observable that still different, distinct speed levels exist within the low-speed domain (up to 12 km/h and up to 25 km/h), leading to varying requirements in e.g. safety or sensor FOV. It is thereby found that distinct elemental clusters of use cases can be built, while it is observed that lower safety requirements often correlate with lower technical demands. Furthermore, the variety of planning environments (structured to unstructured) and planning tasks (parking, free drive, follow-up drive) encountered in different use cases underscores the need for a GLSF that can handle a wide range of tasks and environments when choosing a large cluster such as Cluster E. It can also be seen that there is no continuous hierarchy within the use cases with regard to requirements. In the case of larger use case clusters, the highest occurring requirements per category are not only contributed from one, but from different use cases. The exception here are the previously mentioned Valet Services with external drop-off. Finally, the aggregation of use cases into clusters not only aids in organizing requirements but also presents opportunities for expanding the functional scope of individual use cases. For instance, combining Valet Services with Shuttle Services can enhance the functionality of the latter, leveraging existing parking capabilities.

6 Conclusion and Outlook

In this paper, a methodology is presented to systematically derive potential use cases for low-speed AD functions and to cluster them with respect to applicable requirements, so that use case clusters for a generalized low-speed AD function can be inferred according to defined technical constraints.

The paper contributes to the future development of low-speed AD functions in two dimensions: First, a structured and holistic overview of potential application areas for AD at low speeds is provided, enabling the development of future research areas. Second, future development of generalized low-speed AD functions is facilitated because the ODD underlying a function to be developed, which forms the basis for the further definition of the function's requirements and architecture, can be defined in a simplified manner using the use case clusters derived in this paper. By defining the clusters according to the dimensions of *Safety* and *Technical Capabilities*, it is possible to align the selection of clusters with a developer's own constraints for the desired function development.

The proposed use cases apply only to a speed range up to 25 km/h. Accordingly, an extension of the speed range may lead to further use cases, which will allow to enlarge or form new clusters using the presented methodology.

It should be noted that the results obtained are influenced by certain specifications regarding the boundary conditions of the use cases. For example, expanding the maximum speed of the Group Shuttle Services can lead to different cluster results. Also, assumptions towards required technical capabilities of the functions were made. Therefore, ongoing implementation and validation is essential to ensure that the estimated technical capabilities, which served as minimum requirements, are indeed sufficient to obtain reasonable behavior of the functions in real world applications.

Based on the rough requirements definition presented here, high-level architectures for a GLSF can already be derived for selected clusters. The next step for the development of a GLSF is the concretization of the ODD that results from the use case clusters. Based on this, requirements can be concretized within the categories shown by deriving the worst-case framework conditions of the ODD. These are then used, for example, to derive a suitable sensor module for the short range as well as suitable planner metrics and algorithms.

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Appendix

		$UC_{1.1}$, $UC_{1.2}$, $UC_{1.3}$ ***AVP, AVC, AVW*** *w/o mixed traffic, internal drop-off*	$UC_{2.1}$, $UC_{2.2}$, $UC_{2.3}$ ***AVP, AVC, AVW*** *with mixed traffic, internal drop-off*	$UC_{3.1}$, $UC_{3.2}$, $UC_{3.3}$ ***AVP, AVC, AVW*** *with mixed traffic, external drop-off*	UC_4 ***Group Shuttle***	UC_5, UC_6 ***Cargo Shuttle, Self-Transportation Shuttle***	UC_7 ***Parking Maneuver Assist***	UC_8 ***Narrow Segment Drive***
Safety Requirements	**Severity**	low (unoccupied vehicles)	medium (other road users, VRU, very low speed)	high (other road users, VRU)	medium (occupied vehicle, standing passengers)	low (low speed and no humans inside vehicle)	low (very low speed)	medium (other road users, VRU, very low speed)
	Exposure	low (occasional other road users)	low (occasional other road users)	high (frequent traffic like crossing pedestrians or other vehicles ahead)	low (delimited area with occasional other road users)	low (delimited area with occasional other road users)	low (few other road users during parking)	Low (few other road users during maneuver)
	Contro-llability	low (no human inside car)	low/medium (no human inside car, but reaction of pedestrians due to low speed possible)	low (no human inside car)	low (no control elements in vehicle)	low/medium (no human inside car; humans with system knowledge around vehicle)	L3/L4: medium/low (hum. intervent. possible w. small react. time/ no hum. intervent possible)	L3/L4: high/low (human intervention possible/ no human intervention possible)
	Safety level	low	medium	high	medium	low	low	medium
Technical Requirements	**Sensor FOV**	front, sides, rear (very small blind zone req.)	front, sides, rear (very small blind zone req.)	front, sides, rear (very small blind zone req.)	front, sides (no lane changes, no backward driving)	front, sides (no lane changes, no backward driving)	front, sides, rear (very small blind zone req.)	front, sides, rear (very small blind zone req.)
	Sensing distance (max. speed)	12 km/h	12 km/h	25 km/h	12 km/h	12km/h	5 km/h	12 km/h
	Objects to detect	scenery obstacles, vehicles in path (ahead, oncoming or crossing), empty parking space	scenery obstacles (e.g. shopping trolley), vehicles in path (ahead, oncoming or crossing), empty parking space, pedestrians	scenery obstacles (e.g. shopping trolley), vehicles in path (ahead, oncoming or crossing), empty parking space, lanes, vehicle ahead, pedestrians, cyclists, crossing paths with priority, traffic signs	scenery obstacles, vehicles in path, pedestrians (employees)	scenery obstacles, vehicles in path, pedestrians (employees)	scenery obstacles, other vehicles or persons next to/in parking lot	all kinds of objects very close to vehicle, esp. in path
	Sensing quantities	ego position, size and relative position of relevant objects	ego position, size and relative position of relevant objects	ego position, size and relative position of relevant objects, relative speed to vehicle ahead, sign recognition	ego position, size and relative position of relevant objects	ego position, size and relative position of relevant objects	ego position, size and relative position of relevant objects	ego position, size and relative position of relevant objects
	Object classific.	no	yes	yes	no	no	no	no
	Prediction	no (vehicle will wait until path is cleared)	no (vehicle will wait until path is cleared)	yes (e.g. lane changes should be possible)	no (vehicle will wait until path is cleared)	no (vehicle will wait until path is cleared)	no	no
	Planning task	path & trajectory, parking	path & trajectory, parking	path & trajectory, parking (evtl. behavior planning)	path & trajectory	path & trajectory	parking planner	path & trajectory
	Planning env.	unstructured / semi structured	unstructured / semi structured	unstructured / semi structured & structured environment	semi-structured	semi-structured	semi-structured	(semi)-structured
	Precision req.	high req. (AVC: 20 cm (conductive), 2 cm (inductive))	high req. (AVC: 20 cm (conductive), 2 cm (inductive))	high req. (AVC: 20 cm (conductive), 2 cm (inductive))	low req.	low req.	high req.	high req.

Table 4: Application of the classification scheme to the low-speed AD use cases (I/II)

		UC$_9$ *Traffic-Calmed Area Drive*	UC$_{10}$ *Congestion Pilot (Urban)*	UC$_{11}$ *Congestion Pilot (Highway)*	UC$_{12}$ *Speed Limit Drive*	UC$_{13}$ *Standstill Release*	UC$_{14}$ *Degraded Driving Mode*
Safety Requirements	**Severity**	medium (occupied vehicles, VRU, very low speed)	high (occupied vehicles, VRU, higher speed)	medium (no VRUs, higher speed)	high (other road users, VRU)	medium (other road users, VRU, very low speed)	high (other road users, VRU)
	Exposure	low (occasional other road users)	high (frequent traffic in a congestion)	high (frequent traffic in a congestion)	high (frequent traffic like pedestrians or other vehicles ahead)	high (frequent traffic like crossing pedestrians or other vehicles ahead)	high (frequent traffic like pedestrians or other vehicles ahead)
	Contro-llability	L3: medium (very low speed) L4: low (no intervention possible)	L3: low (small gaps → low time to react) L4: low (no intervention possible)	L3: low (small gaps → low time to react) L4: low (no intervention possible)	L3/L4: high/low (human intervention possible/ no human intervention possible)	low (no human intervention possible)	low (no human intervention possible)
	Safety level	medium	high	medium	high	medium	high
Technical Requirements	**Sensor FOV**	front, sides (no lane changes, no backward driving)	front, sides (no lane changes, no backward driving)	front, sides (no lane changes, no backward driving)	front, sides, rear (lane changes possible)	front & sides (no backward driving)	front & sides (only safeguarding of predefined path)
	Sensing distance (max. speed)	7-8 km/h "walking speed"	25 km/h	25 km/h	20 km/h (first traffic sign below 30 km/h)	0-10 km/h	25 km/h
	Objects to detect	scenery obstacles, vehicles, pedestrians, cyclists & MVs ahead or oncoming or crossing, play tools like ball	scenery obstacles, vehicles, pedestrians, cyclists & MVs ahead or oncoming or crossing, lanes, traffic signs	lanes, vehicles ahead	lanes, vehicle ahead, pedestrians, cyclists, motor vehicles, crossing paths with priority, traffic signs, lane detection	all kinds of objects very close to vehicle, esp. in path, → very small blind zone	all kinds of collision objects and obstacles in path
	Sensing quantities	ego position, size and relative position of relevant objects	ego position, size and relative position and speed of relevant objects, lanes, traffic sign	ego position, distance & relative speed to vehicle ahead	ego position, distance & relative speed to vehicle ahead, distance and size of relevant objects, sign recognition	ego position, size and relative position of relevant objects, sign recognition	ego position, size and relative position of relevant objects in path
	Object classific.	yes (e.g. keep more safety buffer towards pedestrians)	yes (e.g. giving priority to pedestrians)	no	yes	no	no
	Prediction	no (vehicle will wait until path is cleared)	no (vehicle will wait until path is cleared)	no (vehicle will wait until path is cleared)	yes (complex maneuvers like lane changes possible)	sense-only function	no (vehicle will wait until path is cleared)
	Planning task	path & trajectory	path & trajectory	path & trajectory	behaviour planning, path & trajectory		trajectory
	Planning env.	unstructured / semi structured	structured	structured	structured		**path is preplanned**
	Precision req.	low req.	low req.	low req.	low req.		low req.

Table 5: Application of the classification scheme to the low-speed AD use cases (II/II)

ID	Use Case Cluster	Use Cases	Properties	Stakeholders
A.0	Valet Services w/o mixed traffic	AVP/AVC/AVW *w/o mixed traffic*	**Safety requirements**: low **Technical properties**: max. 12 km/h; 360° perception required; delimited un-/semi-structured environment; parking maneuvers required	Vehicle owner
A.1	Valet and Shuttle Services w/o human transport	A.0; Cargo Shuttle; Self-Transportation Shuttle	**Safety requirements**: low **Technical properties**: see A.0; detection of humans required (rare presence of humans)	Vehicle owner; Industry; OEM
A.2	Valet and Shuttle Services with human transport	A.1; Group-Shuttle; AVP/AVC/AVW *with mixed traffic*; Parking Maneuver Assist	**Safety requirements**: medium **Technical properties**: see A.1; increased requirements to object detection capabilities (e.g. object classification) and response time (frequent presence of humans in direct surrounding possible)	Vehicle owner; Industry; OEM; Comm. Operators
A.3	Valet and Shuttle Services with low-speed public traffic extension	A.2; Traffic-Calmed Area Drive; Narrow Segment Drive; Standstill Release	**Safety requirements**: medium **Technical properties**: see A.2; extension to public traffic in semi-structured environment (*Traffic-Calmed Area*)	Vehicle owner; Industry; OEM; Comm. Operators; ADS
B.0	Very low speed public traffic	Traffic-Calmed Area Drive; Narrow Segment Drive; Standstill Release	**Safety requirements**: medium **Technical properties**: max. 12 km/h; no 360° perception required; semi-structured environment; high requirements to object detection capabilities and response time (frequent presence of humans in direct surrounding possible); no parking maneuvers required	Vehicle owner; ADS
C.0	Shuttle Service w/o human transport	Cargo Shuttle; Self-Transportation Shuttle	**Safety requirements**: low **Technical properties**: max. 12 km/h; no 360° perception required; delimited un-/semi-structured environment; detection of humans required (rare presence of humans); no parking maneuvers required	Industry; OEM
C.1	Shuttle Service with human transport	C.0; Group-Shuttle	**Safety requirements**: medium **Technical properties**: see C.0	Industry; OEM; Further Operator
C.2	Shuttle Service with low-speed public traffic extension	C.1; B.0	**Safety requirements**: medium **Technical properties**: see C.0; increased requirements to object detection capabilities and response time (frequent presence of humans in direct surrounding possible)	Industry; OEM; Comm. Operators; ADS
D.0	Highway pilot	Congestion Pilot (Highway); Degrade Driving Mode	**Safety requirements**: high **Technical properties**: max. 25 km/h; no 360° perception required; lane detection required; measurement of relative speed required; structured environment; simple planning task	Vehicle owner; ADS
D.1	Urban und highway pilot	D.0; Congestion Pilot (Urban)	**Safety requirements**: high **Technical properties**: see D.0; increased perception requirements (traffic sign detection, detection of further objects, object classification); higher planning requirements (giving priority to other road users)	Vehicle owner; ADS
D.2	Urban and highway pilot extended	D.1; C.1; B.0; Speed Limit Drive	**Safety requirements**: high **Technical properties**: see D.1; 360° perception required; higher planning requirements (behavior planning, behavior prediction)	Vehicle owner; Industry; OEM; Comm. Operators; ADS
E	Holistic low-speed function	*All Use Cases*	**Safety requirements**: high **Technical properties**: Function covers technical requirements of all mentioned use-cases of low-speed AD functions due to including use case AVP/AVC/AVW *with external drop off*	*All mentioned Stakeholders*

Table 6: Overview of low-speed AD use case clusters