PRoPART

Precise and Robust Positioning for Automated Road Transports

D1.1 Report on Vehicle Application Use Cases and Application Scenarios

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European Global Navigation Satellite Systems Agency

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Leader in charge of deliverable: **Fredrik Hoxell**
Affiliation: Scania CV AB

Authors

Affiliation	Name
Scania CV AB	Fredrik Hoxell
Baselabs GmbH	Liang Zhang

Consortium Members

Organisation	Abbreviation	Country
RISE Research Institutes of Sweden	RISE	Sweden
Scania CV AB	SCANIA	Sweden
Flowscape AB / Waysure Sweden AB	FS / WS	Sweden
Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.	FhG	Germany
Asociacion Centro Tecnologico Ceit-IK4	Ceit-IK4	Spain
Baselabs GmbH	BL	Germany
Commsignia KFT	CMS	Hungary

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List of acronyms

AD	Automated Driving
ADAS	Advanced Driver Assistance System
ADS	Automated Driving System
ECU	Electronic Control Unit
EGNSS	European Global Navigation Satellite System
ETSI	European Telecommunications Standards Institute
GNSS	Global Navigation Satellite System
ITS-G5	A European standard for vehicular communication
OS-NMA	Open Service – Navigation Message Authentication
RSU	Road-Side Unit
RTK	Real Time Kinematics
TRL	Technology Readiness Level
UWB	Ultra-Wideband
V2I	Vehicle-to-Infrastructure (communication)
V2V	Vehicle-to-Vehicle (communication)
V2X	Vehicle-to-Anything (communication)

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Contents

1 Summary of the PRoPART project

The objective of the project 'PRoPART' is the development and demonstration of a high availability positioning solution for connected automated driving applications. It aims to develop and enhance an existing RTK (Real Time Kinematic) software solution developed by Waysure by exploiting the distinguished features of Galileo signals as well as combining it with other positioning and sensor technologies. Also, the possibility to authenticate the navigation message of Galileo and other navigation satellite systems through Open Service – Navigation Message Authentication (OS-NMA), adding resistance to certain spoofing attacks, will be explored during the project. Besides the use of vehicle on board sensors, PRoPART will also use a low-cost Ultra-Wideband (UWB) ranging solution for redundancy and robustness in areas where the coverage of GNSS is poor (e.g. in tunnels or in urban canyons). In order to define the correct requirements for the PRoPART combined positioning solution, a cooperative automated vehicle application will be defined and developed. The vehicle application will rely on the high availability positioning solution and use it to couple its ADAS system with V2X and aggregate information received from other connected vehicles and Road Side Units (RSU). As there will be a transition period where a lot of vehicles are neither connected nor automated, solutions having high impact during low penetration are in focus. Therefore, PRoPART will implement an RSU with high-precision positioning and use both UWB as well as traffic monitoring to supply ranging, object perception and EGNSS RTK correction data via ETSI ITS-G5 to the connected automated vehicle so it can make safe decisions based on robust data. This means that PRoPART also will implement perception layer sensor fusion that uses information collected from external sensors as well as information from both the on-board vehicle sensors and the high availability positioning solution. PRoPART will also exploit possibilities to distribute EGNSS RTK correction data from the RSU to the vehicle. The main objectives and their related impacts can be summarized as follows:

- Precise positioning with EGNSS:
  - Deeply Coupled RTK Positioning using the Galileo E1 and E5 signals for carrier based positioning as well as the GPS L1, L2 and L5 signals.
  - Increased robustness with EGNSS using E1 and E5 signals
  - Performance indicators: Initialization and re-initialization time, vehicle position, velocity and attitude accuracy in specific use case environments.
- High Availability and Robust Positioning:
  - Combining EGNSS RTK positioning with UWB ranging and vehicle motion sensors providing deeply coupled feedback
  - EGNSS RTK correction data from RSU
  - RSU with traffic monitoring capabilities. The project aims to achieve objects detected by an RSU to be aggregated by an automated vehicle (ECU) with an *overall latency of less than 150 ms and combined location error below 2m*.
  - Performance indicators: Availability of accurate, robust position estimate in specific use case environments.
- Cooperative Automated Vehicle Application:
  - Increased cooperation between automated and non-automated vehicles.
  - Safer decisions for traffic manoeuvres
  - More cost efficient high precision positioning

Within this project, these ambitious goals will be demonstrated for a collaborative automated lane change function using the AstaZero proving ground. An expressed goal of the project is the progression on the technology readiness level (TRL) scale of user function specific components for use in automated driving (AD) applications. While the maturity of such subsystems has a direct impact on automated driving systems (ADS) and will represent important steps towards commercialization, the automated driving system itself is not a target for such TRL progression. The ADS to be used in the demonstrations will be somewhere between *partial automation* and *conditional automation*, or level 2 and 3, on the SAE scale of road vehicle automation.

2 Introduction

From the PRoPART application, the D1.1 deliverable is *a description of overall vehicle use cases and scenarios*. As such, it addresses typical scenarios and associated challenges that arise for automated lane changes performed by a heavy truck during highway driving. Typically, a traffic situation is dependent on several factors and can possibly consist of multiple sub-scenarios, each of which may be quite simple, but their superimposed state becomes very difficult to handle. In this deliverable the factored scenarios are outlined (i.e. sub-scenarios). Each one of the scenarios are complete in and of themselves, but more importantly they may be combined with each other in straightforward ways to form more complicated situations.

The main role of the use case and scenarios described below is to serve as main drivers in terms of requirements for the systems to be developed. The goal of the elicitation to follow in the next task of the PRoPART project (T1.2 – System Requirements Elicitation) is to define and elaborate on the requirements in order to lay the foundation for a fully functional demonstration involving automated lateral movements.

The first part of this report presents the target use case as defined in the application. Then the deliverable continues by structuring the sub-scenarios in the proposed use case. The presented scenarios aim to give a high-level understanding of challenges that an Automated Driving System faces in the context of the use case. Finally, the scenarios are considered from a feasibility point of view. In practice, this means they are considered in the light of some of the most prominent limiting factors of the proposed demonstration setup and while no conclusive demonstrations scenarios are decided upon, they are narrowed down to a set of feasible candidates.

3 Use case

As for the use case, what can be currently witnessed in the field of automated driving and ADAS, the implementation of automated driving systems will happen gradually and is heavily affected by for instance availability and cost of sensors and systems, technology advances, infrastructure and legislation. Furthermore, public adoption of automated driving systems will depend on their usability amongst other factors. One of the associated challenges addressed in PRoPART is that partially automated vehicles will initially be able to handle only a restricted set of scenarios. From a usability point of view, it is of great value to maximize not only the number of scenarios that the ADS can handle, but also the overlap of these scenarios in order to minimize the number of handover requests. More specifically, in PRoPART the focus will be on a positioning solution that meets the needs of automated highway driving since this presents a fairly controlled environment while being a common scenario for many transport operators.

Two of the more complicated scenarios arising in highway driving are highway on ramps and lane changes. These scenarios are challenging from both a situational awareness and cooperative vehicle control perspective and, as found in the iQDrive project carried out in cooperation with Scania and Linköping University, a significant share of the accidents on European roads where heavy trucks are involved are caused by lateral movements (e.g. lane changes) performed by the truck (Degerman, 2014). A plausible explanation for this is blind spots close to the cab and potentially large relative speeds between the truck and surrounding vehicles, which are highly relevant factors also in the PRoPART project's use case.

Furthermore, in a study performed by the National Highway Traffic Safety Administration analysing lane change crashes in the US in 1999, they found that the highest involvement of trucks in this family of crash types was in merging[1] scenarios (National Highway Traffic Safety Administration, 2003).

[1] The report defines merging as the action where ”one vehicle merges into the lane of another from entrance to limited access highway and/or other similar entrance, and sideswipes/is sideswiped by the other vehicle”.

Merging crashes caused by merging trucks accounted for 14.1% and the corresponding figure for when a truck going straight was sideswiped by a merging vehicle was 29.1%, which sums up to 42% after correcting for the fact that the scenario of a truck sideswiping a truck (1.3%) is counted twice. Thus, out of all the reported crashes associated with merging in the US during 1999, trucks were involved in almost half. The single highest proportion, apart from light vehicles sideswiping light vehicles, is that of light vehicles sideswiping trucks. In fact, this situation is the core of the demonstration use case in PRoPART. As taken from the NHTSA report, the statistics for crashes caused by merging manoeuvres are found in Table 1 below.

Table 1: Statistics of merging crashes by vehicle types involved

Vehicle merging	Vehicle going straight				Subtotal
	Light vehicle	Truck	Bus	Other vehicle	
Light vehicle	49.1%	27.8%	0.0%	3.1%	80.0%
Truck	12.9%	1.3%	0.0%	0.0%	14.1%
Bus	1.5%	0.0%	0.0%	0.0%	1.5%
Other vehicle	4.4%	0.0%	0.0%	0.0%	4.4%
Subtotal	67.8%	29.1%	0.0%	3.1%	100%

Another relevant discovery highlighted in the report is that large trucks accounted for 11.2% of the crashes caused by typical lane changes (i.e. intentionally changing to a parallel lane on a multi-lane road), where the truck itself changed lane. The corresponding statistics from the report are replicated in Table 2. 10.2% of the total number of crashes caused by a typical lane change involved a truck changing lane and a light vehicle in the target lane. Of all registered lane change crashes in the report, the *typical* lane change crashes accounted for 38.4%, while merging crashes accounted for only 3.5%. Thus, while large trucks were involved in a significant share of the merging accidents, the total number of lane change crashes where a large truck was involved was higher for crashes caused by a typical lane change manoeuvre.

Table 2: Statistics for typical lane change crashes by vehicle types involved

Vehicle changing lane	Vehicle going straight				Subtotal
	Light vehicle	Truck	Bus	Other vehicle	
Light vehicle	75.7%	4.7%	0.5%	1.8%	82.7%
Truck	10.2%	0.8%	0.0%	0.2%	11.2%
Bus	0.3%	0.2%	0.0%	0.0%	0.4%
Other vehicle	5.3%	0.0%	0.0%	0.3%	5.7%
Subtotal	91.5%	5.7%	0.5%	2.3%	100%

A third family of scenarios outlined in the report is that of passing vehicles. This differs from the typical lane change in the sense that in addition to accelerating laterally (changing lane), there is also a longitudinal acceleration involved. According to the report, *passing* is defined as "two vehicles on parallel paths; one moves into the other's lane to pass the other or to pass a third vehicle". The corresponding statistics from the report are presented in Table 3 below.

Table 3: Statistics for passing crashes by vehicle types involved

Vehicle passing	Vehicle going straight				Subtotal
	Light vehicle	Truck	Bus	Other vehicle	
Light vehicle	68.5%	11.8%	1.2%	2.3%	83.8%
Truck	5.3%	0.2%	0.0%	2.2%	7.8%
Bus	0.8%	0.0%	0.0%	0.0%	0.8%
Other vehicle	6.7%	0.9%	0.0%	0.0%	7.7%
Subtotal	81.3%	12.9%	1.2%	4.5%	100%

As a final note regarding the NHTSA, the authors further support the idea presented in the iQDrive report that the blind spots around the truck constitute a plausible explanation for the fact that trucks represent a significant share of accidents caused by lateral movement.

Finally, an important aspect that separates heavy vehicles from other road users is clearly their weight. The weight and resulting dynamics of heavy trucks have for instance led to the invention of systems such as Scania Active Prediction (Scania, 2011) and Volvo's corresponding I-See (Volvo, 2017) among others. These systems help save fuel and reduce emissions and are constantly improved and/or extended to increase customer profitability and reduce environmental impact. A consequence of the heavy weight is that trucks require lots of energy to accelerate. Thus, changing lane ahead of a ramp to help the vehicles on the ramp merge smoothly does not only help the vehicles make a smoother and safer entrance, but typically eliminates, or at least reduces, the need for the truck to adjust its speed, resulting in lower fuel consumption and lower environmental impact.

3.1 Use case definition

The defining use case of PRoPART is an automated lane change performed by a heavy truck. The setting is a crowded highway on ramp as illustrated in Figure 1. The truck is travelling in automated mode in the slow lane when approaching the on ramp. In order to make the merge as smooth as possible for the cars merging from the ramp as well as the surrounding traffic, the truck should perform an automated lane change. From the usability point of view of the ADS, the chosen use case eliminates the need to hand over control to the driver, but the overall implications of the PRoPART project are more far-reaching and aims to advance a set of user function specific components related to positioning and awareness.

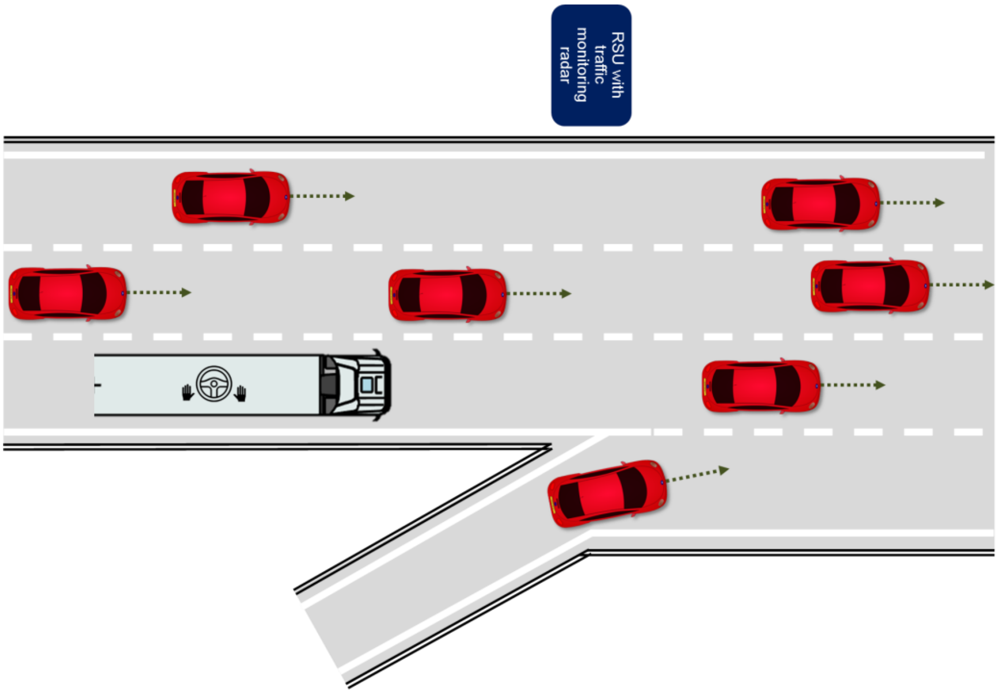

Figure 1 Use case: lane change at crowded highway entrance.

3.1.1 Restrictions

The specific truck to be used in the demonstration is not yet decided, mainly because it is highly dependent on the availability of test vehicles to serve as a prototype platform. Furthermore, the main goal of the project is robust and precise positioning and therefore the consortium reserves itself for using any suitable truck configuration (e.g. tractor, rigid, semitrailer, trailer) for the demonstration since all configurations require redundant information about the environment to gain the confidence needed to perform a safe lateral manoeuvre. Of course, the need to handle the dynamics arising from more complex truck configurations is of fundamental importance to meet the market needs and lay the foundation for wide market adoption, but it would not further the PRoPART positioning solution.

As for the passenger cars included in the scenarios and demonstration, they are restricted to being manually driven and not necessarily have any V2X capabilities, simply as a means to maximize early market penetration and usefulness of the PRoPART systems.

A further restriction exists on cooperative perception service due to the availability of roadside sensors with suitable angle and range. The project will aim to maximize functionality, however effort on vehicle sensing techniques will be limited and narrowed to aspects of positioning.

Importantly, the prototype system to be used in the demonstration will be restricted to handle only a subset of the scenarios outlined in this deliverable. Furthermore, only a subgroup of the components required for automated drive are included in the project's scope, which restricts the number of demonstration scenarios that fit inside this scope. To clarify, robust and reliable sub-components constitute a general need for road vehicle automation, meaning that demonstrating the use of high-accuracy positioning is not directly linked to advanced AD systems. An important point to make is that although the demonstration is designed around a niche application of automated driving, demonstrating an advanced AD system capable of planning and executing lengthy manoeuvres will in general not further the actual demonstration of the positioning accuracy and robustness. Thus, it is neither within the scope nor budget of the project to directly develop the Scania-owned ADS to any considerable extent. Furthermore, Scania will due to resource and possibly competitive reasons only commit to assisting with required (and reasonable) AD capabilities, which does not necessarily imply the most recent software and hardware.

3.2 Scenarios

The use case covers a range of scenarios, but they can roughly be divided into four types:

A. The **target lane is completely free** and there are **no cars approaching** from behind nor are there any stationary or slowly moving cars in the target lane ahead of the truck.
B. The **target lane is currently free**, but there are either **cars approaching** from behind or stationary, braking or slowly moving cars ahead.
C. **Target lane is not free**, but the truck can safely **slip into a suitable gap between cars or indicate** that it plans to change lane so that the cars can make room.
D. The **target lane is not free** and the truck **cannot merge smoothly** due to big difference in speed.

The truck is presumed to be driving in the slow lane, and the target lane is assumed to be the lane adjacent to the slow lane.

This list of categories is also visually presented in Table 4.

Table 4: Classification of scenarios

	No cars approaching/passing	Cars approaching/passing fast
Target lane free	A	B
Target lane not free	C	D

For the PRoPART project the type D scenarios are of little interest other than for verification purposes – even when driving manually, there is not much a truck driver can do in terms of lateral movement. As these scenarios by definition does not involve a lane change, it falls outside the scope of the AD functionality to be implemented/configured for the demonstration. Still, if a type D scenario arises, it must be properly handled by either giving back the control to the driver or handled by another user function implemented as part of the ADS. Just as a lane change may be desired for different reasons (e.g. to avoid an accident, or simply to make the merge more smooth and convenient), the exact action that should be taken by the ADS in a type D scenario will differ. However, to avoid scope drift but also supported by obvious safety arguments, it is reasonable to expect of the system that should the lane change not be possible to carry out in time before the on ramp, the control should be handed back to the driver to avoid dangerous or ambiguous situations.

In conclusion, only scenarios of type A-C involve actually performing a lane change and are properly considered in the following scenario descriptions. Type D scenarios, on the other hand, will simply trigger a fallback solution and need no further elaboration. Similar reasoning applies to the situation B and C in case the scenario develops in such a way that the lane change manoeuvre is impossible to execute before the on ramp. That is, no functionality will be developed to handle this gracefully, but the fallback solution will be triggered.

In addition to the listed types of scenarios they may be further subdivided with respect to a set of factors, such as number of lanes and surrounding traffic in the ego lane. These types of variations that can modify the types A to D are henceforth termed subcategories and denoted ‘S’ in the scenario IDs.

Understandably, surrounding vehicles may be driving at very different speeds from the truck, possibly requiring the truck to regulate its speed accordingly. A factor complicating the situation further is the difference in rapidity between heavy vehicles and passenger cars as well as different legal or technical speed limits. It’s not an uncommon situation for light vehicles to approach at a high speed from behind, either already in the inner lane or in the same lane as the truck, planning on passing. Furthermore, cars do in general accelerate faster than heavy vehicles, which in practice means that a full-fledged ADS has to be able to consider and/or predict possible intentions of surrounding road users as well as predict and evaluate possible developments of the traffic situation that can occur quickly and seemingly irrationally.

Some of the complicating factors are also outlined in the scenario descriptions below. Many of the scenarios and mentioned factors and variants are straightforward to combine to build new, more complicated scenarios. In fact, there's an infinite amount of situations that can arise simply by adjusting the parameters that collectively define a scenario. Importantly, the scenarios mentioned below are controlled, meaning that all drivers (or automated driving systems) have control over their vehicle (i.e. not sliding, drifting out the lane or sleeping etc.) and are exhibiting a level of rationality comparable to that of a typical human driver.

While being able to handle uncontrolled situations is highly relevant for traffic safety, taking them into consideration here would typically move the focus away from the positioning solution towards the automated application itself, which is not the desired purpose of the project. Thus, an exhaustive list of critical, unstructured situations to be handled by a complete ADS is not to be expected.

Finally, it should be noted that the illustrations are not to scale and should be considered in the conceptual sense and not as strict representations of potential demonstration scenarios.

3.2.1 Target lane empty

The simplest scenario involving a lane change is that depicted in Figure 2. In the scenario the target lane is free with no interfering traffic in the target lane (scenario type A). This scenario may be considered a sanity check for the system in terms of *false negatives*, meaning it assesses the system's ability to confidently analyse the situation and conclude that a lane change can be safely performed.

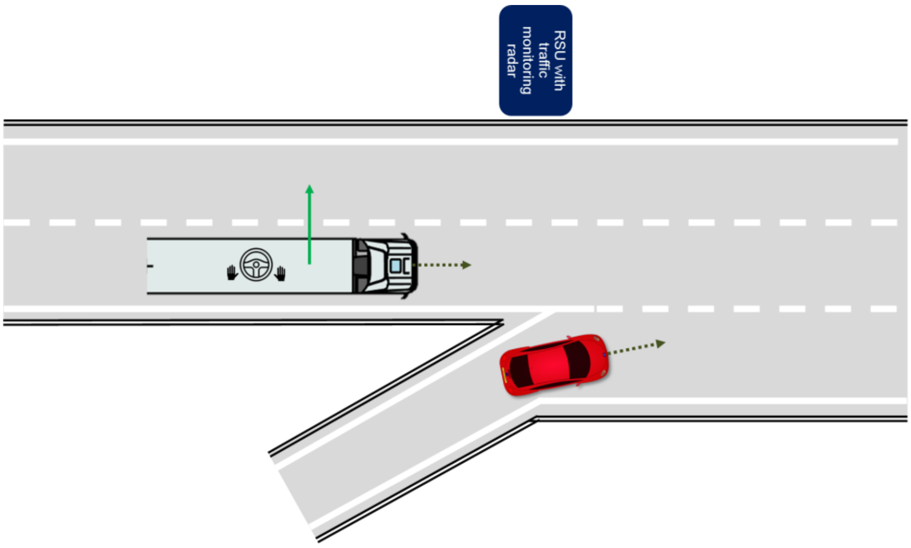

Figure 2 Target lane is free and no approaching cars would be at risk if the truck changed lane.

Scenario ID	A1
Name	Target lane empty
Description	The target lane is empty and there is no interfering or approaching traffic.
Expected action	Change lane

3.2.2 Car (temporarily) occupying target lane

In a crowded situation on the highway a scenario that can occur is that the vehicles in the slow and fast lane are travelling at similar speeds (scenario type C). Commonly, a long vehicle must identify a suitable gap in front of/behind/between cars and adjust its speed to be able to slip into the gap. The situation is illustrated in Figure 3, where the heavy truck must either increase or decrease its speed in order to get in front of or behind the car in the inner lane before it can change lane.

In a related scenario the passenger car in the target lane may be moving at slightly higher (or lower) speed than the truck. If the difference in speed is big enough there will be no need for the truck to adjust its speed since the car will be out of the truck's way soon enough for the truck to change lane before the upcoming on ramp.

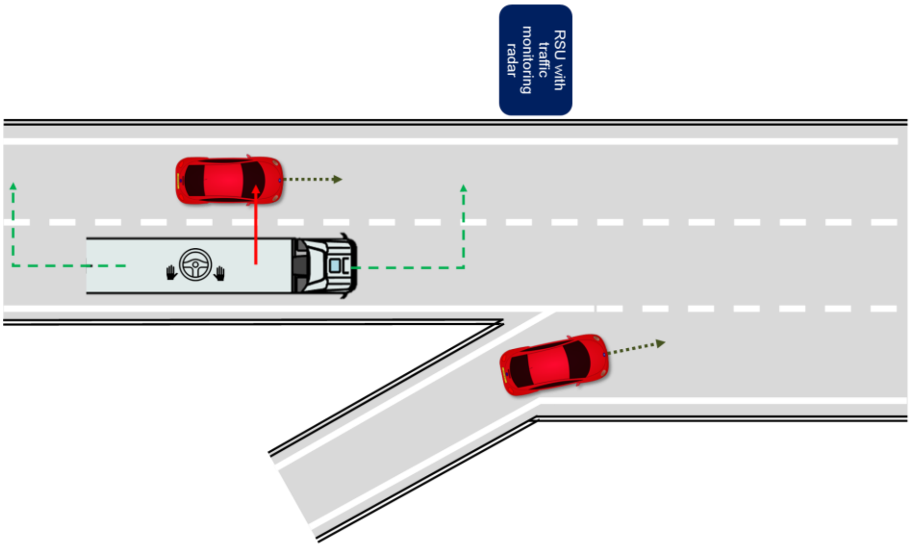

Figure 3 Blocking car in inner lane

Scenario ID	C1
Name	Car (temporarily) blocking target lane
Description	The target lane is blocked by a car travelling at the same speed as the truck or temporarily blocked by a car travelling at different speed from the truck.
Expected action	(a) If the car is travelling at the same speed as the ego vehicle, the ego vehicle should either accelerate or decelerate to position itself behind or ahead of the blocking car. (b) If the car is travelling at a different speed from the truck, the truck should wait until the car is out of the way and then change lane. If this does not happen in time before the on ramp, see option (a).

3.2.3 Vehicle approaching from behind

Another scenario that is relevant in this context is when the target lane is currently empty and a lane change is *physically* possible, but if the truck changes lane it might lead to a dangerous situation (scenario type B). A typical scenario with these characteristics is outlined in Figure 4, which involves a passenger car travelling in the fast lane and at a higher speed than the truck. Thus, since the car is not yet in line with the truck, the part of the target lane in the vicinity of the truck is empty. At best, a lane change would just annoy the driver of the faster car, but in the worst case scenario the car might rear-end the truck or lose control.

Scenario ID	B1
Name	Vehicle approaching from the front or behind
Description	The target lane is free, but a vehicle is approaching (quickly) from behind in the target lane.
Expected action	The truck should detect the approaching car, wait for the car to

	pass and then change lane. If the car has not passed the truck before the on ramp, the control should be handed over to the driver.

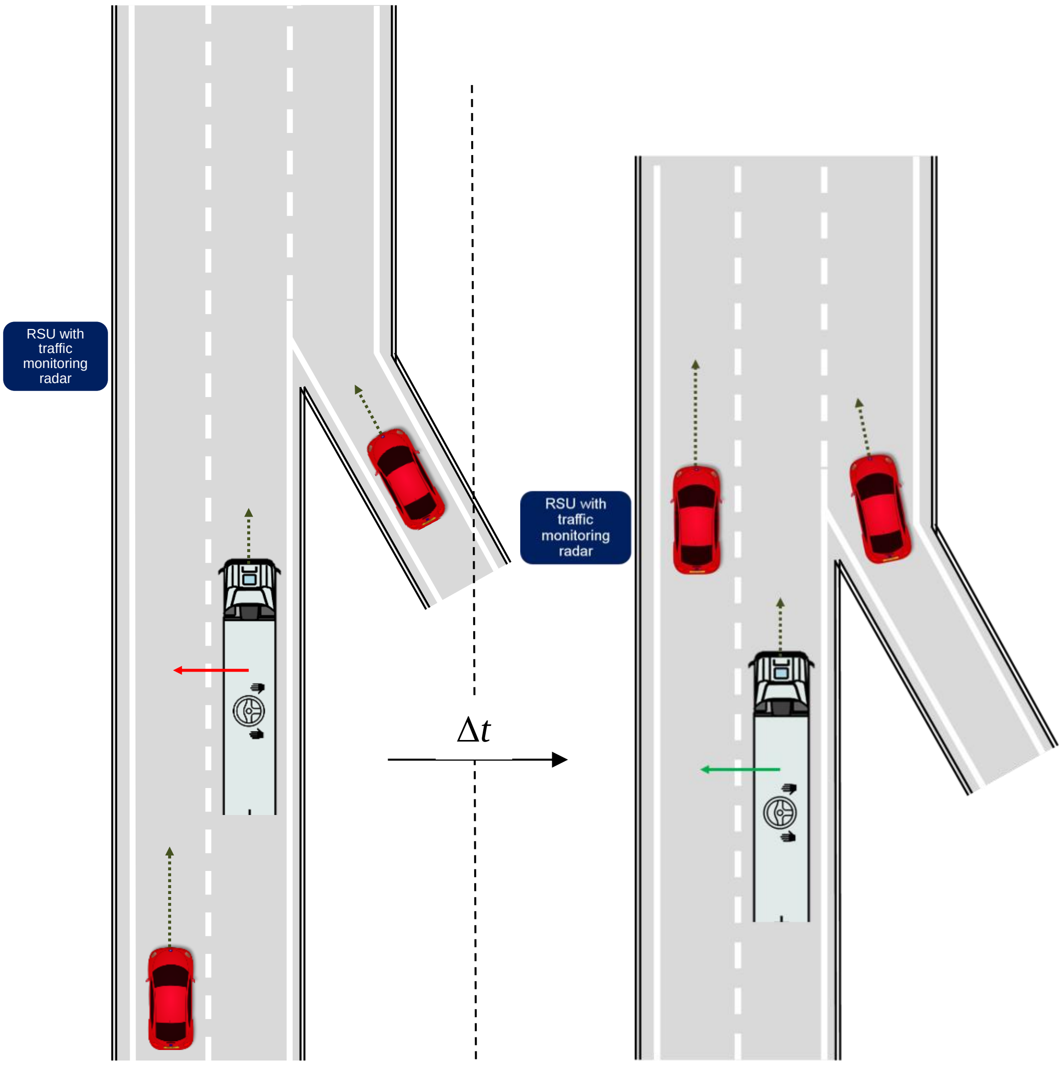

Figure 4 Target lane is free, but a car driving in the target lane is approaching quickly from behind.

3.2.4 Slower vehicle ahead in target lane

It may happen that the truck is driving faster than vehicles travelling in the fast lane (scenario type B). In such a scenario, the truck can either pass the slower car before the slip road (if possible and legal) or decelerate and position itself behind the car in the inner lane.

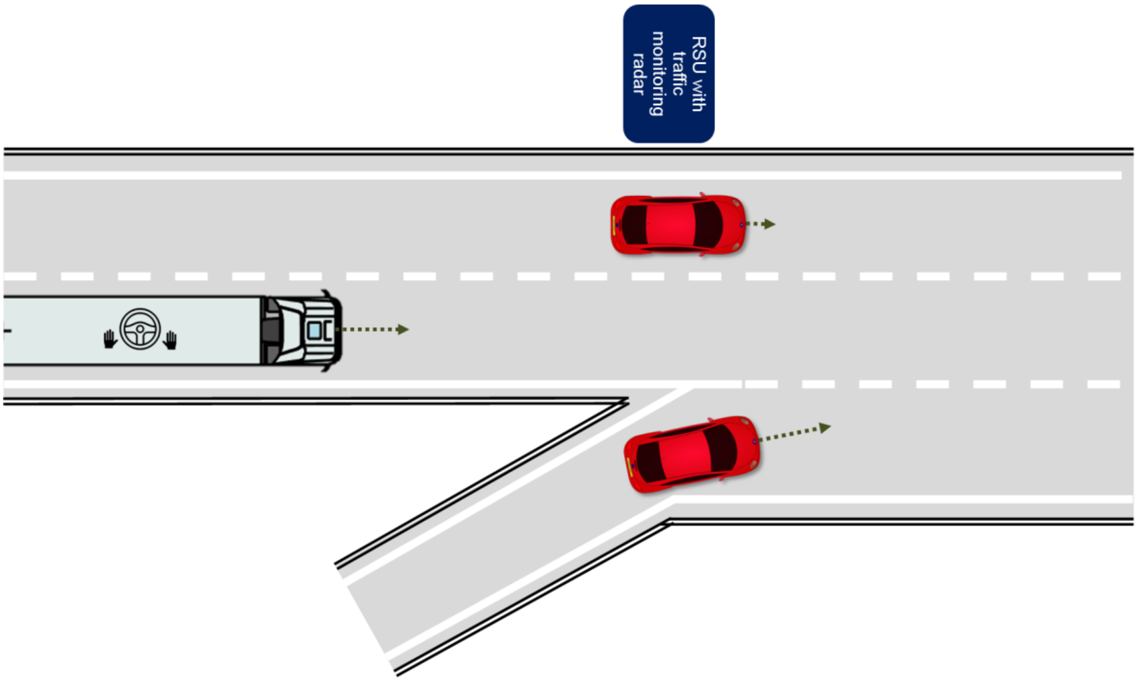

Figure 5 The truck is approaching a slow car in the target lane from behind

Scenario ID	B2
Name	Slower vehicle ahead in target lane
Description	The target lane is free, but a vehicle ahead is moving slower than the truck.
Expected action	Detect the slowly moving car and, if possible (and suitable), brake appropriately and move into the lane behind the slower car.

3.2.5 Braking vehicle ahead in target lane

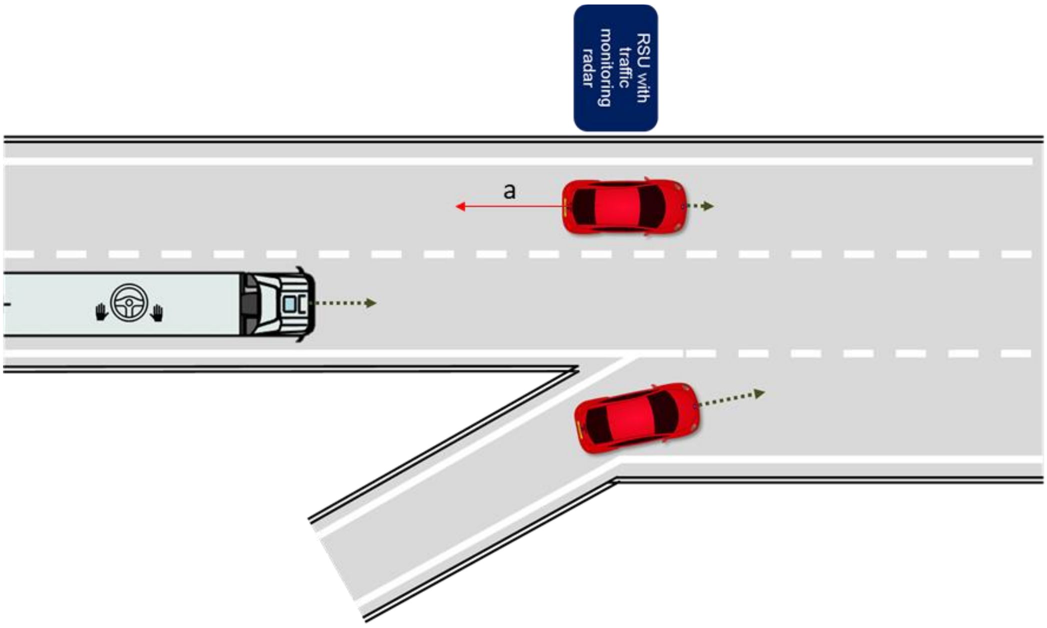

Figure 6 The truck is approaching a braking car in the target lane from behind

A passenger car travelling in the fast lane is ahead of the truck and has initialized a brake (for some reason). A lane change in this case is dangerous although the target lane may remain empty in a near future. In such a scenario, the target lane is considered occupied and the truck should react similarly to C1.

Scenario ID	B3
Name	Braking vehicle ahead in target lane
Description	The target lane is free, but a vehicle ahead is braking.
Expected action	Detect the braking car in time and avoid a lane change.

3.2.6 Merging

A challenge in terms of positioning is to reliably position the ego vehicle in relation to its surroundings, including moving objects. For instance, adaptive cruise control and advanced emergency braking system are systems that use fused sensor information to gain *limited* situational awareness and act on the available information but with a rather small action space (i.e. longitudinal speed control and braking, respectively). With high enough resolution and reliability of the sensor and information input, however, the ego vehicle's action space can be expanded and the vehicle's ability to navigate in the vicinity of other objects and/or cars improves.

A possible scenario where precise positioning is key is showed in Figure 7. In this scenario two passenger cars are travelling in the inner lane at approximately the same speed as the truck (scenario type A/C).

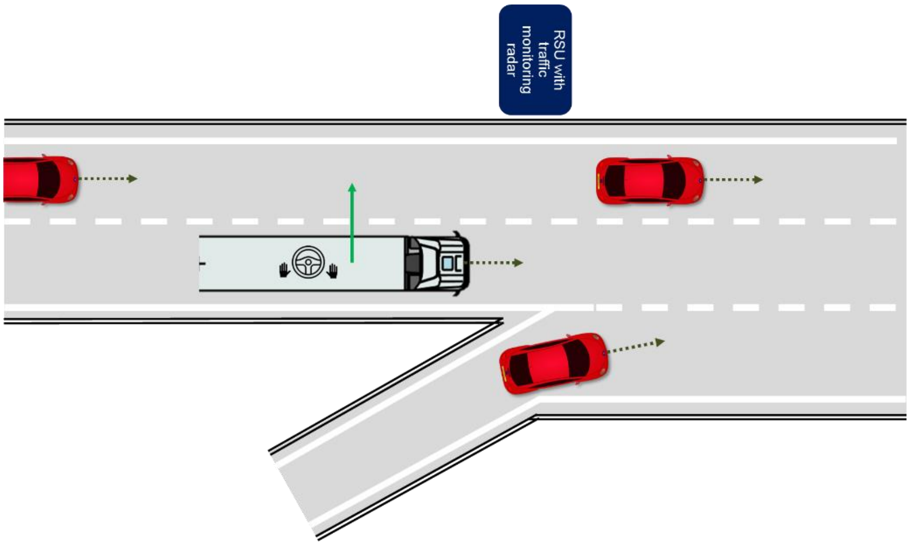

Figure 7 The cars in the inner lane are driving at approximately the same speed as the truck. The space between the cars is big enough for the truck to safely merge.

Scenario ID	A2
Name	Merging
Description	The target lane is (partially) occupied; the cars in the two lanes are moving at comparable speeds.
Expected action	(a) If there is enough space between the vehicles in the target lane, the truck should align itself with the gap and change lane. (b) If there is not enough space, the truck should signal its intention to change lane and wait until enough room has been created for a lane change to be possible.

3.2.7 Car approaching and intending to overtake truck

The generally higher acceleration and quicker movements of smaller vehicles can lead to a set of ambiguous situations where it is not obvious what the smaller vehicle is planning on doing (scenario type B). One such scenario is illustrated in Figure 8 where a passenger car is approaching quickly from behind in the same lane as the truck. In the case that the car is planning on overtaking the truck, the truck must not change lane or a potentially dangerous situation may arise (cf. B1). However, depending on the sensor setup it may be difficult to robustly identify the approaching vehicle and driving at high speed makes the situation even worse since the time-equivalents (range divided by the relative speed of the sensor and sensed object) of the sensor ranges are shorter. Furthermore, there is also the challenge of interpreting the actions of an approaching car that has not communicated its intentions by for instance signalling or changing lane well in advance.

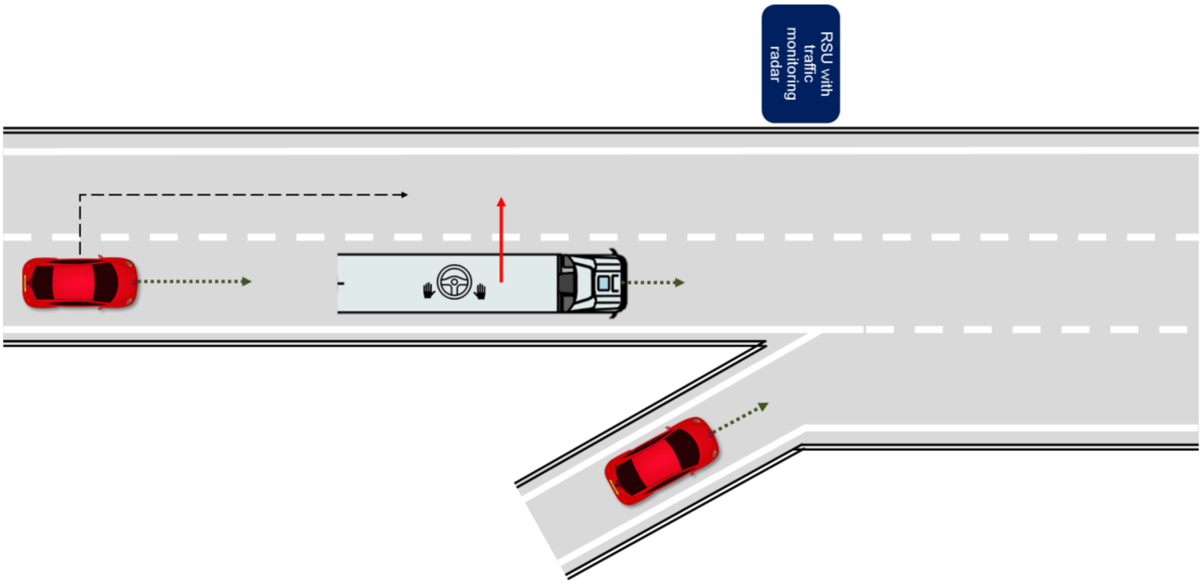

Figure 8 Predicting intentions of road users in ambiguous situations. A passenger car is approaching quickly from behind and it's not obvious what the car will do next (i.e. break or change lane).

Scenario ID	B4
Name	Car approaching and intending to overtake truck
Description	The target lane is free; a car is approaching from behind at high speed in the ego lane and plans on overtaking the truck.
Expected action	The fast car should be detected and the lane change should be performed after it has passed. If the car has not passed the truck before the on ramp, the control should be handed over to the driver.

3.2.8 Car following but planning on overtaking truck

B3 brings up ambiguities and uncertainties of road user actions. In the particular situation outlined there, the rational decision for the truck to take is in most cases simply to avoid changing lane and instead adjust its speed in order to let any cars on the on ramp merge smoothly. This reasoning is quite straightforward when considering the probabilities in combination with the potential risks associated with the corresponding actions. The main point being that the risks and probabilities are non-negligible.

In contrast, there are seemingly static traffic situations where even minor developments can rapidly change the setting. Figure 9 shows such a situation where a passenger car is following the leading truck. The car may at any time decide to accelerate with the intention to pass the truck in the fast lane (scenario type B). The time it takes for the car to gain significant speed and/or move up beside the truck can be rather short which requires fast response times and a precise and robust representation of the environment in case the truck has or is about to initiate a lateral movement.

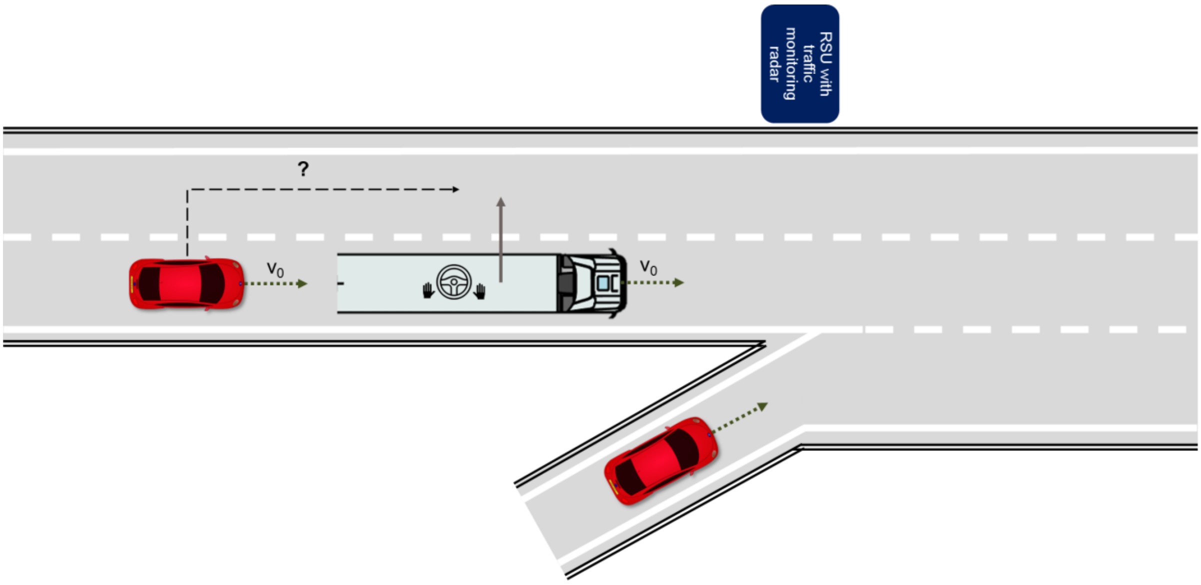

Figure 9 Predicting potential developments in static situations. The trailing car is driving at the same speed as the heavy truck and may or may not quickly accelerate and change lane to pass the truck.

Scenario ID	B5
Name	Car following but planning on overtaking truck
Description	The target lane is free; a car is following behind the truck at the same speed but quickly accelerates (longitudinally) and changes lane intending to overtake the truck.
Expected action	(a) If the trailing car has already gained significant speed, the truck should abort the lane change. (b) If the trailing car starts to accelerate when it is clear that the truck has initiated the lane change, it should (if risk free) go through with the lane change, prioritizing a smooth entrance for the merging car.

3.2.9 Three lanes or more in the same direction

In many cases, the scenarios are quite similar whether the vehicle is driving on a highway with two or three lanes. The requirements on the RSU and environmental perception and awareness are of course a bit different, but many of the scenarios are unaffected as long as the truck only moves into the adjacent lane but no further. For the purpose of helping vehicles entering the highway merge smoothly, it is assumed to be enough to move from the slow lane to the adjacent lane.

The difference between changing lane on a highway with two parallel lanes and a highway with three or more parallel lanes is the additional risk of vehicles simultaneously moving into the same lane from different directions, either sideswiping each other or causing a collision. Thus, the added requirements are those of awareness of traffic in a wider area and the corresponding inference in multi-lane traffic situations.

Obviously, if vehicles in the third lane or beyond (counted from the slow lane) do not go into or interfere with traffic in the second lane, the traffic situations effectively reduce to those for two-lane highways from a scenario description point of view. For the truck, however, the requirement of widened environmental awareness still remains.

The adaption of scenarios B1 and B4 to fit this new setting is straightforward and the car that intends to overtake the truck in the B4 scenario can initially be in either the slow lane (just as in B4) or in the third lane, essentially mirroring the B4 scenario with respect to the middle lane. Figure 10, on the other hand, illustrates the new variant of the lane-change scenario that comes with the addition of the third lane.

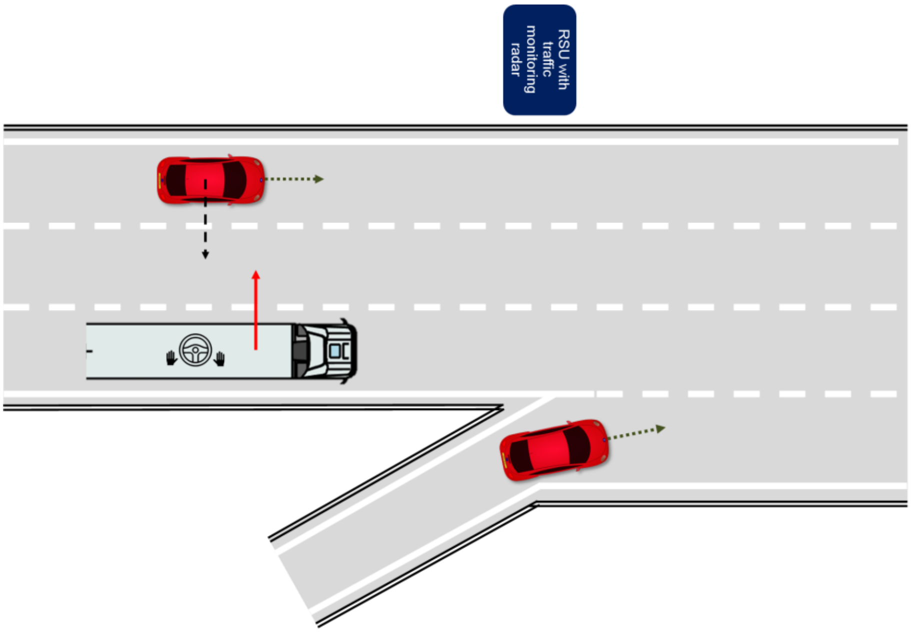

Figure 10 Vehicles moving (or intending to move) into the same lane from different directions simultaneously.

Scenario ID	B6
Name	Three lanes or more in the same direction
Description	With more than two lanes in the same direction comes the possibility of vehicles moving into the target lane from both (lateral) directions.
Expected action	The truck should realize that the car is also changing to the target lane and safely abort the lane change by returning to the outer lane. Attention must be paid to cars that may have slipped into the space to the right of the truck that has been opened up by the truck's lateral movement (even though the lane change was never completed).

3.2.10 Obstructing traffic ahead in ego lane

Obstructing traffic in the ego lane ahead of the truck is illustrated in Figure 11. On the most basic level the implication of this is that attention must be paid to how the vehicle in front is acting as well as reacting to an evolving situation. From a path planning point of view this means that hard boundaries are introduced for how to plan the lane change manoeuvre. Unlike the other scenarios, this particular scenario is most of all introducing a complicating restriction that can be added to all the above scenarios rather than serving as a stand-alone scenario (even though it is indeed a complete scenario).

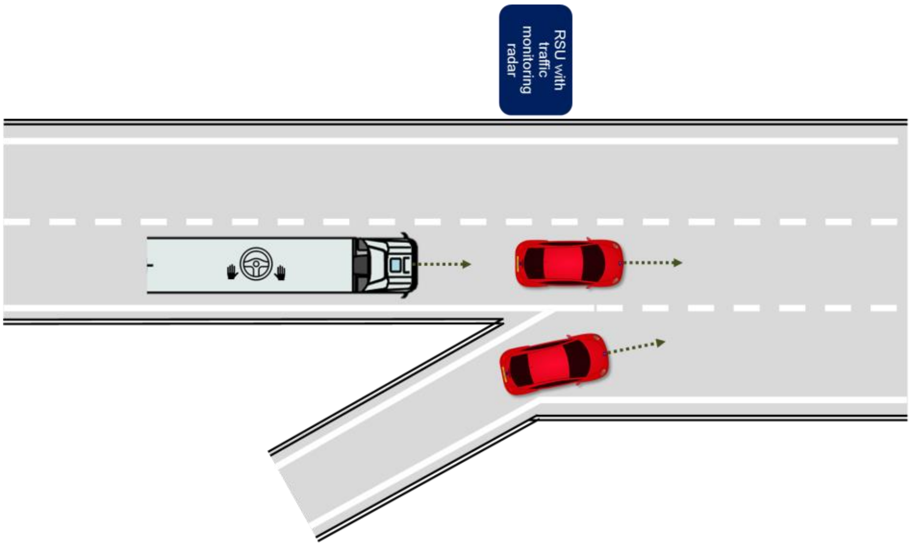

Figure 11 Restricting traffic ahead in current lane.

Scenario ID	S1
Name	Obstructing traffic ahead in ego lane
Description	Subcategory: Vehicle in the ego lane is restricting the longitudinal movements of the truck.
Expected action	Adapt speed and path to the obstructing vehicle.

3.2.11 GNSS signal lost

A situation that will occur is lost GNSS signals. This situation can arise due to many reasons, such as technical malfunction or obstructing objects (e.g. bridges and tunnels). An example of such a scenario is illustrated in Figure 12, where also an UWB node has been explicitly drawn[2].

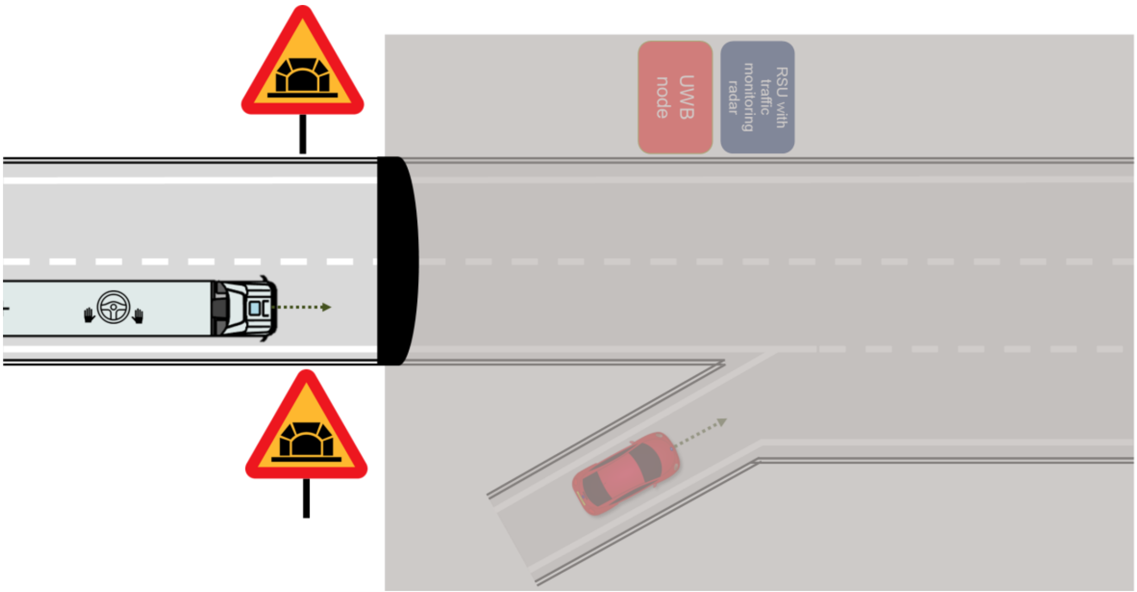

Figure 12 Tunnel blocking GNSS signals

[2] The UWB nodes are present in all scenarios and is integrated in the RSU, but a node is explicitly drawn here to emphasize the absence of GNSS signals and, thus, the reliance on UWB for precise positioning.

Scenario ID	S2
Name	GNSS signal lost
Description	Subcategory: The truck cannot derive its position from the GNSS system.
Expected action	Use UWB for precise positioning.

4 Possible demonstration scenarios

Two important limiting factors of what scenarios will be possible to demonstrate are the range and coverage of the on-board and off-board sensors. Suffering from the restriction that the surrounding cars don't have to be equipped with V2I/V2V and precise positioning capabilities, the AD system has to rely on the truck's and RSU's sensors alone for object detection and tracking. The truck's intended sensor setup does not provide redundancy to the sides and in combination with the fact that the RSU is stationary, a consequence is that redundant side coverage (which is a prerequisite) will only be available on a limited distance on the highway as shown in Figure 13. The setup outlined in the project description (and presented in simplified form in Figure 13) therefore imposes the restriction that *the lane change has to be carried out over a limited distance*, primarily dependent on the range of the RSU's object detection sensors.

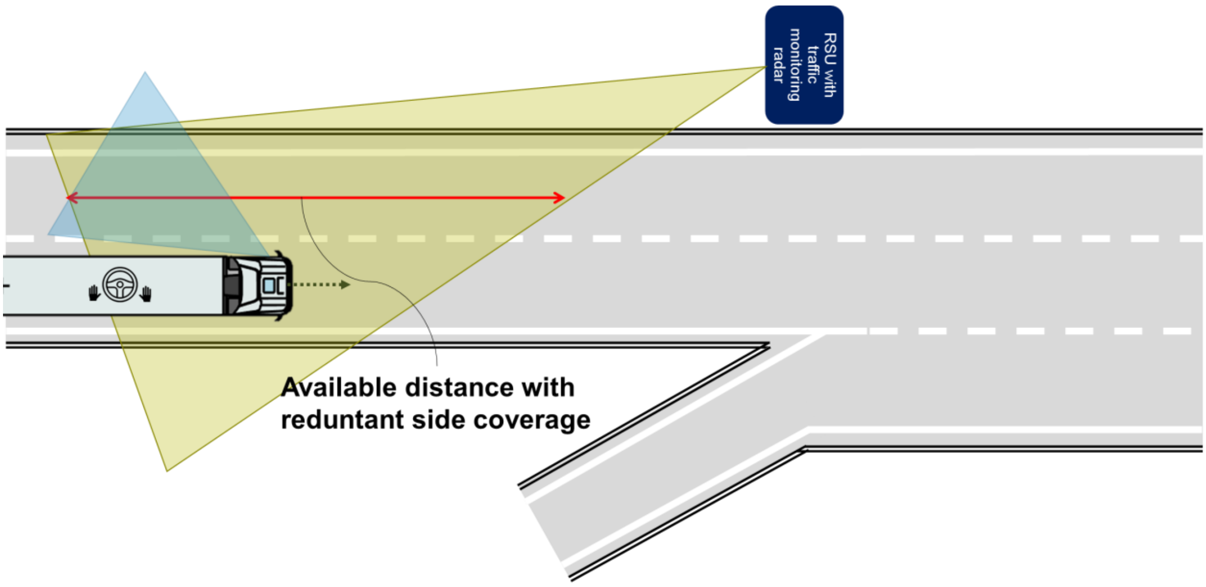

Figure 13 Distance with redundant side coverage from on-board and off-board sensors. Sensor ranges and angles are not to scale.

Thus, it is clear that not all of the above scenarios will be possible to demonstrate (given the setup) as some of the manoeuvres are quite lengthy. In particular, if longitudinal adjustments are necessary, they will introduce significant delays. Consequently, only straightforward scenarios (i.e. minimal longitudinal adjustments) are realistic with respect to the time the truck can be expected to spend in the area covered by the RSU's traffic sensor. Additional limitations and possibilities will surface during the project, but at the outset the indications are that *the most realistic demonstration scenarios are variants of the scenarios A1, A2, B3 and C1 in combinations with S2 and possibly also S1*. That is, target lane empty, car (temporarily) blocking target lane, car blocking target lane soon and merging, mixed with GNSS signal lost and obstructing traffic ahead in ego lane, respectively. In B3, the braking car does not travel a long distance compared to the other scenarios of type B. The car can therefore be covered by the RSU long enough to be detected precisely. As for A2 (car (temporarily) blocking target lane), it refers to the version where the blocking car will move out of the way before the slip road. I

Furthermore, the setting in the demonstration will only be a two-lane road, although this is not an explicit restriction defined in the project.

5 Conclusions

The PRoPART projects aims to develop a positioning (and awareness) platform that's accurate and robust enough to be employed in automated driving applications; here in the form of an automated lane change. To maximize the early impact of the system, the developed solution assumes nothing about V2X capabilities of surrounding traffic. Instead it employs a roadside unit with object detection capabilities, able to communicate both position information and RTK correction data to the automated vehicle via ITS-G5.

As the project acronym tells, the prioritized functionality is positioning, and more precisely, positioning of the ego vehicle and redundant position estimation of surrounding traffic and objects. The scenarios, however, are designed around the use case of a heavy truck changing lane on a highway to help vehicles on the on ramp to merge smoothly onto the highway. The main implication of the project is both improved positioning accuracy and robustness, and efforts to increase the technology readiness levels of positioning and awareness related user function specific components.

In addition to the apparent technology advances and general expectations on vehicle OEMs to deliver increasingly automated systems, the project is clearly related to traffic safety in the context of lateral manoeuvres. Supported by the statistics from section 3, the proposed solution can both help reduce the actual merging accidents, but also the risk of sideswiping or crashing into surrounding vehicles when performing a typical lane change.

Finally, while a goal in the project is to raise the technology readiness levels of specific components, the project will make use of prototype platforms in the development stage as well as the demonstration. In spite of this, the development efforts will be biased towards cost efficient positioning solutions and usability of the results early in the shift towards automated road transport.

6 References

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