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Simulation Environment for Autonomous Function Development and Testing

Bachelor's thesis in Mechatronics

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Cover: Road simulation constructed in Prescan showing a Truck and a bicycle driving trough an intersection.

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Abstract

Systems designed for different levels of driver assistance are a hot topic in today's automotive industry. Increased complexity and demand on fully reliable systems with zero accident invokes a heavy pressure for the developers. The solution is a great amount of testing and validation but it is expensive and different ways to for simulations are desired. PreScan is a tool for traffic situations including environment, vehicles and sensors. That's why this library consisting of traffic scenarios for several different driver assistance systems was created for Volvo Group Truck Technology department of Vehicle Technology and Safety. The work is limited to just a library containing infrastructure, environment and surrounding cars for ten autonomous functions. There is no implementation of sensors or active systems.

Results show that the framework is manly set by environmental demand for each system and vehicle dynamics/setup infuse a low influence for developing the scenario's. Software gave some limitations for example it does not allow vehicle to go in reverse and the dynamics surrounding hauling trailers presents a great complication. In order for easy use of the library documents that gives a more detailed description and a manual was created.

Keywords: PreScan, autonomous functions, road simulations, library, ADAS.

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Sammanfattning

Fordonsautomation är idag ett hett ämne där utvecklingen tyder på ökad komplexitet samtidigt som systemen aldrig får göra fel. Det ställer höga krav på systemutvecklingen där lösningen blir att allt mer testning krävs för att verifiera systemen. Det är dock dyrt och mer simulering är av den anledningen önskvärt. Ett program som kan användas för att simulera trafikscenarion med olika miljöer, fordon och sensorer är PreScan. För att underlätta användandet av PreScan har i detta arbete ett bibliotek med trafikscenarion tagits fram som är anpassat till olika autonoma system.

Arbetet har gjorts på Volvo Group Truck Technology avdelningen för Vehicle Technology and Safety och frågeställningarna runt biblioteket har rört vad som sätter ramarna för scenarierna i form av programvara, system och fordonsdynamik och hur man gör biblioteket användarvänligt. Arbetet innefattar ingen typ av implementering av sensorer eller system.

Resultatet är ett bibliotek uppdelat utifrån systemens krav på omgivningen och där fordonsdynamik hade liten inverkan på utformandet. Programvaran gav begränsningar bland annat vid backning och framförande av släp. Dokument för överblick och mer detaljerad beskrivning av scenarierna har tagits fram samt en kort manual för att komma igång med användandet.

Sökord: PreScan, autonoma system, trafik simuleringar, bibliotek, ADAS.

Acknowledgments

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Jakob Fredriksson & Andreas Nilsson, Gothenburg, June 2015

Definitions Employed

3D	Three Dimensional
ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance System
AEBS	Advanced Emergency Brake System
CACC	Cooperative Adaptive Cruise Control
CC	Cruise Control
CU	Collision Unavoidable
DIL	Driver in the Loop
FE	Front Entry
FH	Front High
FL	Front Low
FM	Front Medium
FMX	Front Medium Cross Country
GPS	Global Positioning System
GUI	Graphic User Interface
HIL	Hardware in the Loop
HMI	Human Machine Interface
Kph	Kilometers per hour
LIDAR	Light Detection and Ranging
m	meter
S&G	Stop and Go
SAE	Society of Automotive Engineer
SIL	Software in the Loop
VRU	Vulnerable Road User
V2V	Vehicle to vehicle
V2X	Vehicle to undefined

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1
Introduction

1.1 Context

The topic of this report originates from and surrounds around the development of autonomous systems and the testing of their behavior in simulated traffic scenarios. Live tests are both time consuming and expensive, this is why we were tasked by Volvo GTT to create an extensive library containing common traffic scenarios in PreScan. Reducing the time for when they want to test and simulate specific systems and functions in the desired environments.

1.2 Background

If you speak about today's automotive industry active safety and Advanced Driver Assistance System (ADAS) is a definite key topic. Reducing the damage from an accident or even prevent it from happening, reduce fuel consumption, increase traffic flow and improve driver comfort. This is what ADAS is all about. By using sensors monitoring the surroundings of the vehicle create a system. A system that can warn the driver of threats, help the driver with minor modifications and in some cases as an example take full control of the vehicle to avert an accident.

Unfortunately this comes with a great deal of difficulties in sorting out and deciphering information. A mistake done by a vehicle at full speed can with ease result in fatal consequences. So these systems have to undergo strict testing because mistakes are unacceptable. But live testing is expensive and that is why simulations are extremely important. To simulate any and all possible outcomes of different events in a computer before the system is implemented and tested in a truck.

1.3 Aim

By Volvo GTT, VTS (Global Truck Technology, Vehicle Technology and Safety) we have been given the task to create a library in PreScan that describes different critical situations in traffic to test active safety and autonomous functions for three different types of Volvo trucks, rigid truck 6x2 and tractor 4x2 with a connected semi-trailer as well as the rigid FMX. The trucks will be simulated in PreScan for the identified use-cases for function development at Volvo. The different types of autonomous systems and situations that will be tested are as following: Advanced Emergency Brake System (AEBS), Cruise Control (CC), Adaptive Cruise Control (ACC), Adaptive Cruise Control with Stop and Go (ACC S&G), Cooperative Adaptive Cruise Control (CACC), Loading&Unload, Park Assist, Platooning, Queue Support and Vulnerable Road User (VRU).

1.4 Research questions

Originating from our aim we would like to see the following questions answered.

1. What type of tool is used for these simulations today?
2. How would a change in the truck setups affect the scenarios?
3. Will there be a difference in the scenarios created for the Volvo truck models FMX and FH-series.
4. Will different systems require customized scenario setups, or can the scenarios be standardized?
5. What limitations will PreScan present in achieving our aim?
6. How can we achieve a seamless integration of such libraries into the current development setup at Volvo so that it is useful for function development and testing?
7. Which benefits will the created library give to VTS?

1.5 Limitations

This report will be limited to the actors and environments that can be built in PreScan 7.0.0.

Scenarios will only be created for the systems listed.

Systems require different sensor setups so sensors will not be mounted onto actors, only visual aids.

Vehicles in PreScan will not be setup with any dynamic models.

Focus is on creating scenarios, no system implementations.

For Matlab we will use version 2012.b.

2

Technical background

Below we will first present some background about electronics in vehicle and a standard for measuring how autonomous a system is. That will be followed by information about systems that are connected to this thesis work, the PreScan simulation tool and some basic information about variation in truck-setup.

2.1 Driver assistance systems in vehicles

The technical development has come far since the first microprocessor was implemented into a commercial car in the late seventies. But today a car includes a lot of software code that is executed of up to 100 microprocessors. This has made the cost for electronics and software significant and can be up to 35-40% of the cars total cost [1]. The increase of electronic systems is mainly because of the goal to reduce fuel consumption and build safer and more comfortable vehicle [2].

Figure 2.1: A Volvo XC90 using sensor and robot functions to follow a queue, Queue Support. Photo taken by Volvo Cars

2.1.1 Levels of automation in vehicles

A standard from SAE international divide vehicle automation into six levels, from 0 to 5 and each step significates to what degree a computer controls the vehicle. To be seen as a system that increases the level of automation interaction with the driver is not enough, the system needs to have increased control over how the vehicle is behaving[3].

Table 2.1: Level of vehicle automation according to SEA International standard J3016.

SEA level	No Automation	Execution of steering and acceleration /deceleration	Monitoring of driving environment	Fallback performance of dynamic driving task	System capability
0	No Automation	Human diver	Human diver	Human diver	n/a
1	Driver Assistance	Human driver and System	Human diver	Human diver	Some driving modes
2	Partial Automation	System	Human diver	Human diver	Some driving modes
3	Conditional Automation	System	System	Human diver	Some driving modes
4	High Automation	System	System	System	Some driving modes
5	Full Automation	System	System	System	All driving modes

A fine line is drawn between level 2 and 3. In level 2 the human driver is the main actor in surveying the area around the vehicle while at level 3 a computer can do most of the driving[3]. Here is also where current legislation starts to be a restricted. According to the Vienna Convention of Road Traffic, that more than 70 countries use [4], every moving vehicle shall have a driver and that driver shall be able to control the vehicle all the times[5]. The conclusion is that fully autonomous vehicles would not be legal today[6].

2.2 Autonomous Systems

This section gives a short introduction to 7 different autonomous systems AEBS, CC, ACC, C-ACC, Park Assist, Platooning and Queue Support. Some of them have been used for several years while others are just in their early stages of being developed and extensive research is required before they can reach the market.

2.2.1 AEBS

Advanced Emergency Braking Systems can appear in different shapes and forms but the purpose is the same. It uses different sensors to predict if an accident is about to happened and if so it automatically breaks to avoid or mitigate the damage[7].

If an emergency brake occurs without first warning the driver it is likely that the driver panic's or gets frightened[8]. So because of this systems in today's vehicle are often built to first prepare the system for rapid brake and notify the driver about an upcoming potential dangerous situation. If there is no action made by the driver and an accident is imminent the system start to decelerate the vehicle while waiting for a driver action. Finally when the accident is impossible to avoid, so called CU-criterion (collision unavoidable) the system then applies maximum break pressure in order to fully stop the vehicle[8, 9].

Figure 2.2: All new buses and trucks will soon be equipped whit AEBS. Photo taken by Volvo

All bus and truck models introduced in EU after 1th of November 2013 are forced to have AEBS. From 1th of November 2015 that will be the case for every new sold bus and truck in EU. In the following year the demand on what the AEBS should be able to achieve is increased[10].

2.2.2 CC

The Cruise control system tries to maintain a desired speed for the vehicle by measuring the actual speed and regulates the throttle by electronic means[11].

2.2.3 ACC

Adaptive Cruise Control is a further development of the CC application. It uses an extra sensor in the front that measures the distance to a vehicle ahead. Thus allowing a vehicle to follow a moving vehicle in front at a certain distance by regulate throttle and brake pressure. If there is no vehicle ahead ACC does the same thing as the ordinary CC system. Sensors for distance measuring are typical LIDAR or Radar[11, 12].

2.2.4 ACC Stop and Go

This is an expansion of the ACC system with the ability of full speed range control allowing ACC to be used in static and slow moving traffic. Lower speed limit for ordinary ACC is around 40 km/h[13].

2.2.5 CACC

The sensors used for Adaptive Cruise Control (ACC) can have significant delay in measuring the distance to vehicles ahead. This is because in order to get a stable data output sometimes heavy filtering has to be done to the data given by the different sensors[12]. The delay will cause variation in distance which can be amplified by each following vehicle and lead to instability[14].

Cooperative Adaptive Cruise Control (CACC) that is under development use V2V (vehicle to vehicle) to communicate with the vehicle ahead to get information about their current speed [15]. The result is less delay in the control loop and more accurate control compared to ACC. This makes it possible to decrease the gap between vehicles without reduce safety [14, 12] and increase the lane capacity [15]. So when CC and ACC just increases driver comfort, CACC can safely bring the vehicles close enough to reduce wind resistance for the following vehicle. Thus allowing improved fuel economy and increases traffic flow[14].

In a more advance CACC I2V (Infrastructure to Vehicle) can be used to receive information about the traffic further ahead. [15].

2.2.6 Park Assist

Parking assistance comes in several different forms but the main goal of the system is to help the driver to execute a parking maneuver. Passive systems have been on the market for several years and help the driver to monitor the area around the vehicle, warning for obstacles or make hided angels visible for the driver through HMI. In this category we also find systems that tell us if a parking lot is big enough for our vehicle and guides the driver when executing a parking maneuver. For a system to be called an active system it has to have some control over the vehicles lateral or longitude movement[16].

Figure 2.3: A Volvo XC90 using sensor and robot functions to find and park itself in an empty parking lot, Park Assist. Photo taken by Volvo Cars

In today's cars you can find parking assist system that manage to find and steer into both parallel and perpendicular parking lots while the driver take care of acceleration, braking and gear shifting by the recommendations from the system[17, 18, 19]. In a not so far away future systems will also take care of that part and the driver just have to monitor the cars movement[20].

2.2.7 Platooning

Several successful platooning experiments have been done over the last decade such as the KONVOI (2005-2009) and currently ongoing project COMPANION that started in 2013[21] focusing on slight different aspects of automated vehicles. This document uses the definition of platooning set by the SARTRE-project that started in 2009 and ended in September 2012.

According to SARTRE platooning include both lateral and longitudinal autonomous control. The technical equipment controls the vehicle without driver involvement[22].

Platooning is most easily described as a train or convoy of vehicles both trucks, buses and cars mixed together. The convoy consists of a lead vehicle (LV) and a number following vehicles (FV). The lead vehicle typically a larger vehicle such as a truck is operated by a trained driver that drives along the road. Setting a speed and heading creating a trail for the following vehicles[23]. Other vehicles with the right ability can then request to follow the leader fully autonomously. Through V2V communication, LIDAR, radar, cameras, lane marking sensors etc. every vehicle then estimates the path and speed of the vehicle in front and follows[24].

Much like CACC platooning improves fuel consumption and safety. But since the following vehicle drives fully autonomously their driver's can now do other things such as reading, using smart-phones and eating to increase driver convenience. Due to the controlled form of movement platooning also improves road congestion[24].

At all times drivers in the following vehicles can access instant and full control of their vehicle easily. So if something happens the driver can always brake or steer away but the vehicle will in most cases still be considered as a vehicle that belongs to the platoon. To exit the platoon the driver pushes a button for a request to exit the platoon. To enter the driver simply drives the vehicle close to the platoon and presses a button to request for entry[24]. A vehicle can enter into any position of the convoy. The entry consists of two parts first off the driver just leave over control of the speed and when the system feels comfortable enough. It takes over steering as well and closes the gap to vehicle in front, giving the driver time to relax.

Concerning whether or not platooning would be legal to implement into production as of today the answer would be no. In a recent study done by the Scania led COMPANION project they state that international, European and local regulations needs to be revised. For example autonomous lateral steering equipment is not feasible inside the frames of regulations[25].

2.2.8 Queue Support

A system that fully autonomously drives a vehicle through a slow moving traffic scenario [26], the system takes complete control of the vehicle when it comes to both speed and steering. It then follows the vehicle in front at a distance to optimize safety and driver comfort [27].

Queue assist or queue support is one of the latest systems for autonomous driving and therefore accurate information is hard to come by. But it is a system that has been implemented and put into manufacturing lately by some of the biggest car manufacturers[28].

In 2008 EU founded and launched the project HAVEit consisting of 17 different companies and universities involved in the automobile industry. One of the main goals with HAVEit was to create a prototype for a queue assistance to take over the vehicle and help the driver while driving in slow moving traffic. In 2011 Volvo Group took a part in the Adaptive project [29] to make a queue support system. This system was named Automated Queue Assistance (AQuA) and was presented at their test track in Hällered. AQuA uses sensors monitoring the area around the truck as well as the driver too safely and securely be able to fully autonomously drive the truck through traffic at a controlled velocity and even stop and start the truck if necessary[30].

2.3 Prescan

PreScan is a software for the automotive industry made by TASS International. It consists of GUI where you can build up your traffic scenarios, a viewer where you can play and record your scenarios and a connection to Simulink to activate vehicle dynamics. It is used for testing and evaluations of Advanced Driver Assistance Systems (ADAS) by using either model-, software-, hardware- or driver-in-the-loop [31].

The three different interfaces will be explained below.

2.3.1 PreScan GUI

The PreScan GUI is the base program and this is where the scenarios you want to run is built through a Graphic User Interfase (GUI)[32]. An easy way to describe how it works is to divide it into three parts that together creates the main structure of your test.

2.3.1.1 Environment and infrastructure

The environment is created through dragging and dropping infrastructure from a library. The library includes objects like roads, road signs and guardrails as well as houses, threes and different types of underlay. To not just have an ideal environment different condition can be simulated such as rain, fog and lighting[33].

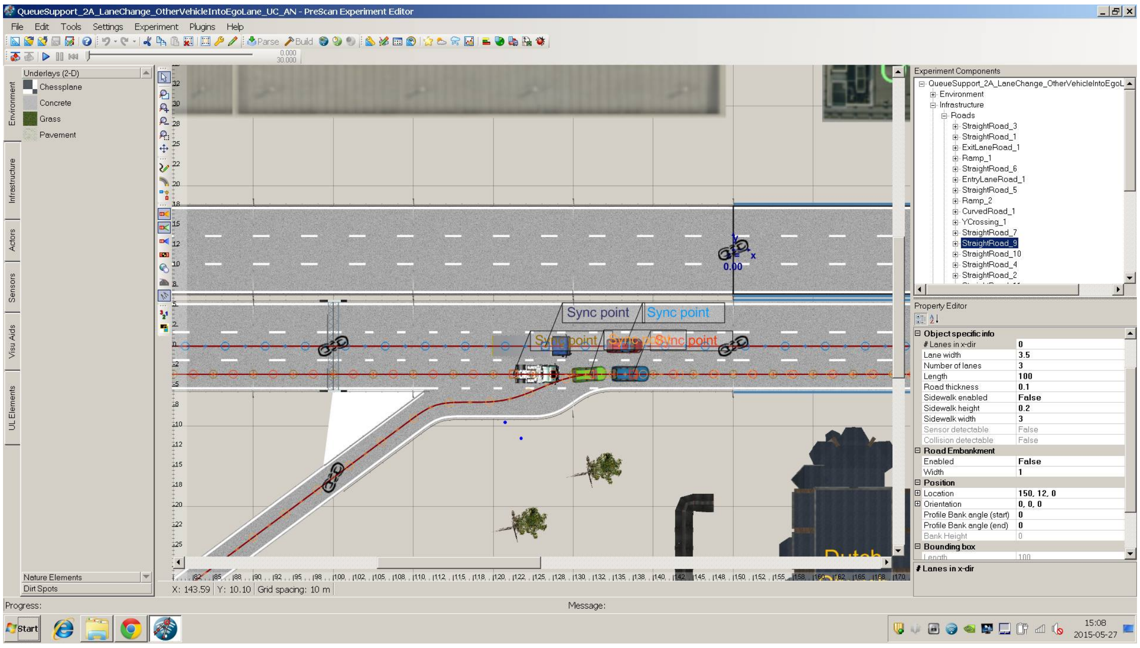


Figure 2.4: The Prescan GUI showing a Queue Assist scenario. Photo from PreScan

2.3.1.2 Actors

When actors are added into the environment the scenario is created. The PreScan library includes cars, trucks, bikes and pedestrians that can be set to follow trajectories that either follows the roads created or user customize trajectories[33]. It is possible to extend the actors library by importing user made Collada and CAD modeled vehicles[34].

2.3.1.3 Sensors

After an actor has been implemented it can be equipped with different setups of sensor models. For monitoring the surroundings there is for example radar, lidar, lane detection and a movement detection camera. The sensor library also includes sensors for GPS and V2V communication[32]. It is also possible to create customized sensors with user specified parameters[33].

2.3.2 Matlab/Simulink

To process vehicle dynamic and sensor models created by PreScan GUI a connection to Matlab/Simulink is used. It is also the interface where the user can insert custom made vehicle dynamic models and ADAS as well as for the analyzing and evaluating of test results[32].

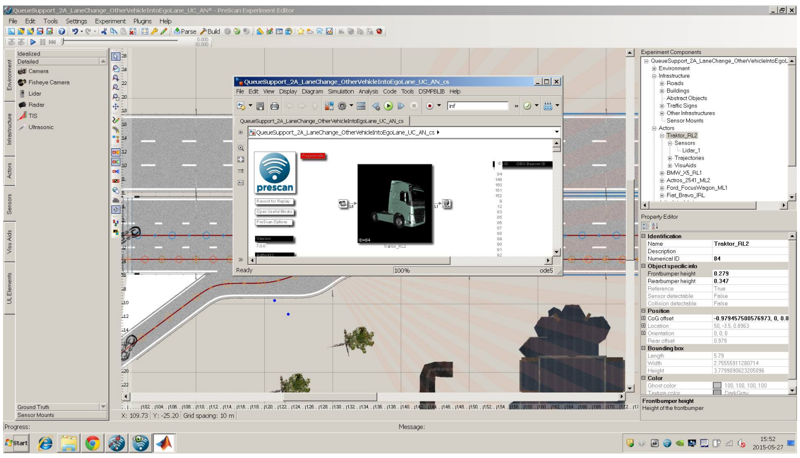


Figure 2.5: A Green Tractor 4x2 Simulink model. Photo from PreScan

2.3.3 PreScan Viewer

This comes as a tool to create a 3D environment where fixed as well as own viewpoints can be chosen to visualize, monitor and record the scenarios[32].

2.4 Variation in truck-setup

2.4.1 Truck Combinations

If you talk about a cargo carrying truck today it's not just a truck. The different variations that could set up a truck are many and in this report we use Semi-truck, tractor-trailer, semi trailer and rigid truck. Although all of them could go under the same name the performance of the vehicle and what they are used for significantly diverge [35].

First of we have the rigid-truck or just truck that is a big vehicle that can transport a lot of gods on its own, equipped with both an engine and storage for storing goods [36]. A semi-truck or tractor on the other hand is just the pulling unit consisting of a powerful engine but no storage and they are made for hauling semi-trailers [35]. A semi-trailer has wheels and no engine so it can't move on its own. It is basically a container on wheels [37]. If you combine semi-truck and semi-trailer to a unit it can be called tractor-trailer [35, 38].

2.4.2 Axle Setups

Another feature that has a major impact on the truck is its axle combination and most trucks comes with a large set of different combinations such as 4×2, 6×2, 6×4, 8×4 or 8×6. The first number tells how many wheels there are in total and the second how many of them can be connected to the driveline. 4x2 means that there are two axles on the truck so 4 wheels in total with 1 axle connected to the driveline. The 4x2 combinations are mainly used for duty cycles carrying low weight at a high frequency such as post mail companies. Fewer wheels mean less weight and a lower tire rolling resistance for reduced fuel consumption [39]. 6x2 on the other hand uses 3 axles and 6 wheels for transporting heavier loads then the 4x2 combination [40]. 6x4 was for a long time the most popular choice of truckers in the United States but recent studies done by various truck/trucking companies and NACFE (North American Council for Freight Efficiency) shows that connecting one axle instead of two to the driveline reduces fuel consumption with up to 5% and when the middle axle is mounted with a lift that can raise the axle the 6x2 has as good traction as the 6x4 [41, 42].

Figure 2.6: A Volvo truck from PreScan with a 6x2 axle setup. Photo from PreScan

2.4.3 Volvo Trucks

Today there exist 5 different types of Volvo models on the market FH FMX FM FE and FL[43]. For this report it's necessary to describe FH (Front High) and FMX (Front Medium Cross Country).

2.4.3.1 FH

The Volvo FH is their largest truck model. It can be made as either a rigid truck or a tractor and its main purpose is long distance travels, transporting heavy loads over great distances with a high driving comfort and a low fuel economy [44].

2.4.3.2 FMX

FMX is made for transportation in rough areas like mines and construction sites. With a higher frame which gives the truck the ability to take steeper hills. A pulled back front axle and several axles with the ability to turn the wheels, both decrease the trucks turning radius and there are also protective steel plates shielding vulnerable parts trough rougher terrain [45].

Figure 2.7: The Volvo FH16 and Volvo FMX. Photos taken by Volvo

3 Methods

3.1 Procedure

Several steps and methods were used during the creation of this 10 week thesis project, in appendix A you can find the original schedule. This chapter will describe each step in detail.

3.1.1 Pre-Study

In order to get a feel for the Volvo family or more importantly to understand the difference in road behavior, a normal car which most people are accustomed to in comparison to a truck. A short pre-study before the thesis started was made, studying two different types of Volvo Truck models, FH and FMX. We also did a short study around different types of vehicle-setup and axle combinations used in trucks.

3.1.1.1 Software Introduction

Initially the software were introduced, how to create road structure, environment, trailer connections, dynamic models, sensor functions, camera views, etcetera. All of that which would be used in the thesis created in PreScan and Matlab or more specifically PreScan and Simulink. To acquire the knowledge we implemented our first use-case, a simple ACC-scenario.

3.1.2 Creating the Library

Below you can read about the main work. The traffic situations that were created are referred to as either a scenario or a use-case.

3.1.2.1 Pre Study of Autonomous Functions

To be able to create scenarios there had to be an understanding in how the different autonomous functions operated, their purpose, what types of sensors they used etc. First of bubble charts describing the different systems were created from simple Internet searches, just to get a grip of the functions. Then better sources were used to create documents describing each and every system in detail.

3.1.2.2 Scenario Outlining and Documentation

First step were to create flow charts with relevant scenarios for each system. With the flowcharts as a guideline more detailed use-case documents were made. The use-case document are Excel sheets that contains detailed text description describing the events taking place in the scenarios as well as a simple pictogram showing the main event.

3.1.2.3 Implementation into PreScan

This part is where the actual scenario library was made following the scenarios defined in the use-case document when implemented into PreScan.

3.1.2.4 Evaluation

Through the work weekly meetings with the supervisor on Volvo has been used to evaluate the work and decide what to be done next. In the term to come up with, create and implement the scenarios has been an iterative process where scenario, document layout and PreScan implementation have undergone constant refinement. The meetings where a good way of pinpointing the scenarios for later usage of Volvo Trucks. Before the final presentation at Volvo additional Volvo personal were invited to a discussion in order to get a better perspective and a wider input.

3.1.3 User Improvements

In order to make the library easier to use movies of every scenario was made and then connected to the flowchart. It allows people to have a look at the scenario whiteout the need for a PreScan license. Also a manual was created describing how the flow charts and use-cases are connected and simple instructions of how to implement autonomous functions into the PreScan scenarios.

3.2 Materials

3.2.1 Software

- PreScan 7.0.0
- Matlab 2012.b
- Simulink
- Microsoft Excel 2010
- Microsoft Power Point 2010
- LaTeX

4

Results

As intended a library with scenarios have been created. Since some of the systems included in this project have the same demands regarding environmental and traffic scenario layout it was unnecessary to create a set of scenarios for all of them. So originating from the ten different systems given, we decided to group them into six categories. The categories are as following and they will be used grouped like this throughout the rest of this report.

- AEBS
- CC, ACC, ACC S&G, CACC
- Parking, Load/Unload
- Platooning
- Queue Support
- VRU

4.1 Library Structure

Under this title the document types and structure creating this library is to be introduced.

4.1.1 Flow Charts

This is a simple overview of the scenarios created for each system. All flow charts for the different systems were constructed using the template shown below.

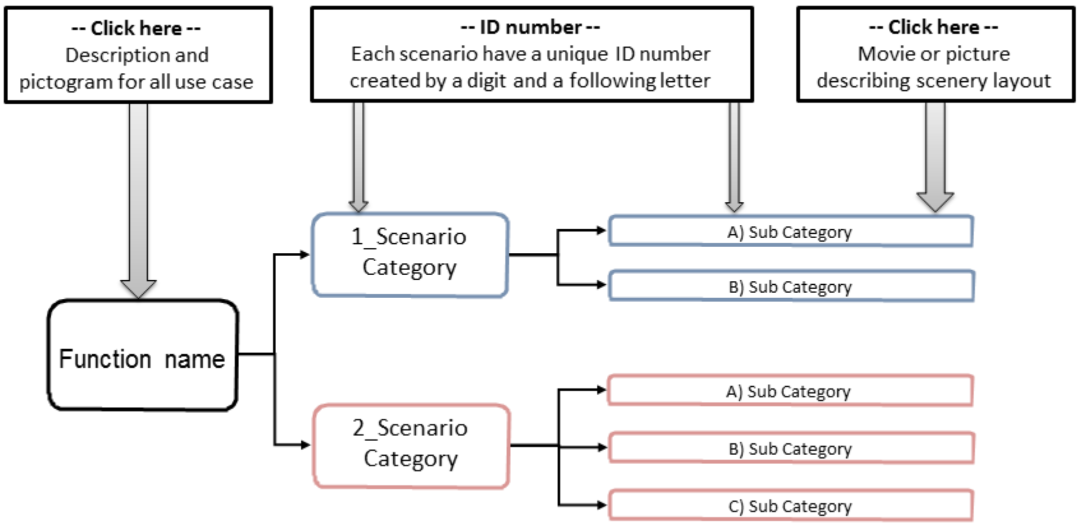


Figure 4.1: Flow chart overview.

Scenarios are divided into three steps first of for every system, function name, secondly into scenario categories which is the headline of the traffic environment or situation and finally the sub categories. The sub categories are variations of the scenario category and the actual traffic situation to be simulated. Scenario categories are separated trough numbers and the sub categories by letters and together they form an unique ID number representative for every scenario.

In the flowchart there is no space for detailed description and this is solved by linking movies and use-cases document to the flow chart. By clicking on the function name box the use-case document (described in next subchapter) for the system is opened and by clicking on the sub category boxes a pitcher or a movie made in PreScan will be shown.

4.1.2 Use-case Documents

The use-case documents are created from a template used by the department and they can be found in Appendix D. It follows the same structure as the flow charts with one document for each system category and describing each scenario with pictogram, a short text and an expected result. The first scenario in one of this use-case document is showed below as an example. In chapter 4.2 you will find text withdrawals from the use-case documents in tables, the definitions employed in there can be found in apendix D at the top of every Excel sheet.

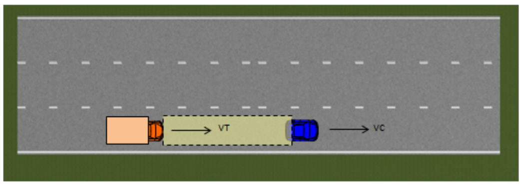
Test case ID	Function title	Test	Expected result
1A Truck Approach Car Same Lane Straight Road		Ego vehicle approach a car. a) A stationary vehicle: VC = 0 b) A moving vehicle: VT > VC	a) Robot function warns driver and CU-criterion stops the truck before the car for every test run. b) Robot function warns driver and CU-criterion stops the truck before the car for every test run.

Figure 4.2: Use-Case: AEBS 1A TruckAproachCar SameLaneStraightRoad

4.1.3 PreScan Scenario

Each scenario is individually created in PreScan with a main focus on environment/ infrastructure and for an easy change of velocity's and vehicle setups.

In order to make the scenarios understandable a ego vehicle, the Green Tractor 4X2 is implemented into every scenario. When a user wants to use the library the Green Tractor 4X2 represents the vehicle to be replaced. The user replaces the tractor, implements a new vehicle combination and equips it with the desired sensors and functions trough the GUI and in Simulink.

4.2 Library Content

This section presents the library and theres one subsection for every system. First of comes the flow chart, second there is a table with the scenario description from the use-case document and thirdly a representative picture from PreScan.

4.2.1 AEBS

This system focuses on events in front of the truck and difficulties occur in predicting an emergency. AEBS has to give as few false alarms as possible and be very distinct in choosing and detecting new critical targets while operating in different traffic environments. Below are the scenarios for AEBS:

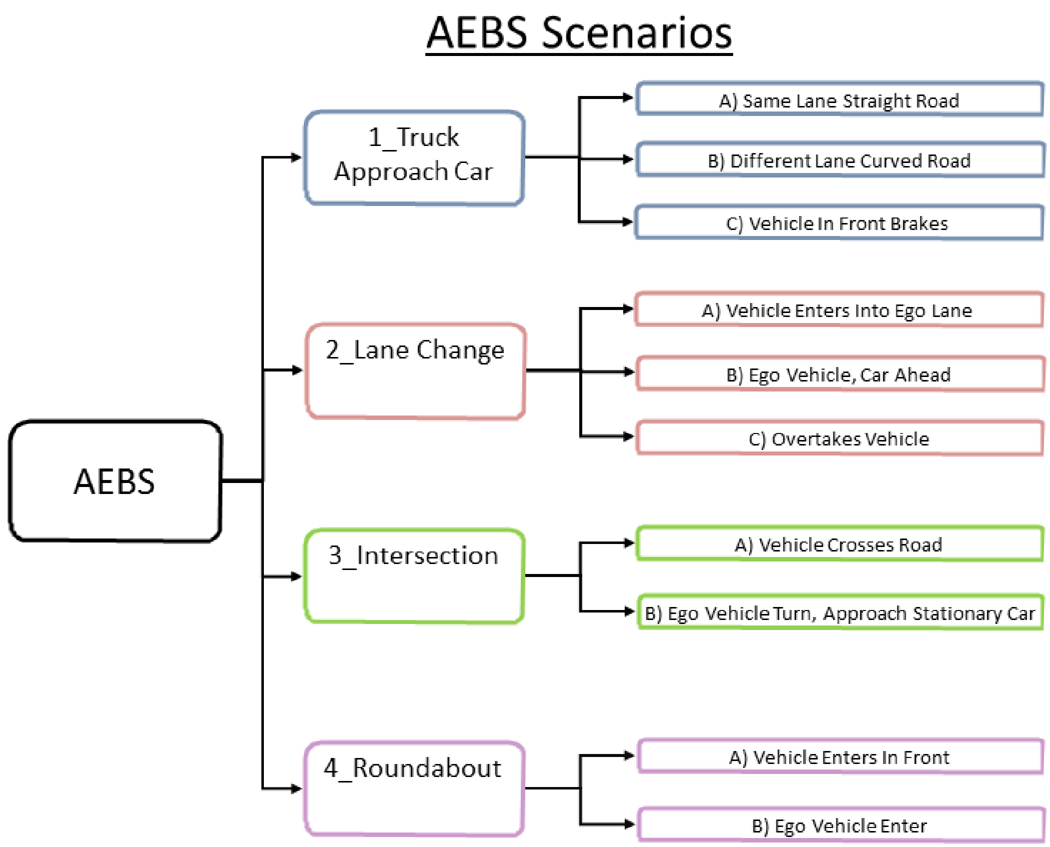


Figure 4.3: Flowchart for AEBS

The table contains a description for each scenario and the complete excel sheet with a describing picture can be found in Appendix D.1

Table 4.1: Test scenario description for AEBS.

ID	Scenario category/ Sub category	Test scenario description
1A	Truck Approach Car/ Same Lane Straight Road	Ego vehicle approach a car. a) A stationary vehicle: VC=0 b) A moving vehicle: VT>VC
1B	Truck Approach Car/ Different Lane Curved Road	Truck can detect car in a different lane. a) A stationary vehicle: VC=0 b) A moving vehicle: VT>VC
1C	Truck Approach Car/ Vehicle In Front Brakes	Initially truck follows vehicle at the same speed on the distance of L meters. The vehicle breaks and the deceleration is a.
2A	Lane change/ Vehicle Enters Into Ego Lane	L is the distance for when the lane change is executed. a) Car change lane in front of the truck VC>VT b) Car change lane and tuck needs to decelerate VC<VT
2B	Lane Change/ Ego Vehicle, Car Ahead	L is the distance for when the lane change is executed. a) Car change lane in front of the truck: VC>VT b) Car change lane and tuck needs to decelerate: VC<VT
2C	Lane Change/ Overtakes Vehicle	L is the distance for when the lane change is executed: VT>VC
3A	Intersection/ Vehicle Crosses Road	a) Car passes across thought trail route before truck reaches. b) Car and truck potential reach intersection point at the same time.
3B	Intersection/ Ego Vehicle Turn, Approach Stationary Car	Truck turns in an intersection and approaches a stationary vehicle.
4A	Roundabout/ Vehicle Enters In Front	a) Car stops and let the truck pass, VC end=0 b) Car enters and just in front of the truck. c) Car passes across thought trail route before truck reaches.
4B	Roundabout/ Ego Vehicle Enter	Truck driver do not notice the car from left when enter the roundabout.

The PreScan environment for AEBS is represented by this picture showing scenario 4B Roundabout, Ego Vehicle Enter.

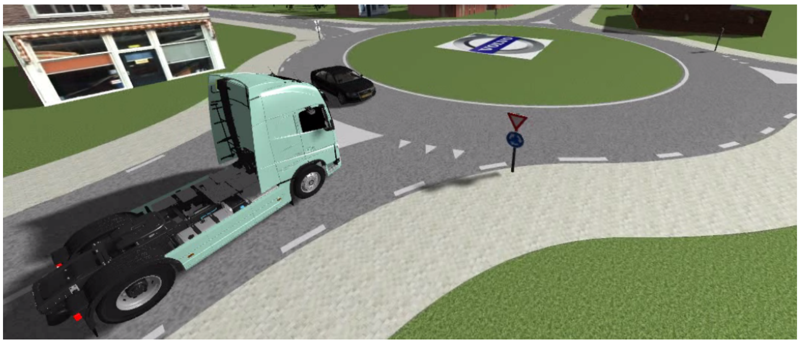


Figure 4.4: Scenario AEBS 4B Roundabout, Ego Vehicle Enter. Photo from PreScan

4.2.2 CC, ACC, ACC S&G, CACC

Cruise control does not really require a scenario but it is the base part of the other system. The systems mainly uses sensors monitoring the area in front of the vehicle and difficulties are found in keeping track of the target in front, which vehicle to target as well as maintaining a god drivers comfort. The traffic environment for CC, ACC, ACC S&G, CACC is mostly high way's.

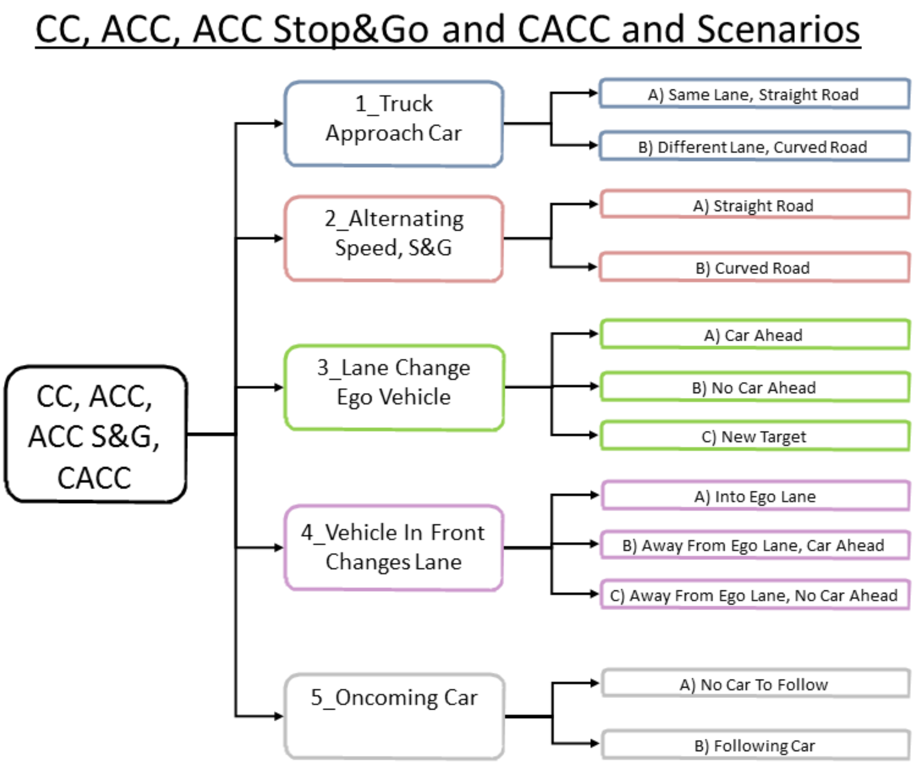


Figure 4.5: Flowchart for CC, ACC, ACC S&G, CACC

The table contains a description for each scenario and the complete excel sheet with a describing picture can be found in Appendix D.2

Table 4.2: Test scenario description for CC, ACC, ACC S&G, CACC.

ID	**Scenario category/ Sub category**	**Test scenario description**
1A	Truck Approach Car/ Same Lane Straight Road	Ego vehicle approach a vehicle. VT is desired CC speed. a) A stationary vehicle: VC=0 b) A moving vehicle VT>VC
1B	Truck Approach Car/ Different Lane Curved Road	Truck can detect car in a different lane. VT is desired CC speed. a) A stationary vehicle: VC=0 b) A moving vehicle VT>VC
2A	Alternating Speed Stop&Go/ Straight Road	Speed can alternate from highway speed to stand still.
2B	Alternating Speed Stop&Go/ Curved Road	Speed can alternate from highway speed to stand still. Every vehicle can have an individual speed profile.
3A	Lane Chage Ego Vehicle/ Car Ahead	Ego vehicle change lane and get a new vehicle in front. VT is desired CC speed. VT>VC
3B	Lane Chage Ego Vehicle/ No car ahead	Ego vehicle follows a car and change into an empty lane. CC speed on truck > initial speed.
3C	Lane Chage Ego Vehicle/ New Target	Ego vehicle change lane and get a new vehicle to follow. Every vehicle can have an individual speed profile.
4A	Vehicle In Front Changes Lane/ Into ego lane	Vehicle from another lane change lane into the gap between ego vehicle and the followed vehicle. Every vehicle can have an individual speed profile.
4B	Vehicle In Front Changes Lane/ Away From Ego Lane, Car Ahead	Followed vehicle change lane. A new car in ego lane got visible and can be followed. Every vehicle can have an individual speed profile.
4C	Vehicle In Front Changes Lane/ Away From Ego Lane, No Car Ahead	Followed vehicle change lane and there is no new car ahead to follow. CC speed on th truck > VC
5A	Oncoming Car/ No Car To Follow	An oncoming car.
5B	Oncoming Car/ Following Car	Ego vehicle follow a car when an oncoming car approach.

The PreScan environment for CC, ACC, ACC S&G and CACC is represented by this picture showing scenario 1A Truck Approach Car, Same Lane Straight Road

Figure 4.6: Scenario ACC, ACC S&G CACC 1A Truck Approach Car, Same Lane Straight Road. Photo from PreScan

4.2.3 Parking, Load/Unload

Load and Unload refers to a stationary place where a truck can perform a load or unload of cargo, which is a variance of parking. The systems do not require any traffic situations but different environments.

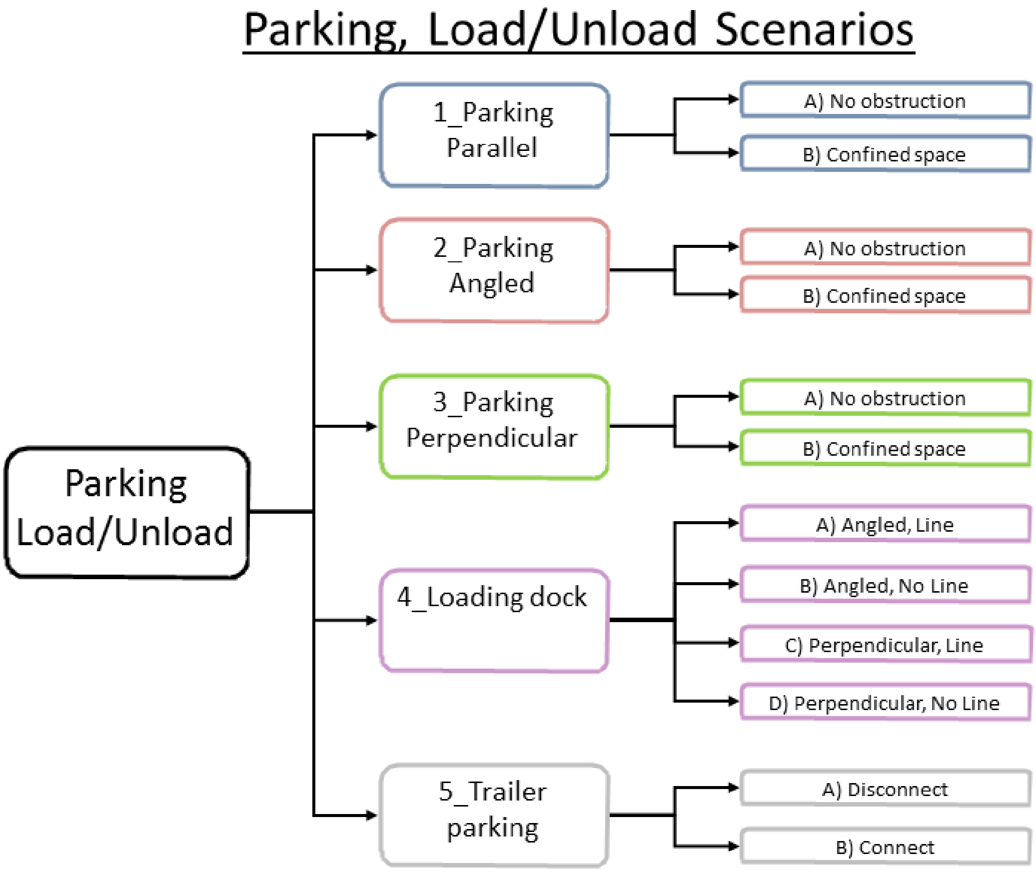


Figure 4.7: Flowchart for Parking Load/Unload.

The table contains a description for each scenario and the complete excel sheet with a describing picture can be found in Appendix D.3.

Table 4.3: Test scenario description for Parking Load/Unload.

ID	Scenario category/ Sub category	Test scenario description
1A	Parking Parallel/ No Obstruction	Find and execute parallel parking.
1B	Parking Parallel/ Confined Space	Find and execute parallel parking.
2A	Parking Angled/ No Obstruction	Find and execute angled parking.
2B	Parking Angled/ Confined Space	Find and execute angled parking. Ego vehicle in PreScan is the blue Mercedes tractor.
3A	Parking Perpendicular/ No Obstruction	Find and execute perpendicular parking.
3B	Parking Perpendicular/ Confined Space	Find and execute perpendicular parking.
4A	Loading Dock/ Angled Line	Truck autonomously docks to loading dock.
4B	Loading Dock/ Angled No line	Truck autonomously docks to loading dock.
4C	Loading Dock/ Perpendicular Line	Truck autonomously docks to loading dock.
4D	Loading Dock/ Perpendicular No Line	Truck autonomously docks to loading dock.
5A	Trailer parking/ Disconnect	Truck disconnects the trailer at a given location (blue X) and then parks itself at a parking slot (red X).
5B	Trailer parking/ Connect	Truck reverses autonomously to the trailer and connect.

The PreScan environment for Parking Load/Unload is represented by this picture showing scenario 2B Parking Angled, Confined Space

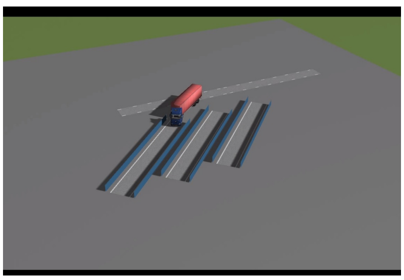


Figure 4.8: Scenario Parking Load/Unload 2B Parking Angled, Confined Space. Photo from PreScan

4.2.4 Platooning

Platooning is about two things, handling of the actual road train as well as monitoring the vehicles surrounding the platoon. Environment is mostly highways.

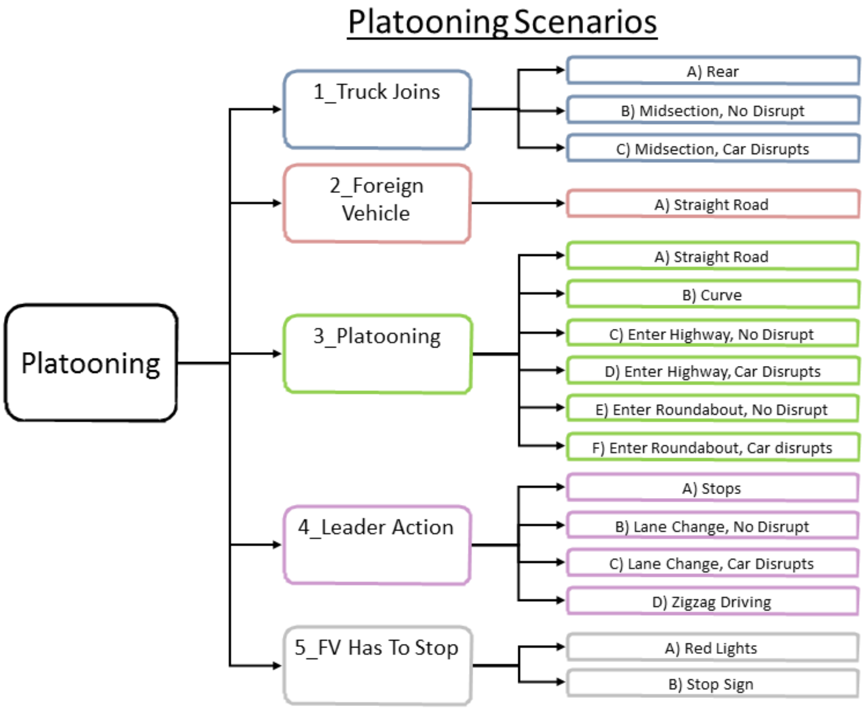


Figure 4.9: Flowchart for Platooning.

The table contains a description for each scenario and the complete excel sheet with a describing picture can be found in Appendix D.4.

Table 4.4: Test scenario description for Platooning.

ID	**Scenario category/ Sub category**	**Test scenario description**
1A	Truck joins/ Rear	Driver asks for permission to enter the Platoon and when the truck has been given permission to enter it matches speed with the platoon and then autonomously starts following the last vehicle in the platoon. L is the distance (m) between vehicles in the platoon.
1B	Truck Joins/ Midsection No Disrupt	Driver asks for permission to enter the Platoon and when the truck has been given permission to enter. The truck autonomously adapts it's speed to match the platoon and waits until L is big enough . Truck then slowly enters the platoon and the distance to both the FV and the LV is adjusted.

Table 4.5: Cont. Test scenario description for Platooning.

1C	Truck Joins/ Midsection Car Disrupts	Truck asks to join the platoon. L is increased but then the green car decelerates and disrupts the maneuver.
2A	Foreign Vehicle/ Straight Road	A platoon consisting of 2 FV's and a LV is driving on a straight road when a foreign vehicle obstructs the platoon.
3A	Platooning, Straight Road	A platoon consisting of 3 FV's and a LV is driving on a straight road. Fv's keep a distance of L meters to the vehicle in front.
3B	Platooning/ Curve	A platoon consisting of 3 FV's and a LV is driving through a curve. Fv's keep a distance of L meters to the vehicle in front.
3C	Platooning, Enter Highway No Disrupt	A platoon consisting of a LV and 2 FV enters a highway.
3D	Platooning/ Enter Highway, Car Disrupts	A platoon consisting of a LV and 2 FV enters a highway when a car speeds in and disrupts the transfer for the FV.
3E	Platooning, Enter Roundabout No Disrupt	A platoon consisting of a LV and 2 FV's drives through a roundabout.
3F	Platooning/ Enter Roundabout Car Disrupts	A platoon consisting of a LV and 2 FV's drives through a roundabout, before the second FV can enter the roundabout a vehicle place itself inbetween FV1 and FV2.
4A	Leader Action/ Leader Stops	A platoon consisting of LV and 3 FV's drive along a straight road when the LV brakes.
4B	Leader Action, Lane Change No Disrupts	A platoon consisting of LV and 3 FV's travel along a straight road when the LV decides to make a lane change.
4C	Leader Action/ Lane Change Car Disrupts	A platoon consisting of LV and 3 FV's travel along a straight road when the LV decides to make a lane change. Suddenly a foreign car speeds in and disrupts the maneuver for FV1.
4D	Leader Action/ Zigzag Driving	A platoon consisting of LV and 2 FV's travel along a straight road when the LV starts driving in a zigzag pattern.
5A	FV Has To Stop/ Red Light	A platoon consisting of a LV and 3 FV's drives through a crossing with a traffic light.
5B	FV Has To Stop/ Stop Sign	A platoon consisting of a LV and 2 FV's drives through a crossing with a stop sign.

The PreScan environment for Platooning is represented by this picture showing scenario 4B Leader Action, Lane Change.

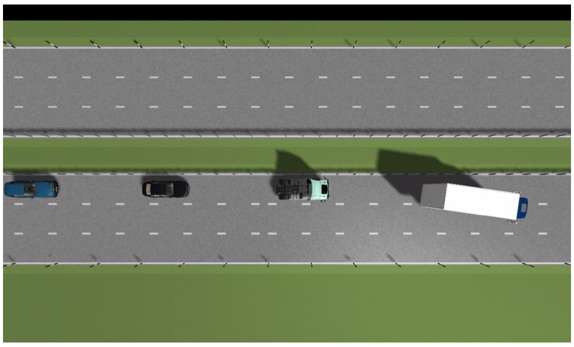


Figure 4.10: Scenario Platooning 4B Leader Action, Lane Change. Photo from PreScan

4.2.5 Queue Support

Queue support monitors the area in front and is made for low speeds, intense traffic in a city like environment. The system has to handle the noisy sensor environments, choice of targets for longitudinal speed control and the lateral steering with or without visible lane markings.

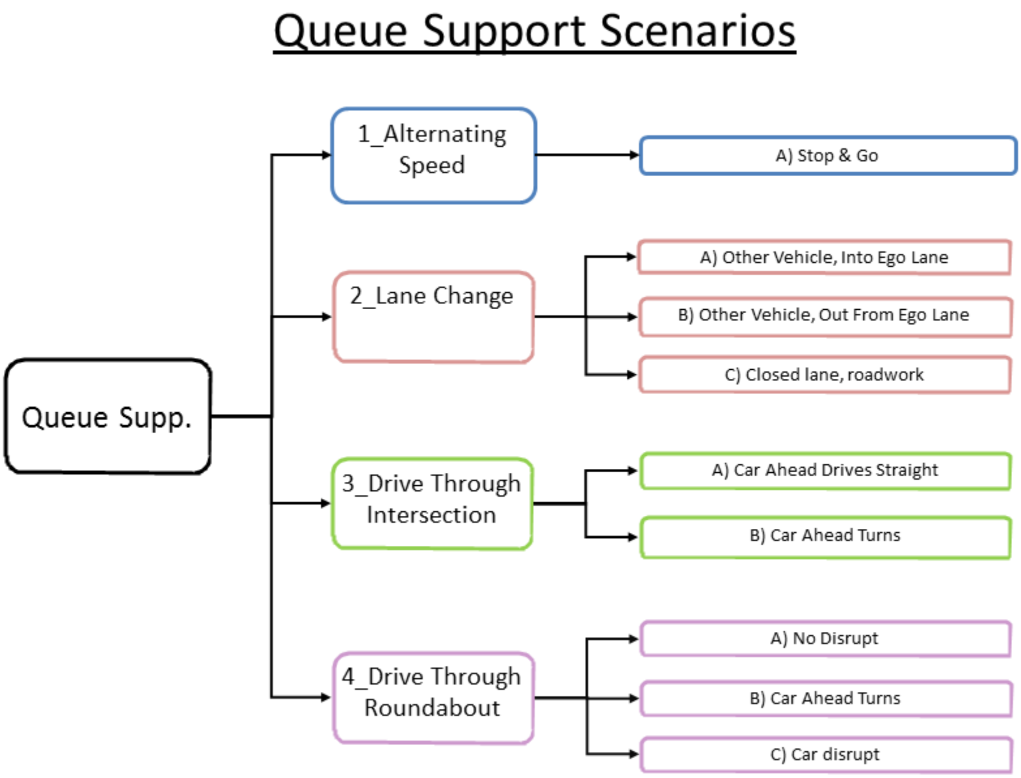


Figure 4.11: Flowchart for Queue Support.

The table contains a description for each scenario and the complete excel sheet with a describing picture can be found in Appendix D.5

Table 4.6: Test scenario description for Queue Support.

ID	Scenario category/ Sub category	Test scenario description
1A	Alternating Speed/ Stop & Go	Speed alternate from stand still to max speed for Queue Support. Every vehicle can have an individual speed profile. Ego vehicle: ML2
2A	Lane Change/ Other Vehicle Into Ego Lane	Vehicle IRL makes a tight lane change in front of ego vehicle. Ego vehicle: RL2
2B	Lane Change/ Other Vehicle	Out From Ego Lane Vehicle ahead of ego vehicle change lane. CC speed on truck > VRL. Ego vehicle: RL2
2C	Lane Change/ Closed Lane Roadwork	A roadwork forces the traffic to make a lane change. Ego vehicle: RL2
3A	Drive Through Intersection/ Car Ahead Drives Straight	The queue runs through an intersection. Every vehicle can have an individual speed profile. Ego vehicle: RL2
3B	Drive Through Intersection/ Car Ahead	Turns The queue run through an intersection and the vehicle ahead of the ego vehicle turns right. VTRRL decrees if necessary before turn. Ego vehicle: RL2
4A	Drive through roundabout/ No Disrupt	The queue runs through a roundabout. Every vehicle can have an individual speed profile. Ego vehicle: RL2
4B	Drives Through Roundabout/ Car Ahead Turns	The queue run through a roundabout and the vehicle ahead of the ego vehicle turns right. Every vehicle can have an individual speed profile. Ego vehicle: RL2
4C	Drive Through Roundabout/ Car Disrupt	The queue run through a roundabout and the trajectory of the ego vehicle intersects by a disrupting car form left already inside the roundabout. Every vehicle can have an individual speed profile. Ego vehicle: RL2

The PreScan environment for Queue Support is represented by this picture showing scenario 1A Alternating Speed, S&G

Figure 4.12: Scenario Queue Support 1A Alternating Speed, S&G. Photo from PreScan

4.2.6 Vulnerable Road User

Similar to AEBS but made for avoiding accidents with bikers, pedestrians and other unprotected road users. VRU appears in several different traffic environments as well as from different outlines and scopes.

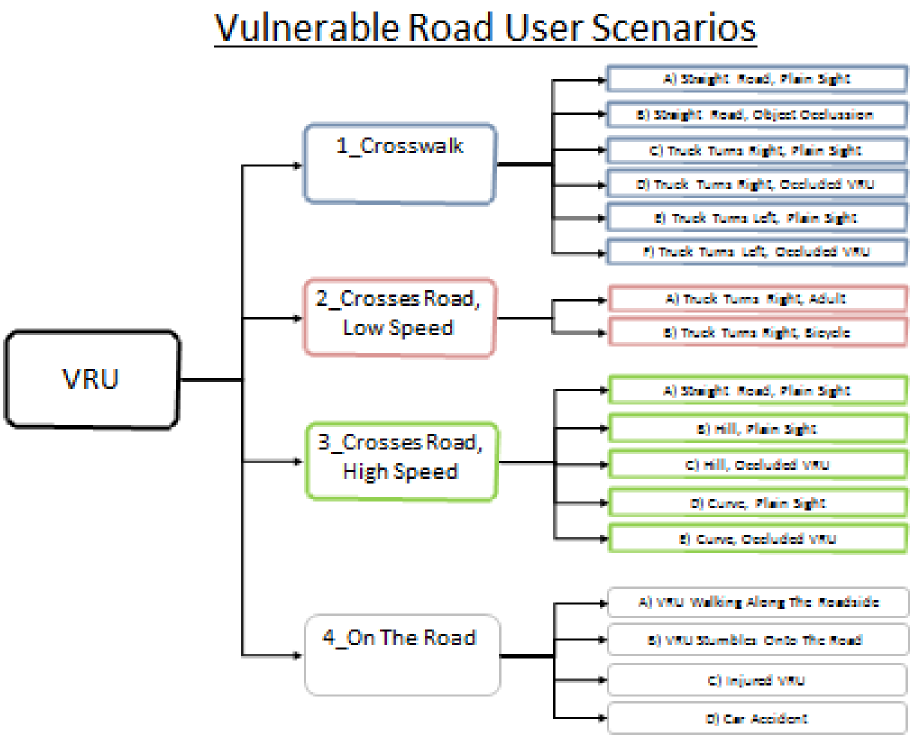


Figure 4.13: Flowchart for VRU.

The table contains a description for each scenario and the complete excel sheet with a describing picture can be found in D.6

Table 4.7: Test scenario description for VRU.

ID	Scenario category/ Sub category	Test scenario description
1A	Crosswalk/ Straight Road Plain Sight	VRU speed ranging from 1-10kph. a) Grown male/female cross road b) Children cross road c) Bicycle cross road d) old person cross road
1B	Crosswalk/ Straight Road Occluded VRU	VRU travels with a speed ranging from 1-10kph. Sensor occlusion by an object (house). a) Grown male/female cross road b) Children cross road c) Bicycle cross road d) old person cross road
1C	Crosswalk/ Truck Turns Right Plain Sight	VRU travels with a speed ranging from 1-10kph. Truck turning radius is 10m measuring from the front right wheel. a) Grown male/female cross road b) Children cross road c) Bicycle cross road d) old person cross road
1D	Crosswalk/ Truck Turns Right Occluded VRU	VRU travels with a speed ranging from 1-10kph. Truck turning radius is 10m measuring from the front right wheel sensor occlusion by an object (Wall). a) Grown male/female cross road b) Children cross road c) Bicycle cross road d) old person cross road
1E	Crosswalk/ Truck Turns Left Plain Sight	VRU speed ranging from 1-10kph. Truck turning radius is 10m measuring from the front left wheel. a) Grown male/female cross road b) Children cross road c) Bicycle cross road d) old person cross road

Table 4.8: Cont. Test scenario description for VRU.

1F	Crosswalk/ Truck Turns Left Occluded VRU	VRU travels with a speed ranging from 1-10kph. Truck turning radius is 10m measuring from the front left wheel sensor occlusion by an object. a) Grown male/female cross road b) Children cross road c) Bicycle cross road d) old person cross road
2A	Crosses Road Low Speed/ Truck Turns Right Adult	Ego vehicle drives along the road and turns right in a crossing, turning with a radius R. A human crosses the road at speeds ranging from 10-20km/h. A is the lateral distance to the truck. L is the distance from the front of the truck to VRU impact.
2B	Crosses Road Low Speed/ Truck Turns Right Bicycle	Ego vehicle drives along the road and turns right in a crossing, turning with a radius R. A bicycle crosses the road at speeds ranging from 10-20km/h. A is the lateral distance to the truck. L is the distance from the front of the truck to VRU impact.
3A	Crosses Road High Speed/ Straight Road Plain Sight	Animal or human speeds across the road.
3B	Crosses Road High Speed/ Hill Plain Sight	Animal or human speeds across the road just beyond the crest of a hill L meters in front.
3C	Crosses Road High Speed/ Hill Occluded VRU	Animal or human occluded by trees speeds (10kph) across the road just beyond the crest of a hill L meters in front.
3D	Crosses Road High Speed/ Curve Plain Sight	Animal or human speeds across the curved road , radius R
3E	Crosses Road High Speed/ Curve Occluded VRU	Animal or human occluded by trees speeds (10kph) across the curved road, radius R.
4A	On The Road/ VRU Walking along The Roadside	a) Grown male/female walks besides the road b) Bicycle travels along the road side
4B	On The Road/ VRU Stumbles Onto The Road	Do tests for different VT. a) Grown male/female walks besides the road and falls into the street L meter in front of the truck. b) Bicycle travels along the road side and crashes into the road L meter in front of the truck.
4C	On The Road/ Injured VRU	Truck drives towards an injured VRU.
4D	On The Road/ Car Accident	Truck drives towards an injured VRU.

The PreScan environment for VRU is represented by this picture showing scenario 1F Crosswalk, Truck Turns Left Occluded VRU.

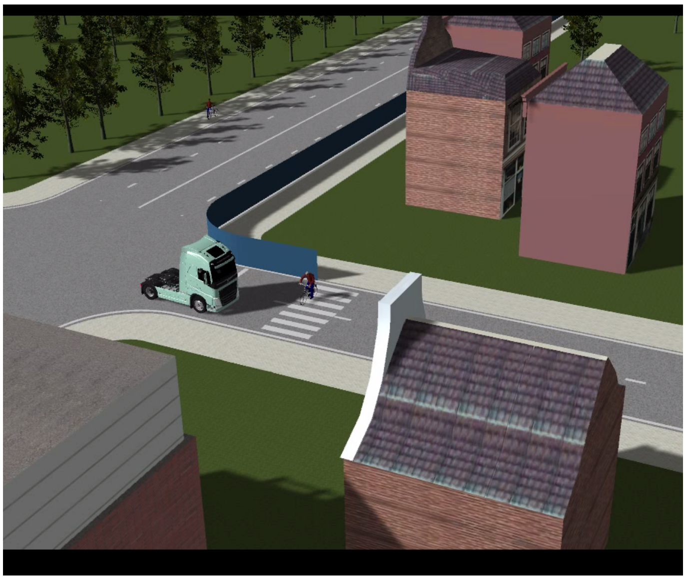


Figure 4.14: Scenario VRU 1F Crosswalk, Truck Turns Left Occluded VRU. Photo from PreScan

4.3 Manual

To introduce users to the library a manual for how to use it together with PreScan and Matlab was created. Its main focus is to give the most essential information only and is henceforth short and users are expected to have knowledge about why the library was made as well as a limited knowledge of PreScan. The Manual can be found in Appendix B Manual.

5

Discussion

Most of the autonomous functions described in the technical background has undergone extensive research programs under the last two decades. So finding accurate and trustworthy data is not hard although for this report Queue Support and Park Assist would be an exception. Both functions are rather new and the vehicle industry has not come up with a standardized concept, instead competing to make the best one in order to attract customers.

What CACC and Platooning are supposed to do is rather clear. For CACC the industry just needs to decide upon a standardized solution. But for both of them a bigger problem exists. Due to rules and regulations set by countries and conventions it would be illegal to implement Platooning and CACC for it's main purpose. For example a lot of the countries in and around Europe (Sweden one of them) require a 3 sec distance in between vehicles in 90kph gives a distance of 75m.

5.1 Combining Systems

The choice to make the same scenarios for CC, ACC, ACC S&G and CACC can be discussed as well as having Queue Support on it's own. Because what Queue support really is, is ACC S&G equipped with lateral control and what differ is that Queue Support is designed focusing on city like environment with a lot of interference. While ACC S&G is more of a highway system like CC, ACC and CACC. To adapt the scenario from ACC to ACC S&G is only a question of speed profile and this can easily be changed in PreScan. Another system that has special demands is CACC with V2X communication. If communication with several vehicles is to be simulated or V2I special scenarios has to be built but since the CACC still is in it's early development, scenarios created for CC are assumed good enough.

Parking Load/Unload might sound different but since the truck manufacturers doesn't produce trailers, creating function's is hard. Because when it comes to truck manufacturers like Volvo they can't get any data from the area behind the trailer while driving in reverse. Then it's not possible to ensure the safety to people behind the trailer and a truck is nothing without it's cargo. In order for proper systems to be designed for parking and load/unload of trucks companies selling trailers and the trucking industry comes up with a standardized set of sensors for trailers. These sensors has to ensures vision around the truck+trailer at all times.

5.2 Scenario Layout and Infrastructure

With the easily accessible data for autonomous systems creating scenarios is no problem, the hard part is too sort out which scenarios would be of the biggest use for Volvo GTT. Especially regarding the minor details that should be implemented into the scenarios. For example what turning radius should be used in curves and the size of intersections or the width of the road. To small and it would be impossible for bigger truck setups to get through and sometimes if the radius is to big the scenario would look unrealistic. Another example would be fence heights and placement, to test worst case scenarios they would seem unnatural when showed in the viewer. So if the scenario included object occlusion the occluding object had to be made easy to change in order for the user to be able to reshape the scenario into a more specific layout.

5.3 PreScan & Matlab(Simulink) Compatibility

While working with PreScan one of the main problems encountered was that PreScan easily crashes. Just running a scenario is no problem but if you want to record a movie or simulate one of the heavier scenario (lots of infrastructure, dynamics and sensors) you will most likely become frustrated. Although this might be because of that we only had a laptop to work with. When comparing PreScan against the preexisting simulator used by Volvo GTT the Volvo in-house driving simulator, we can see both disadvantages and benefits with PreScan (see Appendix C for details about the Volvo simulator). Both systems can connect sensor, V2V and truck models trough Simulink in order to implement and test autonomous functions. The PreScan GUI is easier to use especially when it comes to creating infrastructure, trajectories and mounting sensors/sensor visibility. The environment created by the Volvo simulator on the other hand is easier to make more realistic since it uses actual models of existing traffic environments. Hence Volvo inhouse is better if you want to use a DIL to test driver reactions in a realistic truck simulator. And again the crashes in PreScan but if it's just the laptop then using for testing autonomous functions is definitely not a bad idea, although showing the result might require a live demonstration of the scenario or an external camera recording the screen.

For the library, Simulink models created for PreScan presents a huge disadvantage. If you activate driver vehicle dynamics, to create function blocks for controlling your actor in Simulink. Then if you replace that actor with a different vehicle all those control systems will disappear together with all sensors applied. This means that the user has to create them again from scratch. What could be done is to create standardized Simulink blocks that simulates platooning, ACC S&G and so on. So that when you implement a new actor you go to a Simulink library and choose the desired autonomous function.

6 Conclusion

For simulations done by Volvo today there is an existing simulator created by Volvo, the Volvo inhouse simulator. It features more visual effects and is better when it comes to simulating driver experience. But for the pure purpose of testing autonomous functions PreScan is both easier to use and gives a better overview of the simulation.

During the scenario creations several discoveries were made considering the framework. The focus of this library is to have a platform of test scenarios for each system and it is also the systems that mostly determines the design of the scenario in terms of environment and created situations. On the other hand vehicle dynamics such as truck models and axle setups did not add any extra requirements on the scenario since all vehicles can face the same difficulties in traffic. However truck-trailer-combinations have given one environmental demand, in order to make the scenario suitable for any vehicle setup the turning radius cannot be too small.

It can also conclude that most of the functions require specific scenarios to test certain details of the function. Although some of the systems are very similar and was categorized into groups, this is discussed in chapter 5.1.

PreScan also gave some limitations for what could be done. First of, the limitation for user imported vehicles when hauling trailers. To have the articulation work on the vehicle combinations and not just to be seen as one straight block, the simulation had to be run from Simulink. Which is considerably more time consuming compared to just running the scenario directly from the PreScan GUI. Also for user imported vehicles the dynamics sometimes fails when driving trough a curve so for articulated vehicle combinations using original PreScan vehicles is recommended.
Another limitation without the usage of Simulink models is that it is not possible to reverse the vehicles. You cannot just follow a trajectory in order to go in reverse the vehicle dynamic must be activated and a user designed driver model- or driver-in-the-loop is necessary.
When investigating if there can be any preparation done in Simulink in order for easier system implementations, a limitation for a PreScan library was discovered. Most users using the library will remove the ego vehicle and change it into another vehicle. When this happens every Simulink block created for the ego vehicle will disappear and for that reason creations in Simulink are useless.

In order for the library to be useful various efforts was made. To make the library small and focused closely related systems share the same scenarios while systems with special requirements like Platooning and VRU have their own. To enhance the overview and make it more user friendly flowcharts where created with links to the more describing Use-cases. As well as a with a link to a short movie or picture showing the scenario running in PreScan. To simplify it's usage even more a manual has been created in order to help the first time users. The manual expects that the user knows the purpose of the library and have some primal knowledge in PreScan and Simulink.

PreScan is a system developed for the usage of testing sensors and autonomous systems. In difference to the previous simulation tool used by VDAS PreScan increases the possibility's of simulations that can be run and it can also reduces work hours because of a simpler GUI. The library with the help documents added can increase the usability of PreScan with the possible advantage of faster development of systems and less traveling and time spend on the test track.

Looking at the bigger picture some of the vehicle systems discussed in this work can when implemented into real traffic inflict a major change in terms of fuel usage, vehicle emission and a reduced wounds/death ratio. In order for these benefits to come true system developers and legislators has to come together and create laws to clarify what is allowed and who will be responsible.

7

Future Work

Looking at the discussion and conclusion we give the following recommendations to optimize the usage and user friendliness of this library.

To be as useful as possible keep the library scenarios and categories updated to match the need of latest functions and systems.

Create a Simulink library to simplify the data output of sensors and Simulink block for simple functions that will be used repeatedly in scenarios.

Use better hardware in order for the simulations to be faster and smother.

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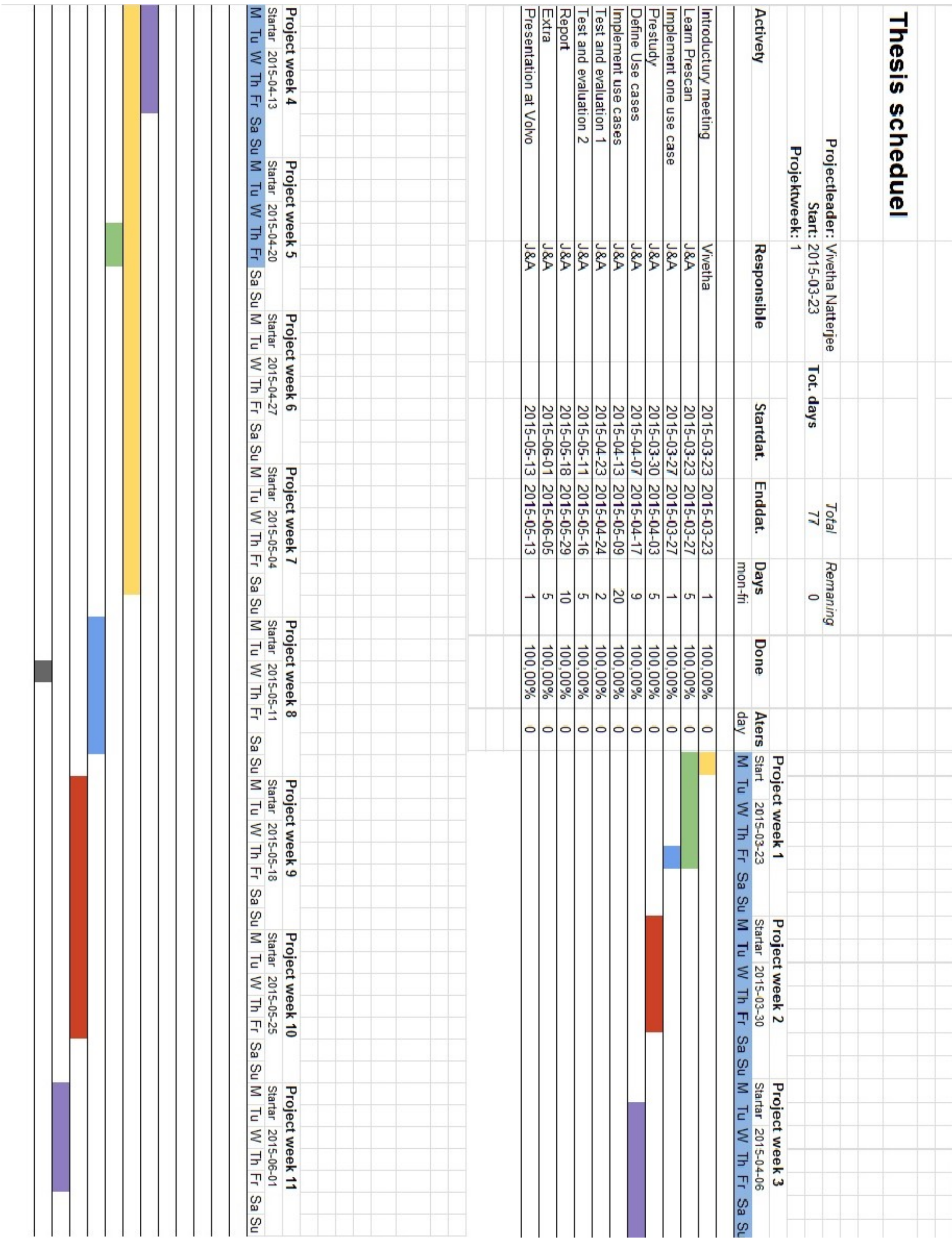
A

Appendix A Schedule



B

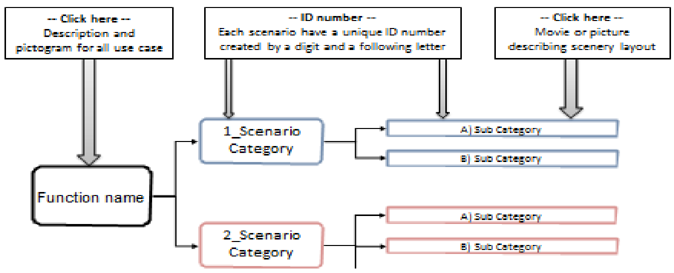
Appendix B Manual

Manual

Volvo GTT's PreScan Library for Autonomous Functions, Development and Testing

By Andreas Nilsson & Jakob Fredriksson

This library includes traffic scenarios for AEBS, ACC, S&G, C-ACC, Parking Load/Unload, Platooning, Queue Support and VRU. For every autonomous function there is a flow chart and you must note that the links from the flowcharts only work while in reading or slide show mode.



To find the scenario you want to use just follow these 4 steps:

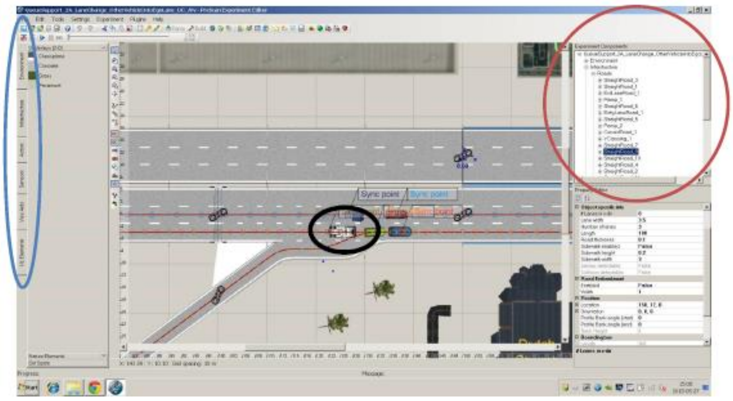
1. Run the Flow chart in presentation mode, links from the function name opens an excel document with a short description and a pictogram.

2. The link from the Sub Category gives a short movie or picture showing the main event.

3. After you have found your scenario open up the PreScan GUI, open experiment and go to the PreScan library.

4. The PreScan library consists of folders with the function name and subfolders. To find your scenario choose the subfolder with the names from the flow chart Function_ID_Scenario_SubCategory and double click on the .pex file.

The scenario will open up and your screen will look something like this to keep the library intact please resave the experiment into a location of your choice.

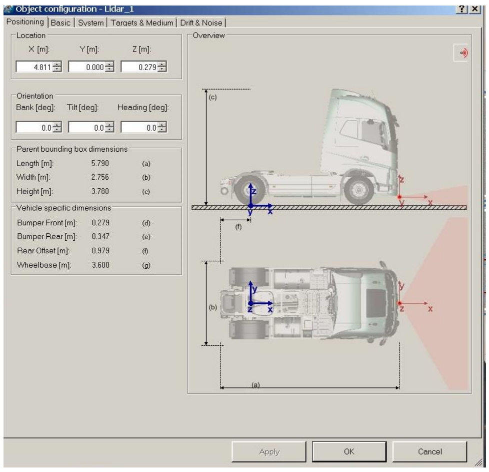


To the right (red circle) you find a list of all components in the current scenario and below is a simple modification window.

The menu to the left (blue circle) contains everything you need for your scenario sensors, actors and infrastructure. If you want to add something to the scenario simply drag something from the menu and drop it where you want it.

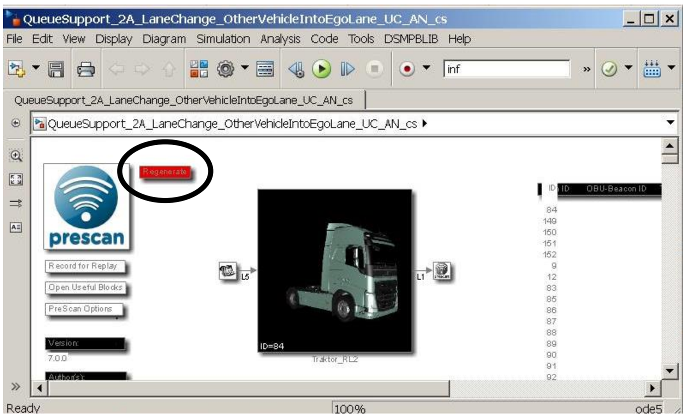
Remove the Green Tractor_4X2T_VN (black circle) and replace it with the vehicle setup that you want to test.

Drag the sensors you need and drop them onto your actor, a window will pop up with a picture of the actor so that you can position the sensor where you want it to be.

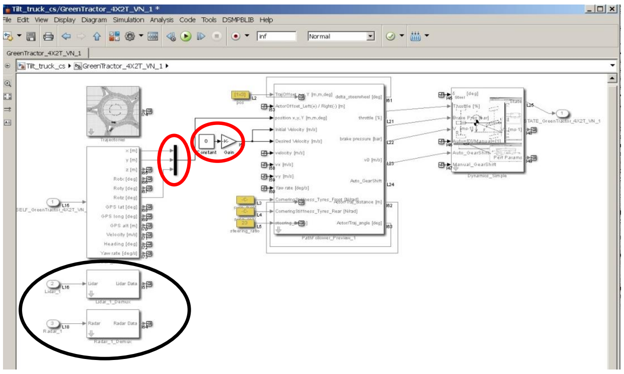


After you've applied all the necessary sensors find the actor in the component list and right click it, open Object Configuration, Dynamics and activate 2D Simple and then go to Driver Model and activate PathFollower (Steering-Automatic Shift) press ok and Build. This gives the ability to override the predefined trajectories in Simulink.

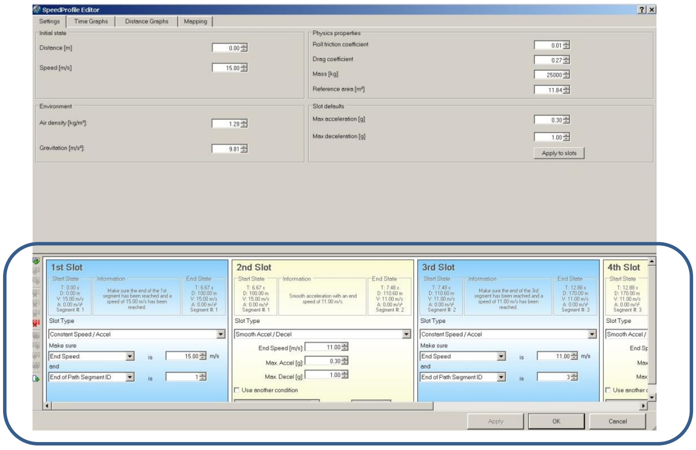
Press the Invoke Simulink Run Mode in the center of the top menu this will start Matlab. In the folders to the left choose the Function_ID_Scenario_SubCategory.mdl file, this will give you a Simulink model for all actors in that scenario.



Press the red regenerate button and then double tap on the actor you want to control a new window will open up. This window will include a Simulink model for the actor and one for every sensor.



If the 2D simple was activated you can now make the vehicle behave as you wish it to do. But a standard feedback connecting x,y and Rotz to position x,y,Y and an initial velocity is recommended (red rings). The black ring contains all sensors connected to the actor and if you connect additional sensors they will appear in a line below the ones marked.



If you want to change the velocity and acceleration of an actor without using Simulink you can use the built in function for speed profiles. Top left you can adjust the starting state of the actor, speed and offset along the set trajectory.

You can also add slots to create dummy actors following the exact same speed profile for every test run (blue rectangle). Acceleration, deceleration and desired speed are set along a given trajectory and changes in speed can be done at a given distance, time or segment ID.

C

Appendix C Interview Per

Interview with Per Nordqvist Volvo GTT ATR DEHF (driver environment human factors) Volvo in-house driving simulator

- Why did Volvo decide upon creating their own simulator?

  It is originally a thesis work, 15 years ago. It was created when Volvo cars & trucks belonged to the same company, mostly for the purpose of evaluating new HMI ideas for drivers. The technology used in the simulator is similar to other simulators in the vis-sim industry.

- Where would you like the simulator to be and where would you like it to go?

  Broaden it for the use of Penta, Construction and Busses making it a globally known resource for the entire Volvo concern. Today, Volvo is not very good at housing & marketing internal software products. So every department tends to create their own local simulations & solutions, either by own development or buying from external suppliers. A joint effort would be more effective.

- Is it possible to use it for simulating Autonomous functions?

  Yes it is possible to use sensors to create robot functions. You can also connect external robots functions such as Simulink models and it is a fairly simple process. Force feedback is available for both steering wheel and pedals.

- Robot functions for lateral and longitudinal steering are they easy to implement or is it even possible?

  Both lat and long exists, see previous question.

- What type of sensors can you equip your truck with and how accurate are they? Have you done any tests for verification?
  Ground truth sensors: LIDAR, radar, cameras and line detection cameras exist. Tho this data you can add delay, noise etc. Also we have done HIL tests where a real camera was connected reading line detections from a simulated road projection including fog and snow. We can save a log, replay it to re run the exact same path under different whether conditions.

- Can you implement V2X communication?

  Yes both in real-time through direct (fake) commands with syntetic delays or more realistic in sync with another simulator called NS-2 (the "standard" network simulator). The latter is not in real time.

- Is it easy to include objects like fences and hedges for object occlusion and vehicles that can disrupt, brake in front of the truck or intersect?

Occlusion has not yet been implemented. However, controlling vehicles in advanced ways is a very fundamental function of this simulator. This includes lat/long control, depending on many conditions such as time, position, speed, our position etc.

- Infrastructure, is it easy to change road layouts width, length and radiuses?

  We have a tool to create new environment's but after they have been created you cannot change them easily.

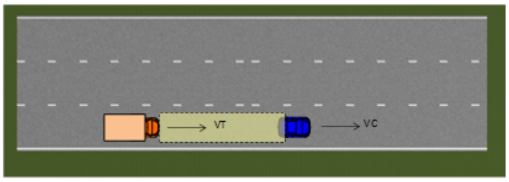
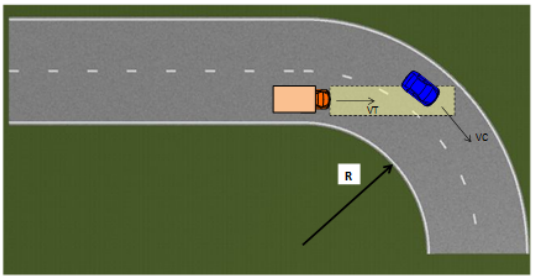
D

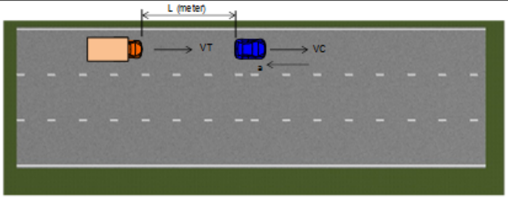
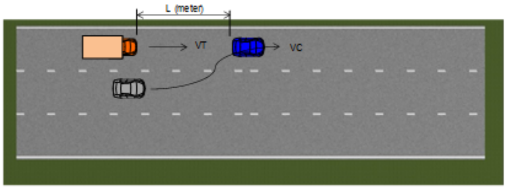
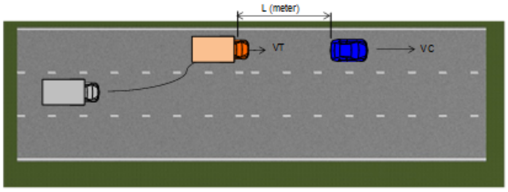
Appendix D Use-Cases

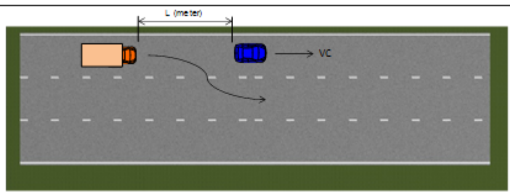
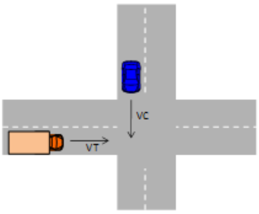
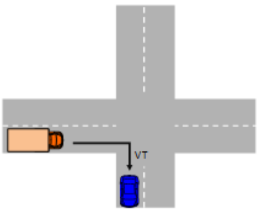
D.1 AEBS

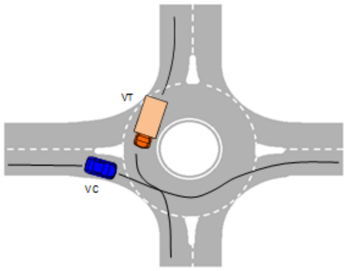
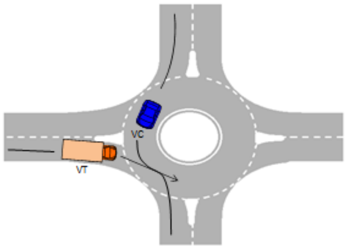
Test Scenarios AEBS

V = Velocity
T = Truck
C = Car
RL = Right lane
ML = Middle lane
LL = Left lane

Test case ID	Function title	Test	Expected result
1A Truck Approach Car Same Lane Straight Road		Ego vehicle approach a car. a) A stationary vehicle: VC = 0 b) A moving vehicle: VT > VC	a) Robot function warns driver and CU-criterion stops the truck before the car for every test run. b) Robot function warns driver and CU-criterion stops the truck before the car for every test run.
1B Truck Approach Car Different Lane Curved Road		Truck can detect car in a different lane. a) A stationary vehicle: VC = 0 b) A moving vehicle VT > VC	a) Robot function ignores vehicle. b) Robot function ignores vehicle.

1C Truck Approach Car Vehicle in Front Brakes		Initially truck follows vehicle at the same speed on the distance of L meters. The vehicle breaks and the deceleration is a.	Robot function warns driver and CU-criterion stops the truck before the car for every test run.
2A Lane change Vehicle Enters into Ego Lane		L is the distance for when the lane change is executed. a) Car change lane in front of the truck VC > VT b) Car change lane and tuck needs to decelerate VC < VT	a) Robot function ignores vehicle. b) Robot function warns driver and CU-criterion stops the truck before the car for every test run.
2B Lane Change Ego Vehicle, Car Ahead		L is the distance for when the lane change is executed. a) Car change lane in front of the truck VC > VT b) Car change lane and tuck needs to decelerate VC < VT	Robot function warns driver and CU-criterion stops the truck before the car for every test run.

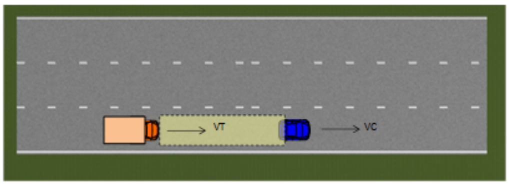
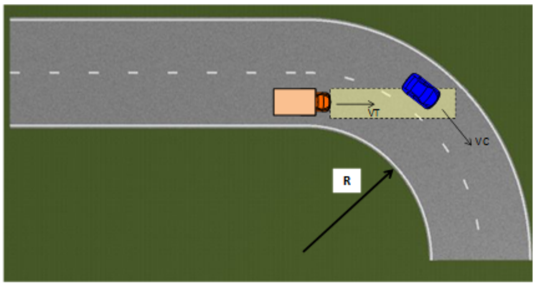
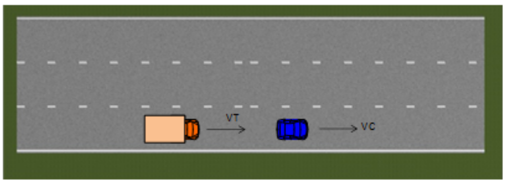
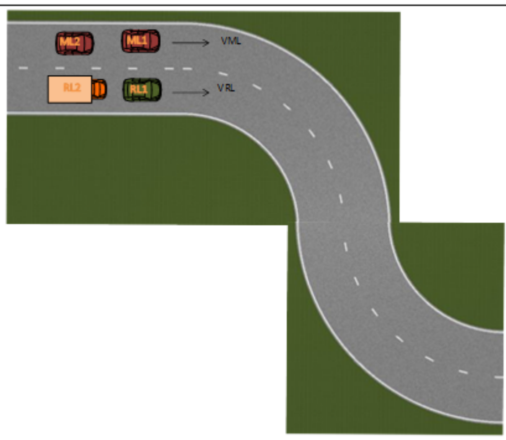
2C Lane Change Overtakes Vehicle		L is the distance for when the lane change is executed. VT > VC	Robot function ignores vehicle.
3A Intersection Vehicle Crosses Road		a) Car passes across thought trail route before truck reaches. b) Car and truck potential reach intersection point at the same time.	a) Robot function ignores vehicle. b) Robot function warns driver and CU-criterion stops the truck before the car for every test run.
3B Intersection Ego Vehicle Turn, Approach Stationary Car		Truck turns in an intersection and approaches a stationary vehicle.	Robot function warns driver and CU-criterion stops the truck before the car for every test run.

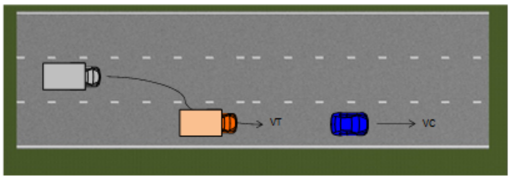
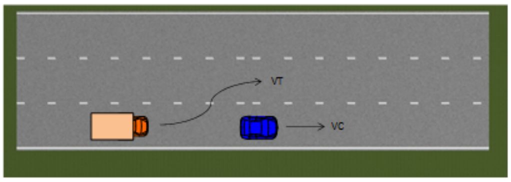
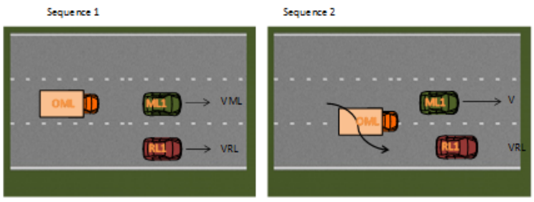
4A Roundabout Vehicle Enters in Front		a) Car stops and let the truck pass, VC end = 0 b) Car enters and just in front of the truck. c) Car passes across thought trail route before truck reaches.	a) Robot function ignores vehicle. b) Robot function warns driver and CU-criterion stops the truck before the car for every test run. c) Robot function ignores vehicle.
4B Roundabout Ego Vehicle Enter		Truck driver do not notice the car from left when enter the roundabout.	Robot function warns driver and CU-criterion stops the truck before the car for every test run.

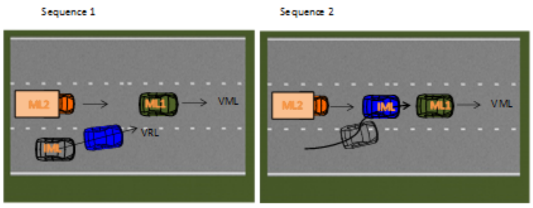
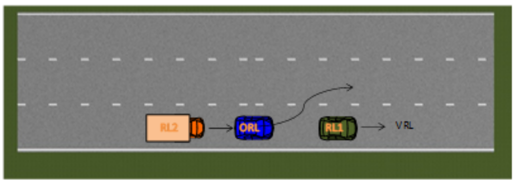
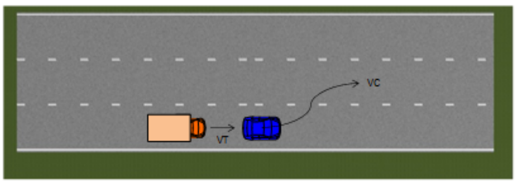
D.2 CC ACC ACCS&G CACC

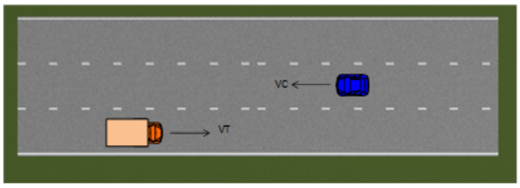
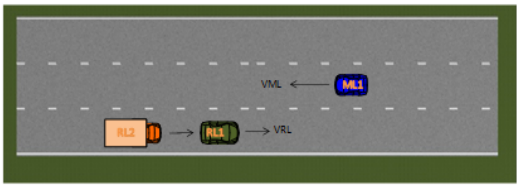
Test Scenarios CC, ACC, ACC S&G and CACC.

V = Velocity
T = Truck
C = Car
RL = Right lane
ML = Middle lane
LL = Left lane
I = Into
O = Out from

Test case ID	Function title	Test	Expected result
1A Truck Approach Car Same Lane Straight Road		Ego vehicle approach a vehicle. VT is desired CC speed. a) A stationary vehicle: VC = 0 b) A moving vehicle VT > VC:	a) Robot function slow down and warns driver or avoid a collision. b) Robot function slow down and warns driver or avoid a collision.
1B Truck Approach Car Different Lane Curved Road		Truck can detect car in a different lane. VT is desired CC speed. a) A stationary vehicle: VC = 0 b) A moving vehicle VT > VC:	a) Robot function ignores vehicle. b) Robot function ignores vehicle.
2A Alternating Speed Stop&Go Straight Road		Speed can alternate from highway speed to stand still.	Robot function adapts speed and distance to the vehicle ahead.
2B Alternating Speed Stop&Go Curved Road		Speed can alternate from highway speed to stand still. Every vehicle can have an individual speed profile.	Robot function adapts speed and distance to the vehicle ahead and ignores vehicle in other lane.

3A Lane Chage Ego Vehicle Car Ahead		Ego vehicle change lane and get a new vehicle in front. VT is desired CC speed. VT > VC	Robot function slow down and warns driver or avoid a collision.
3B Lane Chage Ego Vehicle No car ahead		Ego vehicle follows a car and change into an empty lane. CC speed on truck > initial speed.	Robot function follow vehicle and accelerate after lane change.
3C Lane Chage Ego Vehicle New Target		Ego vehicle change lane and get a new vehicle to follow. Every vehicle can have an individual speed profile.	Robot function wait for enough space and then change lane.

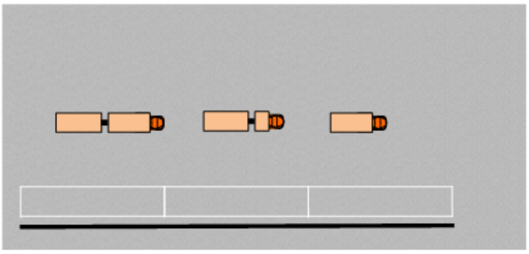
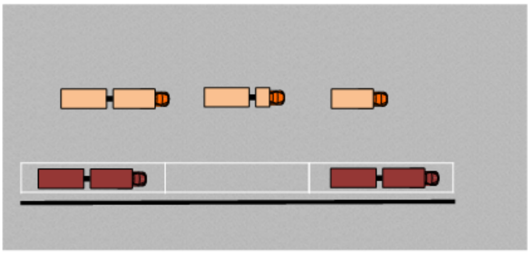
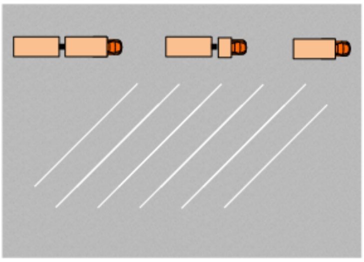
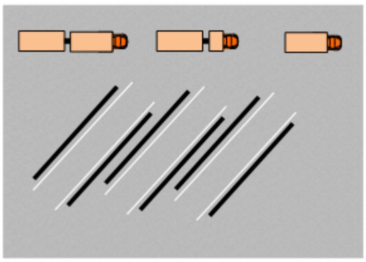
4A Vehicle in Front Changes Lane Into ego lane		Vehicle from another lane change lane into the gap between ego vehicle and the followed vehicle. Every vehicle can have an individual speed profile.	Robot function detect vehicle and adapt speed and distance.
4B Vehicle in Front Changes Lane Away From Ego Lane, Car Ahead		Followed vehicle change lane. A new car in ego lane got visible and can be followed. Every vehicle can have an individual speed profile.	Robot function adapts distance to the new vehicle ahead when safe to do so.
4C Vehicle in Front Changes Lane Away From Ego Lane, No Car Ahead		Followed vehicle change lane and there is no new car ahead to follow. CC speed on th truck > VC	Robot function follow vehicle and accelerate after lane change.

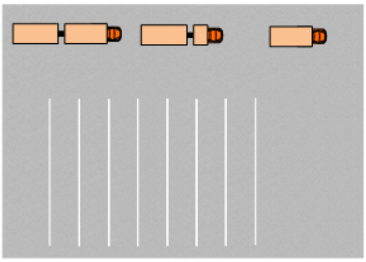
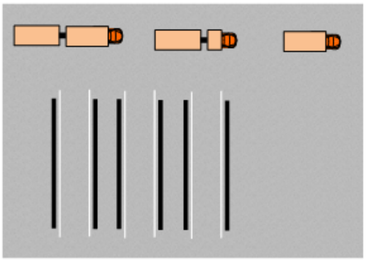
5A Oncoming Car No Car To Follow		An oncoming car.	Robot function ignores oncoming vehicle.
5B Oncoming Car Following Car		Ego vehicle follow a car when an oncoming car approach.	Robot function ignores oncoming vehicle.

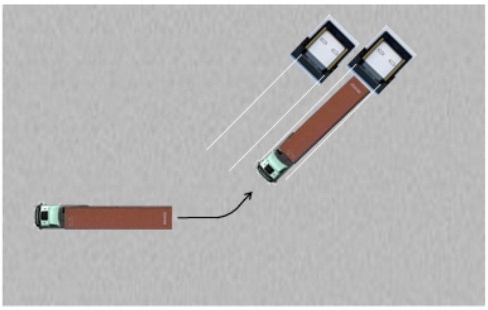
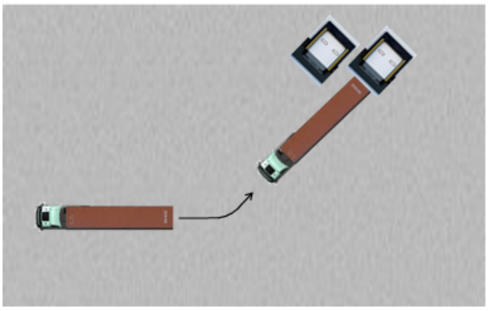
D.3 Parking Load/Unload

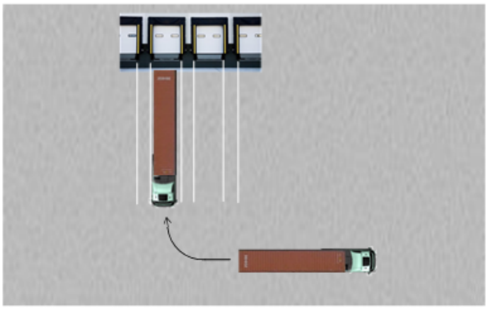
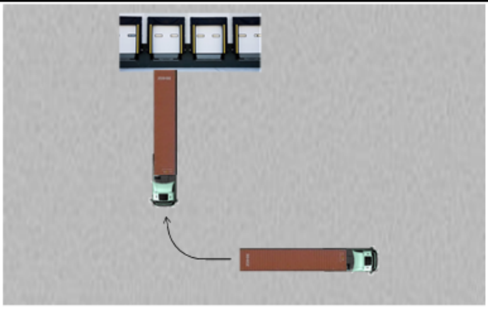
Test Scenarios Parking, Load, Unload

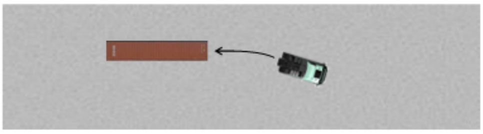
Ego vehicle:

Test case ID	Function title	Test	Expected result
1A Parking Parallel No Obstruction		Find and execute parallel parking.	Robot function finds empty parking space and execute parking.
1B Parking Parallel Confined Space		Find and execute parallel parking.	Robot function finds empty parking space and execute parking.
2A Parking Angled No Obstruction		Find and execute angled parking.	Robot function finds empty parking space and execute parking.
2B Parking Angled Confined Space		Find and execute angled parking. Ego vehicle in PreScan is the blue Mercedes tractor.	Robot function finds empty parking space and execute parking.

3A Parking Perpendicular No Obstruction		Find and execute perpendicular parking.	Robot function finds empty parking space and execute parking.
3B Parking Perpendicular Confined Space		Find and execute perpendicular parking.	Robot function finds empty parking space and execute parking.

4A Loading Dock Angled Line		Truck autonomously docks to loading dock.	Robot function succesfully docks to loading dock for every test run.
4B Loading Dock Angled No line		Truck autonomously docks to loading dock.	Robot function succesfully docks to loading dock for every test run.

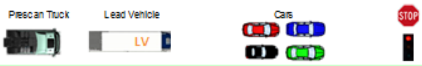
4C Loading Dock Perpendicular Line		Truck autonomously docks to loading dock.	Robot function succesfully docks to loading dock for every test run.
4D Loading Dock Perpendicular No Line		Truck autonomously docks to loading dock.	Robot function succesfully docks to loading dock for every test run.

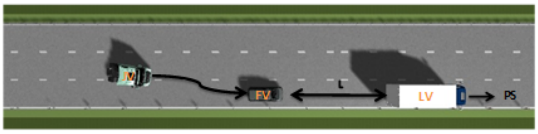
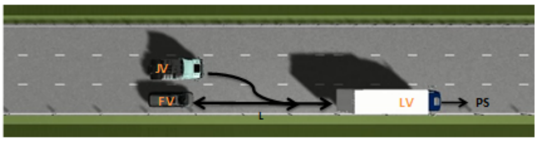
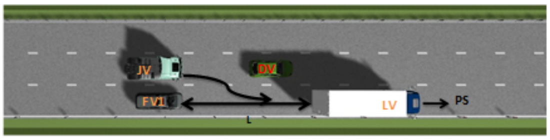
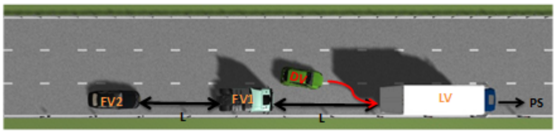
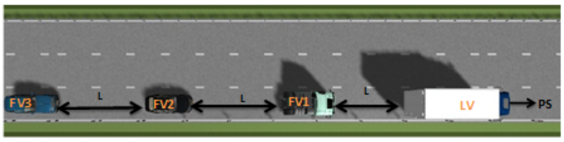
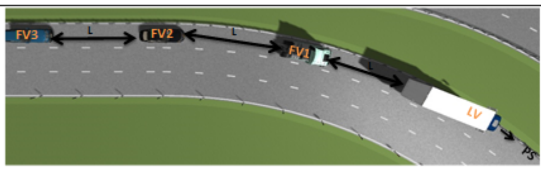
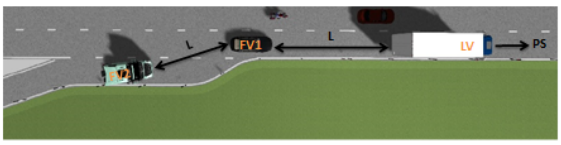
5A Trailer parking Disconnect		Truck disconnects the trailer at a given location (blue X) and then parks itself at a parking slot (red X). Ego vehicle in PreScan is the green tractor as well as the blue Mercedes tractor.	Robot function drives the truck to the designated position disconnects the truck and safely drives to its parking slot.
5B Trailer parking Connect		Truck reverses autonomously to the trailer and connect.	Robot function identifies trailer trough sensors and a given location and succesfully connects for every test run.

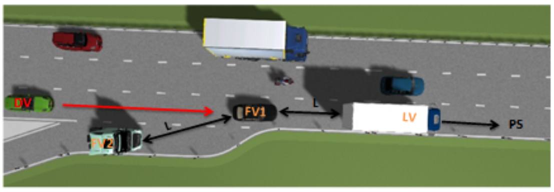
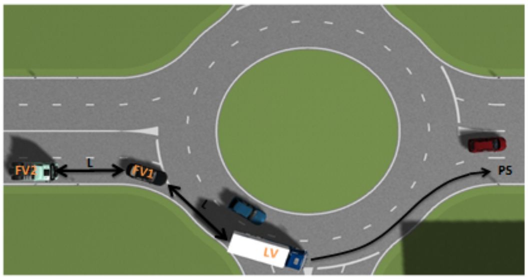
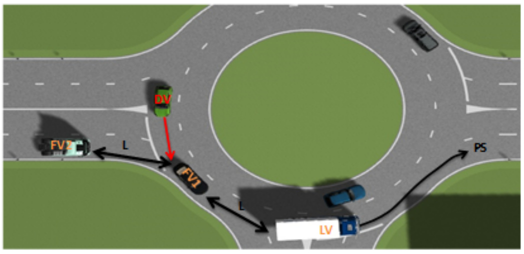
D.4 Platooning

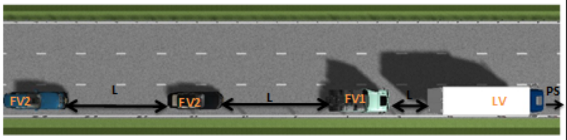
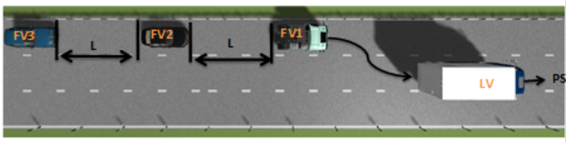
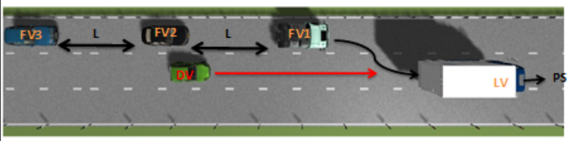
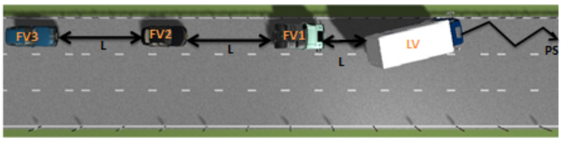
Test Scenarios Platooning

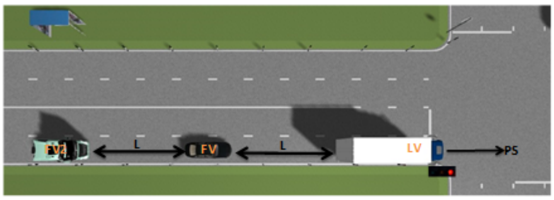
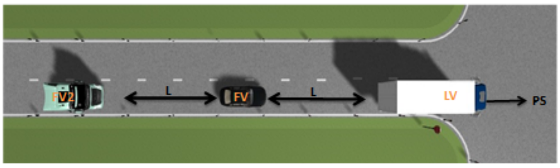
FV –Following vehicle
LV–Lead vehicle
JV–Joining Vehicle
PS–Platoon Speed
DV–Disrupting Vehicle



Test case ID	Function title	Test	Expected result
1A Truck joins Rear		Driver asks for permission to enter the Platoon and when the truck has been given permission to enter it matches speed with the platoon and then autonomously starts following the last vehicle in the platoon. L is the distance (m) between vehicles in the platoon.	Robot system safely implements the truck into the platoon.
1B Truck Joins Midsection, No Disrupt		Driver asks for permission to enter the Platoon and when the truck has been given permission to enter. The truck autonomously adapts it's speed to match the platoon and waits until L is big enough . Truck then slowly enters the platoon and the distance to both the FV and the LV is adjusted.	Robot system safely implements the truck into the platoon.
1C Truck Joins Midsection, Car Disrupts		Truck asks to join the platoon. L is increased but then the green car decelerates and disrupts the maneuver.	Robot system notices that the car is decelerating and aborts implementation of the truck to the platoon. The distance L returns to normal.
2A Foreign Vehicle Straight Road		A platoon consisting of 2 FV's and a LV is driving on a straight road when a foreign vehicle obstructs the platoon.	Robot System notice intersecting car and the FV behind the obstructing vehicle backs up to a safe distance behind the obstructing vehicle.
3A Platooning Straight Road		A platoon consisting of 3 FV's and a LV is driving on a straight road. FV's keep a distance of L meters to the vehicle in front.	Robot system keeps the requested distance L for every test run.
3B Platooning Curve		A platoon consisting of 3 FV's and a LV is driving through a curve. FV's keep a distance of L meters to the vehicle in front.	Robot system keeps the requested distance L for every test run.
3C Platooning Enter Highway , No Disrupt		A platoon consisting of a LV and 2 FV enters a higway.	Robot system safely enters highway for every test run.

3D Platooning Enter Highway , Car Disrupts		A platoon consisting of a LV and 2 FV enters a highway when a car speeds in and disrupts the transfer for the FV.	Robot system sees the car and creates a gap for the disrupting vehicle while keeping the platoon intact and entering the highway.
3E Platooning Enter Round about, No Disrupt		A platoon consisting of a LV and 2 FV's drives through a roundabout.	Robot system safely drives through roundabout for every test run.
3F Platooning Enter Round about, Car Disrupts		A platoon consisting of a LV and 2 FV's drives through a roundabout, before the second FV can enter the roundabout a vehicle place itself in-between FV1 and FV2.	Robot system sees the car and creates a gap for the disrupting vehicle, keeping the platoon intact while driving through the roundabout.

4A Leader Action Stops		A platoon consisting of LV and 3 FV's drive along a straight road when the LV brakes.	Robot system safely reduce the speed of all vehicles in the platoon for every test run The final distance for L is 5m between every vehicle in the platoon.
4B Leader Action Lane Change, No Disrupts		A platoon consisting of LV and 3 FV's travel along a straight road when the LV decides to make a lane change.	Robot system safely make all vehicles in the platoon change lane for every test run.
4C Leader Action Lane Change, Car Disrupts		A platoon consisting of LV and 3 FV's travel along a straight road when the LV decides to make a lane change. Suddenly a foreign car speeds in and disrupts the maneuver for FV1.	Robot system notice and identifies the approaching car then it delays the lane change. FV1 delays the lane change and after the lane change is done it takes a safe distance behind DV.
4D Leader Action Zigzag Driving		A platoon consisting of LV and 2 FV's travel along a straight road when the LV starts driving in a zigzag pattern.	Robot system does not start to self-propagate.

5A FV Has To Stop Red Light		A platoon consisting of a LV and 3 FV's drives through a crossing with a traffic light.	Robot system recognizes the stop sign and makes every Vehicle stop before driving through the crossing.
5B FV Has To Stop Stop Sign		A platoon consisting of a LV and 2 FV's drives through a crossing with a stop sign.	Robot system recognizes the stop sign and makes every vehicle stop befor befor driving through the crossing. It also sees the car and creates a gap for the disrupting vehicle, keeping the platoon intact while waiting for the disrupting vehicle to cross.

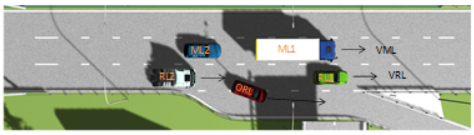
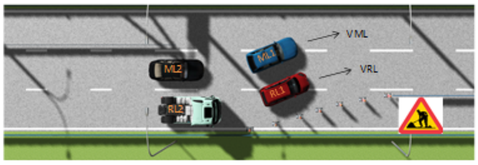
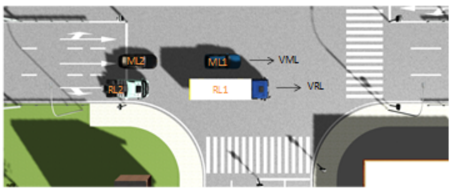
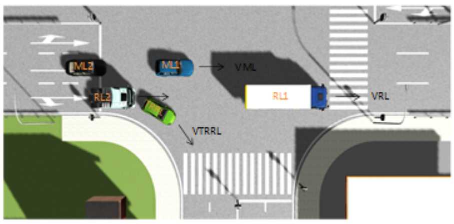
D.5 Queue Support

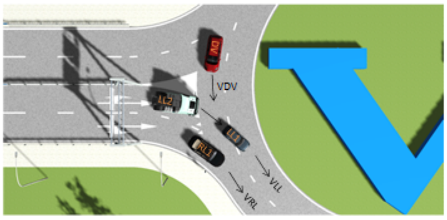
Test Scenarios Queue Support

Ego Vehicle

V = Velocity
RL = Right lane
ML = Middle lane
LL = Left lane

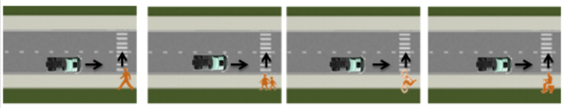
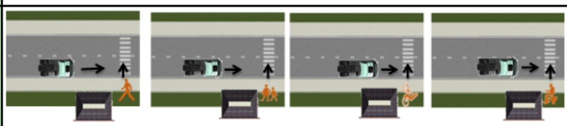
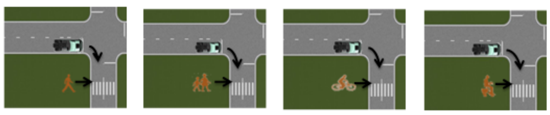
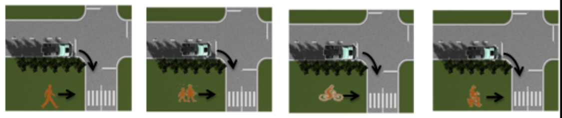
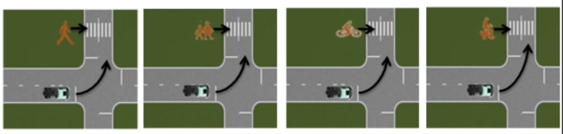
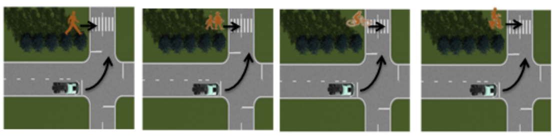
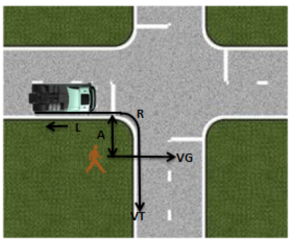
I = Into
O = Out from
TR = Turn right
DV = Disrupting vehicle

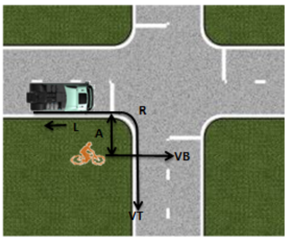
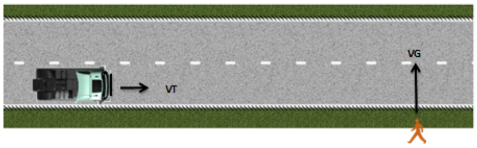
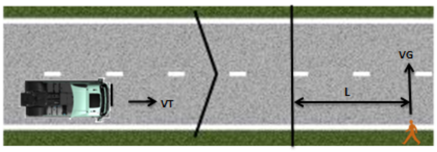
Test case ID	Function title	Test	Expected result
1A Alternating Speed Stop & Go		Speed alternate from stand still to max speed for Queue Support. Every vehicle can have an individual speed profile. Ego vehicle: ML2	Robot function adapts speed and distance to the vehicle ahead.
2A Lane Change Other Vehicle Into Ego Lane		Vehicle IRL makes a tight lane change in front of ego vehicle. Ego vehicle: RL2	Robot function detect vehicle and make space for it.
2B Lane Change Other Vehicle Out From Ego Lane		Vehicle ahead of ego vehicle change lane. CC speed on truck > VRL. Ego vehicle: RL2	Robot function adapts distance to the new vehicle ahead when safe to do so.
2C Lane Change Closed Lane Roadwork		A roadwork forces the traffic to make a lane change. Ego vehicle: RL2	Robot function follow vhicle ahead.
3A Drive Through Intersection Car Ahead Drives Straight		The queue run through an intersection. Every vehicle can have an individual speed profile. Ego vehicle: RL2	Robot function follow vehicle ahead.
3B Drive Through Intersection Car Ahead Turns		The queue run through an intersection and the vehicle ahead of the ego vehicle turns right. VTRRL decrees if necessary before turn. Ego vehicle: RL2	Robot function adapts distance to the new vehicle ahead when safe to do so.

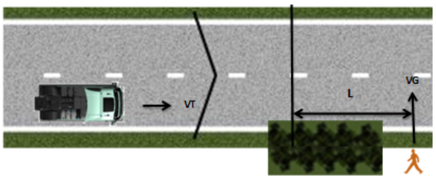
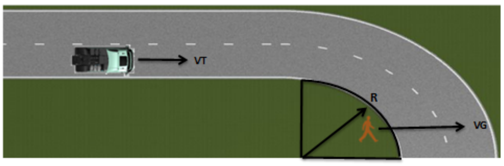
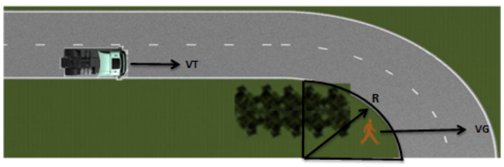
4A Drive through roundabout No Disrupt		The queue runs through a roundabout. Every vehicle can have an individual speed profile. Ego vehicle: RL2	Robot function follow vehicle ahead.
4B Drives Through Roundabout Car Ahead Turns		The queue run through a roundabout and the vehicle ahead of the ego vehicle turns right. Every vehicle can have an individual speed profile. Ego vehicle: RL2	Robot function adapts distance to the new vehicle ahead when safe to do so.
4C Drive Through Roundabout Car Disrupt		The queue run through a roundabout and the trajectory of the ego vehicle intersects by a disrupting car form left already inside the roundabout. Every vehicle can have an individual speed profile. Ego vehicle: RL2	Robot function detect vehicle and let it through.

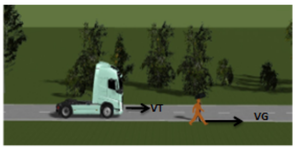
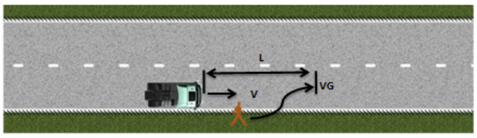
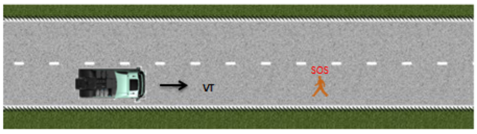
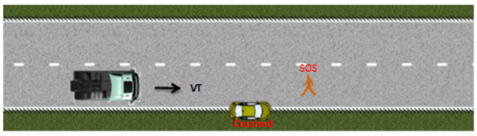
D.6 VRU

Test Scenarios, VRU

Test case ID	Function title	Test	Expected result
1A Crosswalk Straight Road Plain Sight		(LS) VRU speed ranging from 1-10kph. a) Grown male/female cross road b) Children cross road c) Bicycle cross road d) old person cross road	Robot system identifies and classifies VRU then prevents an accident for every test run
1B Crosswalk Straight Road Occluded VRU		(LS) VRU travels with a speed ranging from 1-10kph. Sensor occlusion by an object (house). a) Grown male/female cross road b) Children cross road c) Bicycle cross road d) old person cross road	Robot system identifies and classifies VRU then prevents an accident for every test run
1C Crosswalk Truck Turns Right Plain Sight		(LS) VRU travels with a speed ranging from 1-10kph. Truck turning radius is 10m measuring from the front right wheel. a) Grown male/female cross road b) Children cross road c) Bicycle cross road d) old person cross road	Robot system identifies and classifies VRU then prevents an accident for every test run
1D Crosswalk Truck Turns Right Occluded VRU		(LS) VRU travels with a speed ranging from 1-10kph. Truck turning radius is 10m measuring from the front right wheel sensor occlusion by an object (Wall). a) Grown male/female cross road b) Children cross road c) Bicycle cross road d) old person cross road	Robot system identifies and classifies VRU then prevents an accident for every test run
1E Crosswalk Truck Turns Left Plain Sight		(LS) VRU speed ranging from 1-10kph. Truck turning radius is 10m measuring from the front left whee. a) Grown male/female cross road b) Children cross road c) Bicycle cross road d) old person cross road	Robot system identifies and classifies VRU then prevents an accident for every test run
1F Crosswalk Truck Turns Left Occluded VRU		(LS) VRU travels with a speed ranging from 1-10kph. Truck turning radius is 10m measuring from the front left wheel sensor occlusion by an object (Wall). a) Grown male/female cross road b) Children cross road c) Bicycle cross road d) old person cross road	Robot system identifies and classifies VRU then prevents an accident for every test run
2A Crosses Road Low Speed Truck Turns Right Adult		(LS) Ego vehicle drives along the road and turns right in a crossing, turning with a radius R. A human crosses the road at speeds ranging from 10-20km/h. A is the lateral distance to the truck. L is the distance from the front of the truck to VRU impact.	Robot system identifies bicycle and the truck brakes before an accident occurs.

2B Crosses Road Low Speed Truck Turns Right Bicycle		(LS) Ego vehicle drives along the road and turns right in a crossing, turning with a radius R. A bicycle crosses the road at speeds ranging from 10-20km/h. A is the lateral distance to the truck. L is the distance from the front of the truck to VRU impact.	Robot system identifies bicycle and the truck brakes before an accident occurs.
3A Crosses Road High Speed Straight Road Plain Sight		(HS) Animal or human speeds (6-10kph) across the road.	Robot system identifies VRU and avoides accident for every test run
3B Crosses Road High Speed Hill Plain Sight		(HS) Animal or human speeds (10kph) across the road just beyond the crest of a hill L meters in front.	Robot system identifies VRU and avoides accident for every test run

3C Crosses Road High Speed Hill Occluded VRU		(HS) Animal or human occluded by trees speeds (10kph) across the road just beyond the crest of a hill L meters in front.	Robot system identifies VRU and avoides accident for every test run
3D Crosses Road High Speed Curve Plain Sight		(HS) Animal or human speeds (10kph) across the curved road , radius R	Robot system identifies VRU and avoides accident for every test run
3E Crosses Road High Speed Curve Occluded VRU		(HS) Animal or human occluded by trees speeds (10kph) across the curved road , radius R.	Robot system identifies VRU and avoides accident for every test run

4A On The Road VRU Walking along The Roadside		(HS) a) Grown male/female walks besides the road b) Bicycle travels along the road side	Robot system identifies and classifies VRU for every test run.
4B On The Road VRU Stumbles Onto The Road		(HS) Do tests for different VT. a) Grown male/female walks besides the road and falls into the street L meter in front of the truck. b) Bicycle travels along the road side and crashes into the road L meter in front of the truck.	Robot system identifies and classifies VRU and executes evasive manuver for every test run.
4C On The Road Injured VRU		(HS) Truck drives towards an injured VRU.	Robot function identifies VRU and avoids an accident for every test run.
4D On The Road Car Accident		(HS) Truck drives towards an injured VRU.	Robot function identifies both VRU and car then avoids an accident for every test run.