Maneuver-based Adaptive Safety Zone for Infrastructure-Supported Automated Valet Parking

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Abstract: One of the major challenges for the release of fully automated driving is the design of safe vehicle automation systems. This work presents a structure to determine a maneuver-specific and adaptive safety zone for collision avoidance. For this, the overall automated driving system is split into functional scenarios that occur during the driving task in the operational design domain. Maneuvers are derived from the given scenarios and car park layouts. Minimum safety distances are determined by injecting worst-case parameters into derived maneuvers. The superposition of these safety distances leads to a new term: the *safety zone*. The safety zone adapts its size according to the performed maneuver as well as the dynamic driving parameters of the engaged traffic participants such as velocities, timing constraints and deceleration capabilities. The methodology is applied on the example of cooperative automated valet parking (AVP).

1 INTRODUCTION

The Non-Traffic Surveillance (NTS) data indicate that from 2012 to 2014 around 5,700 people were killed and 277,000 were injured in non-traffic crashes in the US (Singh, 2016). According to the National Highway Traffic Safety Administration (NHTSA) non-traffic crashes are classified as single-vehicle crashes on private roads, two-vehicle crashes in parking facilities, or collisions with pedestrians in driveways. Thereby, an average of 42% of the nonoccupants such as pedestrians and bicyclists were killed by a forward moving vehicle, 35% by a backing vehicle, 19% due to a rollaway and 94% of occupant fatalities occurred in single-vehicle crashes.

New safety issues have to be targeted due to the design of fully automated vehicles in the upcoming future. The challenges lie in the release of safe automated driving systems. A major problem is the test coverage of the rapidly expanding parameter space to approve the safety of the automated system (Wachenfeld and Winner, 2016).

As indicated in Figure 1 automated valet parking (AVP) provides the service of an autonomous parking procedure starting at the entrance of a parking facility. The responsibility of the driving task is shared between the parking area management (PAM) system and the automated vehicle. The AVP service is executed driverless and is classified as level 4 of SAE International's taxonomy of driving automation. The authors assume the following pre-conditions for AVP:

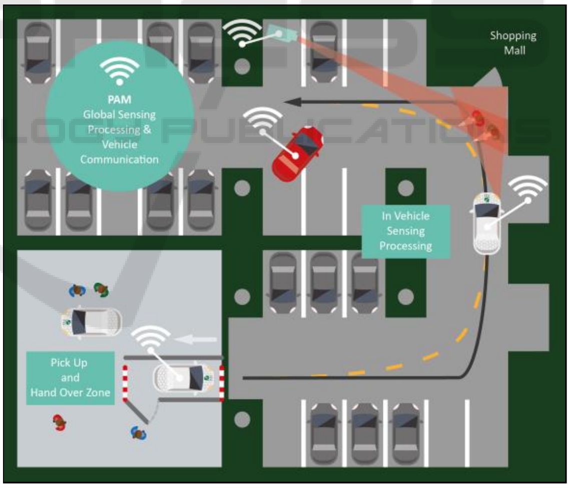

Figure 1: Cooperation between parking area management (PAM) and automated vehicle to provide an automated valet parking (AVP) service. Manually driven, driverless vehicles and pedestrians are present in the parking garage. (Schönemann, 2018).

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1. Parking management system and automated vehicle manage the driving task in cooperation.
2. The procedure of handing the automated vehicle over to and requesting it back from the PAM is instructed via a terminal (human-machine interface, HMI).
3. Manually and automatically operated vehicles are allowed to enter the parking garage.
4. Pedestrians, animals (e.g. dogs), stationary objects, etc. are present in the car park.
5. Drivers and passengers have to leave the automated vehicle before AVP is activated.

Today's automated systems are designed according to the international standard for functional safety of road vehicles known as ISO 26262 (ISO, 2011). In previous work, we applied the design process of the ISO 26262 on a distributed valet parking system. A detailed hazard and risk analysis was performed and corresponding safety requirements were elaborated in order to provide an as yet uninvestigated safety concept for valet parking. The safety analysis leads to the conclusion that parameters such as pose, dimensions, velocity, existence and the class of membership have to be known in order to avoid a potential collision. Figure 2 shows the correlation between these parameters. According to Dietmayer (Dietmayer et al., 2016), the following uncertainties exist:

- State uncertainty: Represents the measuring errors of the object's dimensions (length, width, height), the object's pose and the object's velocity.
- Existence uncertainty: Uncertainties whether an object mapped into the representation actually exists. This concerns mainly false positives and false negatives.
- Class uncertainty: Describes uncertainties in classifying an object and predicting its behavior. The classes pedestrians, stationary objects, vehicles, or other are available. The degree of granularity depends on the use case.

However, in our previous work we did not yet investigate in which area these parameters have to be measured. A maneuver-specific safety zone is elaborated to avoid collisions with static objects, pedestrians and automated or manually driven vehicles.

2 RELATED WORK

Safety is crucial for the commercialization of automated driving. Safe vehicle automation systems

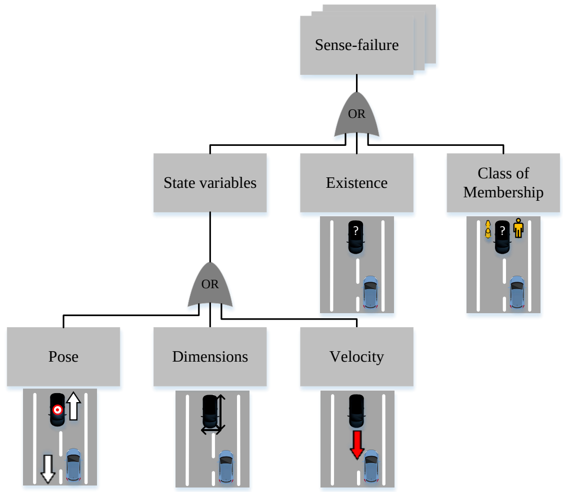

Figure 2: Uncertainty domains in the environment perception and parameters which has to be determined for collision avoidance (the object's position, orientation, dimensions, velocity, existence and class of membership).

shall intervene in case of an upcoming accident and release the driver from this burden. A major challenge is to design distributed systems which share the responsibility for the driving task. Fully automated valet parking is such a distributed system.

Each complex automation system causes the issue of testing. Up to now, there is no international standard for approving the safety of an automated driving system. The ISO 26262 only addresses a systematic approach for designing functionally safe electrical and electronic systems of road vehicles. Neither a standard, nor a methodology is specified to develop a safety concept specifically for automated driving systems. However, the safety approval and new testing methods are required for the release of automated driving (Winner, 2015).

Reschka et al. (Reschka, 2016) examined various safety concepts for autonomous driving without driver monitoring. An automated driving system requires safety mechanisms to transfer the system into a safe state. For an AVP system, the authors introduced a remote operator. An external mechanism provides the possibility to stop a driverless vehicle in case of an emergency. This requires a secure and reliable communication between the vehicle and a remote control station. Furthermore, the authors surveyed safety concepts in other domains. Safety mechanisms for railway are integrated into the infrastructure: a monitoring system prevents a train to enter a track that is already occupied. The stopping distances for railway are relatively large compared to vehicles and the complexity of scenarios is lower due to the control mainly in longitudinal direction.

Chellaswamy et al. (Chellaswamy, 2015) introduces a system to identify crowded areas to avoid collisions. The authors state that most accidents occur in dense traffic areas. The system adapts the vehicle velocity at various safety zones. Once a vehicle enters a dense traffic area, a controller automatically reduces the vehicle velocity. The described safety zone is not realized vehicle-specific but area-specific. The methodology reduces the severity of accidents for traffic participants, but automated driving at lower velocities becomes more time consuming.

Bosch and Daimler (Automotive World, 2018) recently developed a prototype for a cooperative valet parking system. The driving task is shared between vehicles and intelligent infrastructure during mixed traffic. Manually driven and automated vehicles as well as pedestrians are present in the parking garage. Environment perception and trajectory planning is performed by the parking area management system whereas the lateral and longitudinal actions are executed by the vehicle. The prototype marks the first pilot of its kind. However, further information concerning the safety concept is not provided.

Schwesinger et al. (Schwesinger, 2016) and Löper et al. (Löper, 2013) focus on a functional development of a valet parking prototype capable of performing fully automated navigation, but a specification of a safety relevant space is not part of the investigation.

The state of the art reveals that a safety concept for automated valet parking is missing. Areas of interest for safety considerations are not yet addressed for AVP. However, a definition of an area, in which the perception of objects for collision avoidance is mandatory, has to be given. Outside of this area the perception of objects is not required. The magnitude of this area is maneuver-specific and therefore an investigation of occurring maneuvers in a parking garage is required. Additionally, a specification for the infrastructure support has to be given for a cooperative valet parking service.

This work aims to specify areas of interest around the ego-vehicle in which the traffic participant's parameters have to be determined for collision avoidance. The safety zone provides a description of the relevant space in the environment perception task that is executed by the parking area management system and the automated vehicle. The results of this work can be used to increase the safety performance of the overall system and optimize the system accordingly.

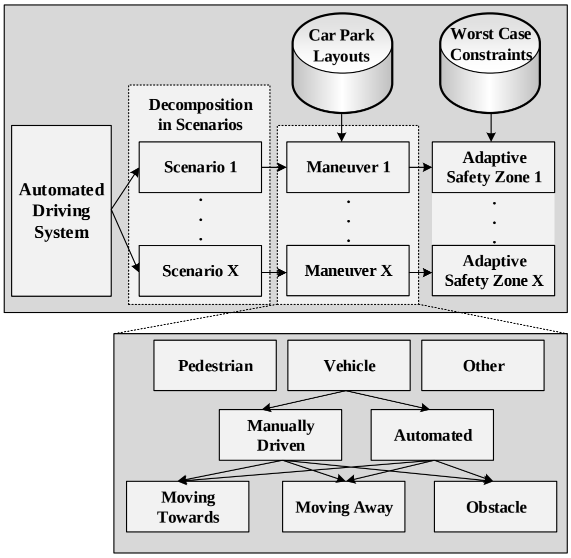

Figure 3: Decomposition of the automated driving system in functional scenarios and investigation of possible maneuvers for each scenario. The classification, and the moving behavior as well as worst-case constraints ensure the calculation of required safety distances for collision avoidance.

3 METHODOLOGY

As illustrated in Figure 3 the overall valet parking system is split into functional scenarios that occur during the execution of the valet parking procedure. According to Ulbrich et al. (Ulbrich, 2015) a scenario describes snapshots of the environment and the interaction of entities while time is progressing. Thereby, 6 major scenarios can be investigated: vehicle handover to parking area management system, automated driving to a point of interest, automated maneuvering into the parking space, automated leaving of the parking space, vehicle handover to driver and aborting the valet parking procedure. These scenarios are further described in the following section.

Each scenario is examined according to specific maneuvers that are instructed by the automation system. Maneuvers are extracted from layouts of car parks (Pech, 2009). The determination of the safety distances depends on the object's class which ideally is known. If the class type equals a vehicle, it can be distinguished whether the potential collision partner is manually driven or driverless. This kind of information could be provided by the parking area management system or C2C. If the vehicle is operated driverless, it was registered by the PAM during the handover and tracked. If no object information is

provided, it should be assumed that the potential collision partner is a manually driven vehicle. The assumption is valid since compared to an automated vehicle, more conservative parameters will be assigned to the collision partner. Even if the assumption is false, a sufficient safety distance is still provided. Furthermore, the moving behavior of the potential collision partner can be examined in order to check whether the object is moving towards the ego-vehicle, moving away or neither moving away nor moving towards.
Worst case constraints such as timing, maximum allowed velocity and minimum required deceleration are defined for the operational domain and serve as an input for each maneuver to specify a minimum required safety distance for collision avoidance. The safety zone adapts its size parameter-dependent at each time step.

4 DECOMPOSITION OF SCENARIOS

In the previous work, the valet parking system was decomposed into functional scenarios that occur during operation. These scenarios are illustrated in Figure 4 and are used in combination with layouts of car parks to identify executed maneuvers within AVP.

A. Vehicle Handover to Parking Area Management System

The valet parking procedure starts with the drop-off of the automated vehicle at the handover zone. The system checks whether the vehicle is located in the handover zone, is in standstill and, correctly oriented and, whether all doors are closed and all persons have left the handover zone. The PAM may transmit a static map of the parking garage and a predefined trajectory to the corresponding parking spot. After the parking request is instructed, the vehicle is handed over to the parking area management and the automation takes over the responsibility for the further steps of the driving task. The handover is successful if the specified constraints are met and a parking spot can be assigned.

B. Automated Driving to a Point of Interest

If the handover is successful, the system has to navigate the vehicle to the point of interest. The point of interest is defined as the desired location which mainly includes the assigned parking spot, the pick-up zone or the location after an emergency brake and full stop. Thereby, the system shall ensure that the vehicle stays in the statically defined drivable area. The environment is perceived via radar, lidar and ultrasonic sensors. Several maneuvers have to be accomplished: following the straight or curved lane, turning left/right, crossing of an intersection and driving on a ramp. The end state is reached if the vehicle arrives at the desired point of interest without colliding. This scenario does not include the maneuvering into the parking space.

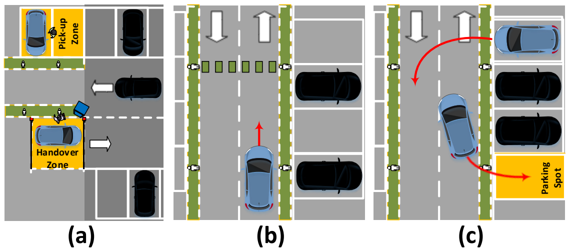

Figure 4: Scenarios which occur during automated valet parking: (a) vehicle handover to parking area management system and vehicle handover to driver after a handback request, (b) automated driving to a point of interest such as the parking spot or the exit, (c) automated maneuvering into and automated leaving of the parking space.

C. Automated Maneuvering into the Parking Space

When the automated vehicle arrives nearby the parking spot, the parking maneuver can be executed. Either the PAM has already checked the required free parking space and/ or the vehicle takes over the analysis of the parking spot to decide whether the parking space is appropriate for parking. Thereafter, longitudinal or lateral actions have to be executed to place the vehicle properly. The maneuver *driving backwards* is part of the scenario. The vehicle may park forward or reverse. The parking spots are arranged from 0° to 90° with respect to the lane. However, reverse parking is recommended in order to reduce the required range of the rear side sensors when leaving the parking spot in reverse. The sensor range requirements can then be shifted to the vehicle front since the sensor range is already required for intersection crossings. The end state is successfully reached if the assigned parking spot is arrived collision-free, the vehicle size does not exceed the parking spot, the parking brake is set and the vehicle is on standby.

D. Automated Leaving of the Parking Space

If the driver initiates a handback request, the automated vehicle is triggered to leave the parking space. The required trajectory to the pick-up zone is either computed by the ego-vehicle or received from the PAM. Maneuvering out of the parking spot is possible in forward and reverse direction. However, as already stated in scenario C, forward leaving is recommended. The maneuvers accelerate/ decelerate, maneuvering out of the parking spot, and driving backwards are required. The execution is successful if no traffic participant is harmed and the automated vehicle left the parking spot until the maneuver 'following the straight or curved lane' from scenario B can be performed.

E. Vehicle Handover to Driver

When the vehicle arrives at the exit of the parking garage, the vehicle will be placed at the pick-up zone, the parking brake has to be set, the vehicle engine has to be turned off, and the valet parking function needs to be deactivated. If the constraints are met and no traffic participant is harmed, the scenario is considered to be successful.

F. Aborting the Valet Parking Procedure

This scenario describes the abort of the valet parking service, which is equivalent to an early initiated handback request. The automated vehicle does not drive to the assigned parking spot but instead directly to the exit of the parking garage. Therefore, scenario B and E still have to be executed. Once the vehicle is located in the pick-up zone in standstill, the valet parking procedure can be deactivated and the driver is able to enter the vehicle.

5 EXAMINATION OF MANEUVERS

The scenarios A - F serve as an input to derive maneuvers for AVP. A stopping distance is required for each maneuver in order to avoid a collision with traffic participants. The superposition of these maneuver-specific stopping distances leads to the introduction of a new term: the *safety zone*. The safety zone adapts its distances according to the performed maneuver as well as dynamic driving parameters of the engaged traffic participants such as velocities, timing constraints and deceleration capabilities. The following maneuvers were found:

- Following a straight or curved lane: This maneuver includes the primitives accelerate and decelerate for longitudinal control as well as lane keeping/ steering for lateral control. The ego-vehicle's position is thereby kept at the lane center.
- Driving backwards: This maneuver is executed during the maneuvering into the parking spot. Thereby, reverse parking is recommended in order to reduce the system's perception requirements to the rear side.
- Turning left/right: A turn is required at intersection crossings and when leaving the parking space to the left or to the right for parking spaces oriented in lateral direction.
- Crossing an intersection: If the vehicle arrives at an intersection, turning left, turning right or crossing the intersection is possible. The maneuver addresses the crossing.
- Coverage during maneuvers: Coverage of objects by other traffic participants or by parking construction causes undetected objects inside the ego-vehicle's safety zone without the vehicle's knowledge.

6 WORST-CASE CONSTRAINTS

Before the safety distances are determined systematically, the defined constraints used here should be mentioned. These assumptions serve as constraints to calculate the stopping distances. Once worst-case safety distances are determined, they are also valid for less critical situations and should avoid collisions. Thereby, the parameters are defined as velocity v, system response time $t_{\mathrm{R,ad}}$ from the plausibility check until the initiation of the brakes, driver reaction time $\mathrm{t_{R,md}}$, response time of the brakes $t_{\mathrm{R,b}}$, time delay of the brake until buildup of deceleration $t_{\mathrm{B,b}}$, a minimum guaranteed deceleration $D_{\min} = \mu_{\min} \cdot g$ given by the friction coefficient μ and gravity constant g. In a parking garage, the authors assume a maximum allowed forward velocity of $v_{\mathrm{max,f}}$, a velocity in reverse $v_{\mathrm{max,r}}$ and a maximum allowed velocity at intersections $v_{\mathrm{max,i}}$. Additionally, a safety margin d_{tol} is required to prevent a collision. These rather conservative considerations are valid for the operational design domain and are summarized in Table 1.

7 DERIVATION OF AN ADAPTIVE SAFETY ZONE

Based on the found maneuvers and worst case constraints an adaptive safety zone is derived. As described in the methodology it is necessary to

Table 1: Pre-defined Constraints for Automated Valet Parking.

ID	Description	Value
C01	Maximum allowed velocities: in forward $v_{\max,f}$, in reverse $v_{\max,r}$, at intersections $v_{\max,i}$	$v_{\max,f} = 30\ \mathrm{km/h}$ $v_{\max,r} = 10\,\mathrm{km/h}$ $v_{\max,i} = 10\,\mathrm{km/h}$
C02	Worst-case expected time delays: system response time from the plausibility check until initiating the brakes $t_{\mathrm{R,ad}}$, driver reaction time $t_{\mathrm{R,md}}$, lag time of the brake $t_{\mathrm{B,lag}}$ given by the response time of the brake $t_{\mathrm{R,b}}$ and the time until buildup of deceleration $t_{\mathrm{B,b}}$	$t_{\mathrm{R,ad}} = 0.3\ \mathrm{s}$ $t_{\mathrm{R,md}} = 1.5\ \mathrm{s}$ $t_{\mathrm{B,lag}} \approx t_{\mathrm{R,b}} + \frac{t_{\mathrm{B,b}}}{2}$ [1]$t_{\mathrm{lag}} = 0.2\ \mathrm{s}$
C03	Minimum expected deceleration $D_{\min} = \mu_{\min} \cdot g$ for object- and ego-vehicle	$D_{\min} = 8\ \frac{\mathrm{m}^2}{\mathrm{s}}$
C04	Safety margin d_{tol}	$d_{\mathrm{tol}} = 0.5\ \mathrm{m}$

1) Breuer and Bill, 2008

distinguish between several cases which will be explored for each maneuver in the following.

A. *Following a Straight or Curved Lane*

When the ego-vehicle follows the lane there are three cases regarding the stopping distances as shown in Figure 5:

- Case (A,a): The detected object is moving towards the ego-vehicle. In this case, it is useful to distinguish between two possibilities: A collision of two vehicles and either both vehicles are braking (A,a1) or only the automated vehicle is braking (A,a2).
- Case (A,b): The object is moving away and $v_{\mathrm{ego}} > v_{\mathrm{obj}}$
- Case (A,c): The object is neither moving towards the ego-vehicle nor moving away.

For each of these cases different stopping distances have to be considered. In case (A,a1), it is assumed that both vehicles react at the same time. The object vehicle can either be manually driven or driverless. Thus, the worst case object's reaction time $t_{\mathrm{R,obj}}$ has to be taken into account. The overall required stopping distance is given by the overlap of the single stopping distances calculated by

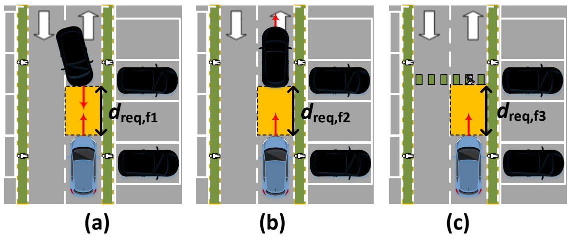

Figure 5: Safety zone (yellow) for following a straight or curved lane: (a) object is moving towards the ego-vehicle, (b) object is moving away and $v_{\mathrm{ego}} > v_{\mathrm{obj}}$, (c) object is neither moving away nor moving towards.

$$d_{\mathrm{req,f1}} \geq (v_{\mathrm{ego}} + v_{\mathrm{obj}}) \cdot (t_{\mathrm{B,lag}} + t_{\mathrm{R,ad}}) + v_{\mathrm{obj}} \cdot (t_{\mathrm{R,obj}} - t_{\mathrm{R,ad}}) + \frac{v_{\mathrm{ego}}^2 + v_{\mathrm{obj}}^2}{2 \cdot D_{\min}} + d_{\mathrm{tol}} \quad (1)$$

Equation (1) produces the maximum spanned safety zone for the worst-case $v_{\mathrm{ego}} = v_{\mathrm{obj}} = v_{\max,f}$. This can be seen as the minimum required perception range $d_{\mathrm{req,f1}}$ to the front for AVP. Once the object is measured in this area, the safety zone adapts its size according to the object's velocity and reaction capability as presented in Figure 5.

For the manually driven vehicle the driver's reaction time has to be injected into the formula by $t_{\mathrm{R,obj}} = t_{\mathrm{R,md}}$, whereas for an automated vehicle as a collision partner the equation simplifies by setting $t_{\mathrm{R,obj}} = t_{\mathrm{R,ad}}$.

The case (A,a2) occurs if the automated vehicle has to be in standstill for collision avoidance and only the control of the automated vehicle is possible. The required distance d_{req} is then given by the stopping distance of the ego-vehicle and the driven distance of the manually operated or automated vehicle

$$d_{\mathrm{req,f1}} \geq (v_{\mathrm{ego}} + v_{\mathrm{obj}}) \cdot (t_{\mathrm{B,lag}} + t_{\mathrm{R,ad}}) + v_{\mathrm{obj}} \cdot \frac{v_{\mathrm{ego}}}{D_{\min}} + \frac{v_{\mathrm{ego}}^2}{2 \cdot D_{\min}} + d_{\mathrm{tol}} \quad (2)$$

Case (A,b) can be approximated by assuming an object that is not moving since stopping in front of a standing object is always more safety critical compared to objects that are moving away. When considering this approximation, the object has no impact on the stopping distance and therefore the stopping distance is only influenced by the ego-vehicle's parameters. This is achieved by setting $v_{\mathrm{obj}} = 0$ in equation (2). The same considerations can be applied to case (A,c), since case (A,b) is reduced to case (A,c).

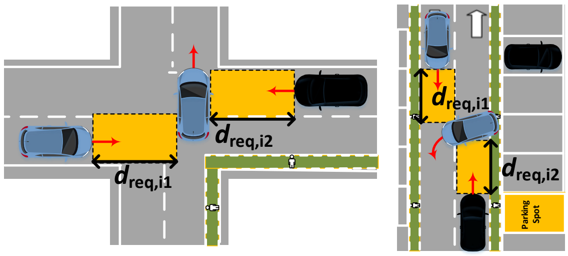

Figure 6: Safety zone (yellow) for intersection crossing (left) which reveals similar characteristics to leaving the parking spot (right).

B. Driving Backwards

This maneuver has similar characteristics to the maneuver *following a straight or curved lane.* Similarly, three cases occur while driving in reverse:

- Case (B,a): The detected object is moving towards the ego-vehicle
- Case (B,b): The object is moving away and $v_{\text{ego}} > v_{\text{obj}}$
- Case (B,c): The object is neither moving towards the ego-vehicle nor moving away.

The stopping distances are calculated as described in the maneuver *following a straight or curved lane*, but considering that the ego-vehicle is driving in reverse and an object is detected to the rear. The minimum required perception range to the rear for AVP is given for $v_{\text{ego}} = v_{\text{max,r}}$, $v_{\text{obj}} = v_{\text{max,f}}$ and $t_{\text{R,obj}} = t_{\text{R,md}}$. Once an object is measured in this area, the safety zone adapts its size according to the object's parameters.

C. Turning Left/ Right:

In case of turning right at an intersection or when leaving the parking spot as shown in Figure 6, traffic participants coming from the left need to have at least a minimum distance $d_{\text{req,i}}$ to the ego-vehicle in order to be able to successfully brake in case of an emergency. The required distance is dependent on whether the object-vehicle is manually driven or driverless.

$$d_{\text{req,i}} \geq v_{\text{obj}} \cdot (t_{\text{B,lag}} + t_{\text{R,obj}}) + \frac{v_{\text{obj}}^2}{2 \cdot D_{\min}} + d_{\text{tol}} \tag{3}$$

For an automated collision partner approaching from the side with a velocity v_{obj}, the required safety distance is given by setting the reaction time $t_{\text{R,obj}} = t_{\text{R,ad}}$. If no information is provided by the infrastructure about the type of object, the system assumes that the object is a manually driven vehicle. The assumption is valid since rather conservative parameters are allocated to the traffic participant.

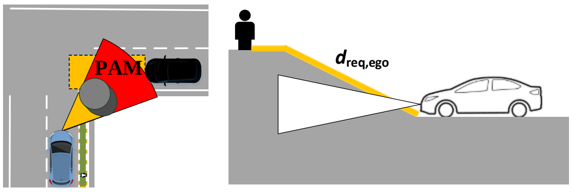

Figure 7: Covered perception area at an intersection (left). Relevant object which is not in the ego-vehicle's sensor view when driving on a ramp (right).

Even if the assumption is false, a sufficient safety distance is assigned by $t_{\text{R,obj}} = t_{\text{R,md}}$.

The minimum required distance that has to be checked by the ego-vehicle when entering the corresponding lane is given for $v_{\text{obj}} = v_{\text{max,i}}$.

D. Crossing an Intersection

This maneuver includes the same safety distances as described in the maneuver *turning left/ right* except that no turn is actually performed by the ego-vehicle. Same dependencies occur: either the vehicle-type has to be known or a manually driven vehicle as a worst case is assumed to provide a sufficient safety distance.

E. Coverage

The system has to manage potential collisions for each of the upper described maneuvers even if the collision partner is covered for the ego-vehicle. The issue can only be solved by C2I since top mounted sensors will not be covered by traffic participants or by parking construction. Therefore, the required information from safety areas have to be transmitted to the ego-vehicle. The covered area for the ego-vehicle has to be determined by the parking area management system and top-mounted sensors located in this area have to replace the ego-vehicle's sensor view.

The case of driving on a ramp requires the system to distinguish whether a detected object is a ramp. Here, similar safety distances as described for *following a straight or curved lane* have to be considered just that the deceleration depends on the slope α of the ramp

$$D_{\text{res}} = D_{\min} \mp g \cdot \sin \alpha \tag{4}$$

These safety distances have to be provided by the parking area management system as shown in Figure 7.

Derivation of the Overall Safety Zone

The superposition of the derived maneuver-based stopping distances shows that the overall safety zone is created by the ego-vehicle's and the object's travelled envelopes given by their widths and stopping distances. A radius with the object's stopping distance can be spanned around the ego-vehicle to the front and to the rear. Furthermore, the ego-vehicle's stopping envelope has to be added when following a straight lane or driving backwards. Once the object is oriented in a 90° angle to the ego-vehicle such as at intersections, only the object's stopping envelope has to be considered. As a result, the overall safety zone is given by the ego-vehicle and the object's travelled envelope as shown in Figure 8. The main equation and overall maneuver specific constraints are listed in Table 2.

Table 2: Main equation and maneuver-specific constraints for determining the required safety zone.

Main Equation	
$d_{\mathrm{req}} \geq (v_{\mathrm{ego}} + v_{\mathrm{obj}}) \cdot (t_{\mathrm{B,lag}} + t_{\mathrm{R}}) + v_{\mathrm{obj}} \cdot t_x + \frac{v_{\mathrm{ego}}^2 + v_{\mathrm{obj}}^2}{2 \cdot D_{\mathrm{min}}} + d_{\mathrm{tol}}$	
Maneuvers	**Safety Zone**
Following a straight or curved lane or Driving backwards or Coverage	$t_{\mathrm{R}} = t_{\mathrm{R,ad}}$ **Case (A/B/E,a1):** $t_x = t_{\mathrm{R,obj}} - t_{\mathrm{R,ad}}$ **Case (A/B/E,a2):** $\frac{v_{\mathrm{obj}}^2}{2 \cdot D_{\mathrm{min}}} = 0$ $t_x = \frac{v_{\mathrm{ego}}}{D_{\mathrm{min}}}$ **Case (A/B/E,b/c):** $v_{\mathrm{obj}} = 0$
Turning left/ right or Crossing an intersection or Coverage	**Case (C/D/E):** $t_x = 0$ $v_{\mathrm{ego}} = 0$ $t_{\mathrm{R}} = t_{\mathrm{R,obj}}$

8 CONCLUSION

Automated driving has revealed challenges for functional safety. A safety concept for automated valet parking was not yet targeted. Furthermore, mandatory perception areas for collision avoidance were not yet addressed in the state of the art for AVP. The shapes of these areas are maneuver-specific and therefore an examination of occurring maneuvers in a parking garage was required. For this, the overall system is decomposed in functional scenarios and each scenario is investigated for the executed maneuvers. Worst-case constraints such as timing, maximum allowed velocity and minimum required

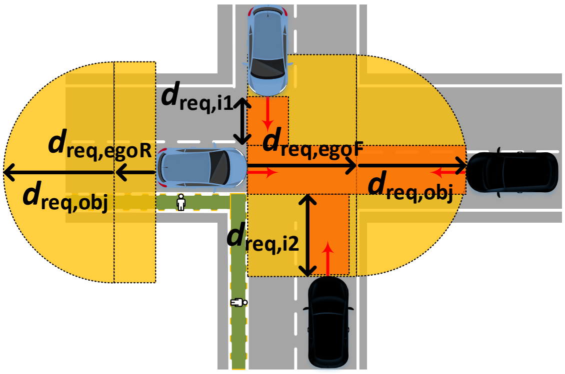

Figure 8: Overall safety zone (yellow) to the front and to the rear given by the superposition of the ego-vehicle's and object's travelled envelopes and corresponding adaptation (red) due to the occurrence of moving traffic participants.

deceleration are derived for cooperative valet parking in a mixed traffic environment. These constraints served as an input to calculate minimum required safety distances for each maneuver. The authors investigated in which areas parameters such as pose, dimensions, velocity, existence, and the class have to be known in order to avoid a potential collision for automated valet parking.

The superposition of these safety areas leads to the term *adaptive safety zone*. The safety zone provides a description of a safety-relevant space for the environment perception. The collision partner's parameters are measured in a minimum required perception zone. The adaptive safety zone is determined for each maneuver by distinguishing between the collision partner's characteristic and it's moving behavior. The parking area management system provides the safety zone for the automated vehicle if coverage prevents the perception task or if safety critical objects do not appear in the vehicle's sensor view. The results of this work can be used to adjust the AVP system requirements for the environment perception task according the determined safety zone. The results illustrate which areas top mounted sensors have to examine to increase the safety performance of the overall system.

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Portugal, Poland, Ireland, Belgium, France, Netherlands, United Kingdom, Slovakia, Norway.

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