TestWare Package UNECE ADAS

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1 Commissioning

To have a short overview about the implementation of the UNECE ADAS test protocols in CarMaker you can use the predefined vehicle controller and the DemoCar.

All TestRuns, Tcl scripts, etc. are based on the predefined CarMaker vehicle controller and on the dimensions of the DemoCar (VW Beetle). Changing one of these settings requires some adaptation of the TestRuns, scripts, etc. The necessary steps for the commissioning are described in the sections 1.2 - 1.4.

1.1 Quick Start

Extract the zipped folder *TW_UNECE_ADAS_v1.0_CM_XXX.zip* or *TW_UNECE_ADAS_v1.0_CM_XXX.tgz* in the project folder (XXX representing the respective CarMaker version). For various files a message will pop up, that the file already exists. Overwrite the existing files with the new ones. If CarMaker is open you need to restart the application to activate the AddOn.

1.1.1 TestWare Package ALKS

Load the predefined TestSeries ALKS_template.ts or ELKS_template.ts that is located in *Data/TestRun/TestWare/ALKS or ELKS* (see Figure 1).

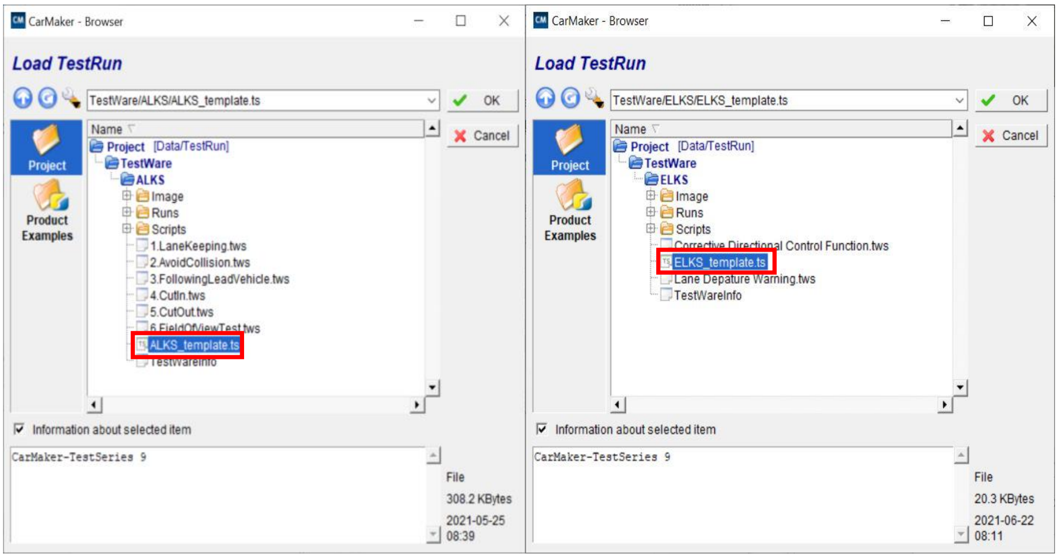

Figure 1 Load TestSeries ALKS_template.ts or ELKS_template.ts

Double click on the test configuration item named ALKS or ELKS (marked in Figure 1) to open the Test Configurator window (Figure 2).

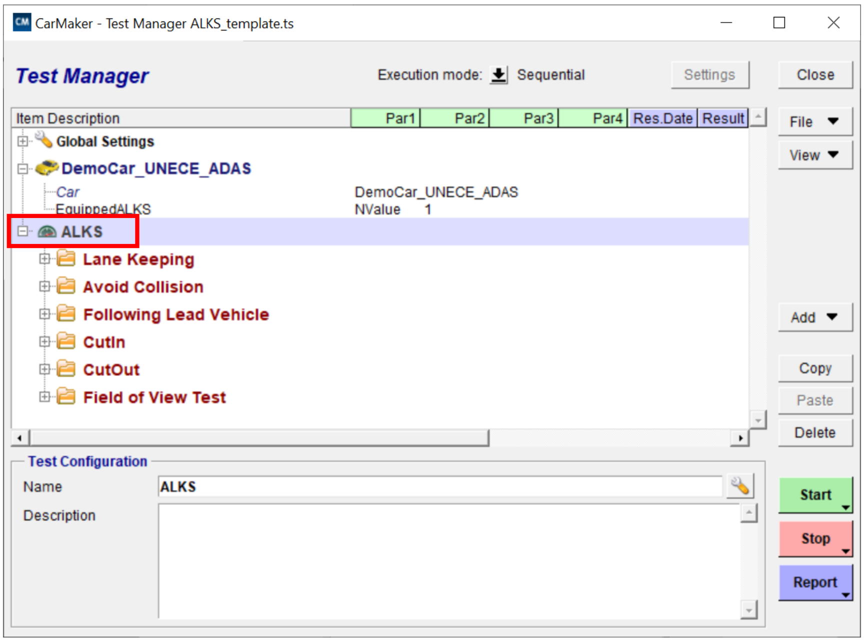

Figure 2 - TestSeries *ALKS_template.ts*

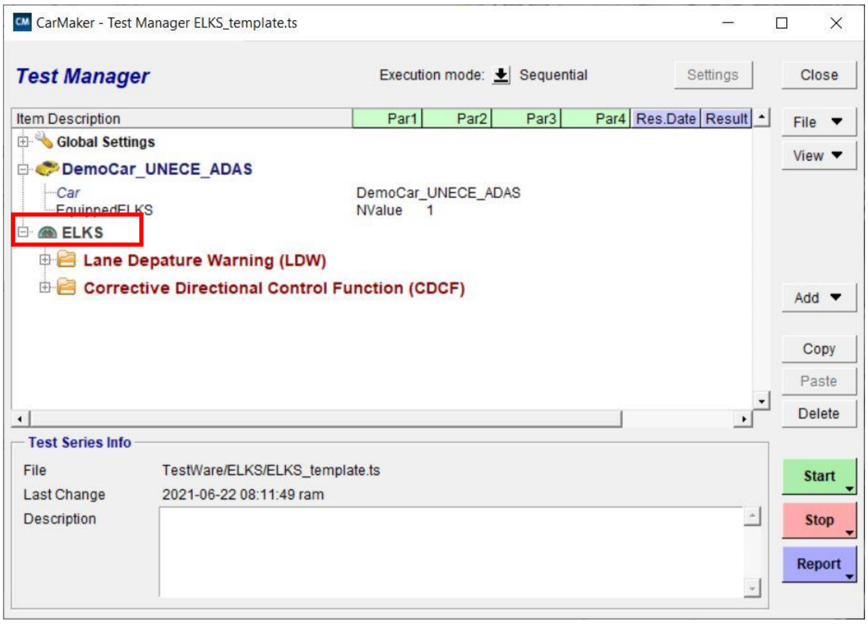

Figure 3 TestSeries ELKS_template.ts

ALKS:

After the selection of the TestWare package ALKS, click on *File -> Open* to open the *Load Parameter Settings* window (see Figure 6). Select the *example_config.cmtwp* file. This file sets some predefined parameter filters .This is important in order to combine the parameters in a correct and meaningful way in some tests. More information about this procedure can be found in chapter 1.5.1.

The user must always load the file when he opens the test configurator, as the settings contained in the file are no longer loaded when the file is opened again.

After that the user can select the tests by clicking on the checkbox (Figure 4). After clicking on the OK button the chosen tests are implemented into the Test Manager and the TestSeries can be started (see Figure 7). After all tests are performed, you can generate a test report to get an overview about all characteristics and criteria.

ELKS:

After the selection of the TestWare package ELKS the user can select the tests by clicking on the checkbox (Figure 5). After clicking on the OK button the chosen tests are implemented into the Test Manager and the TestSeries can be started (see Figure 8). After all tests are performed, you can generate a test report to get an overview about all characteristics and criteria.

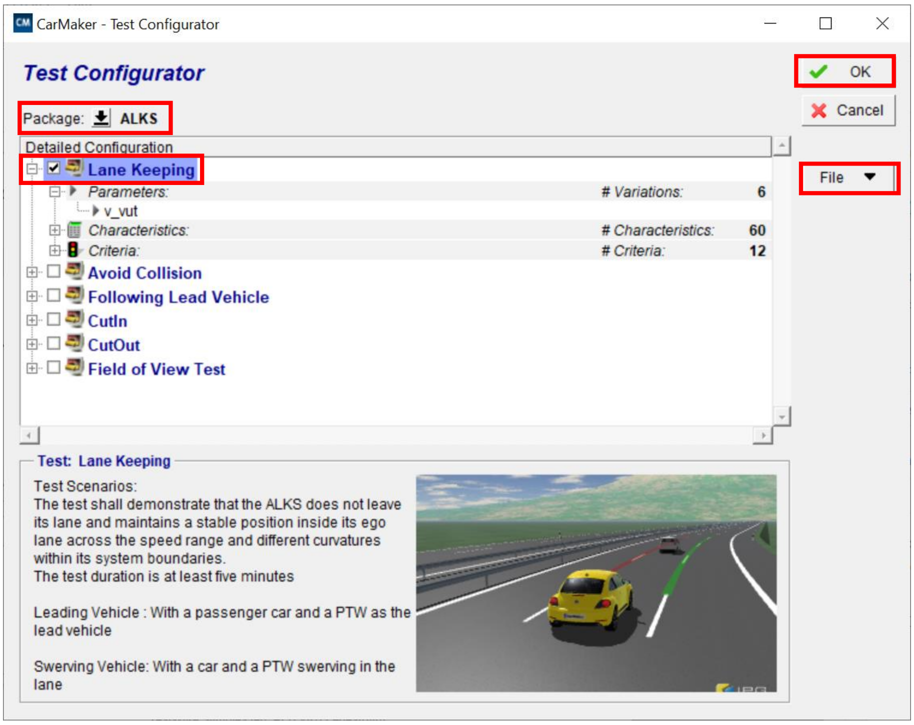

Figure 4 - Selection of TestWare Package ALKS & TestWare Samples (eg. Lane Keeping)

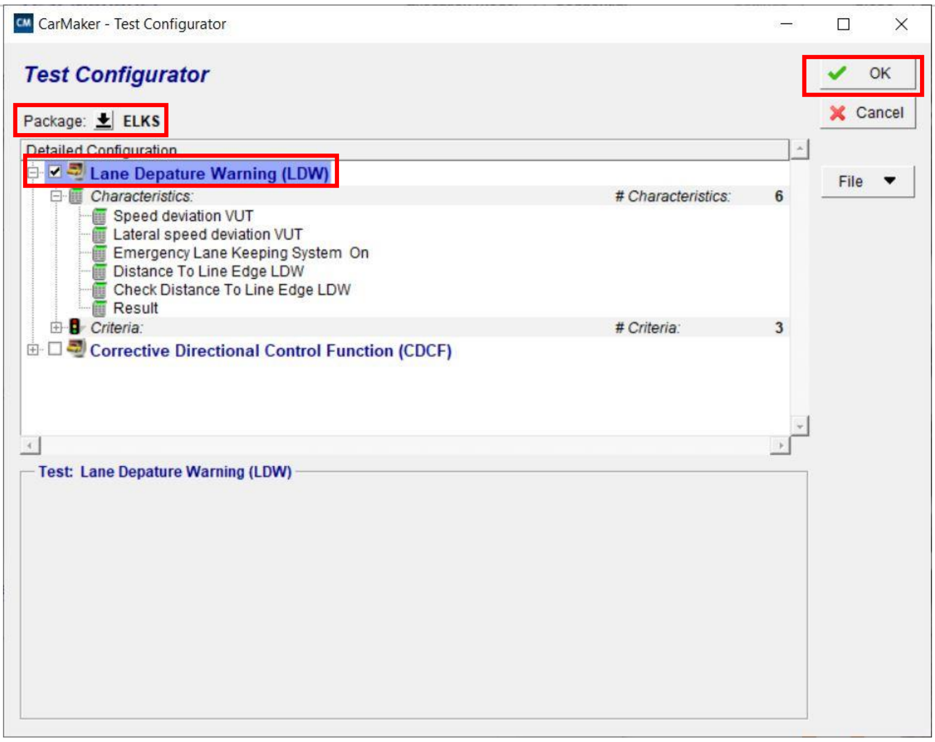

Figure 5 - Selection of TestWare Package ELKS & TestWare Samples (eg. Lane Depature Warning)

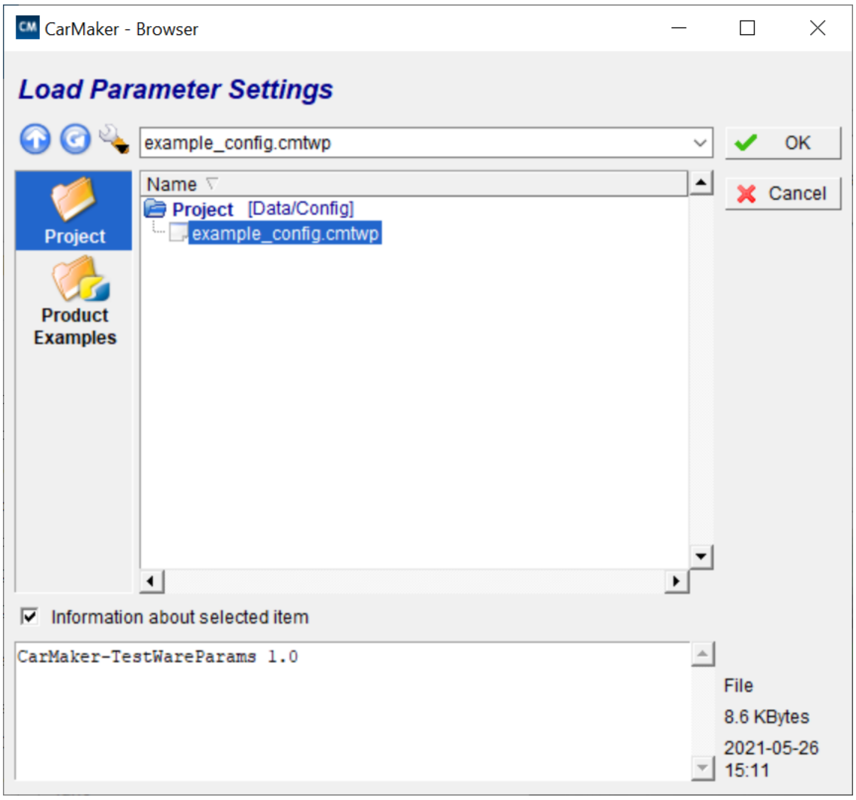

Figure 6: Load Parameter Settings

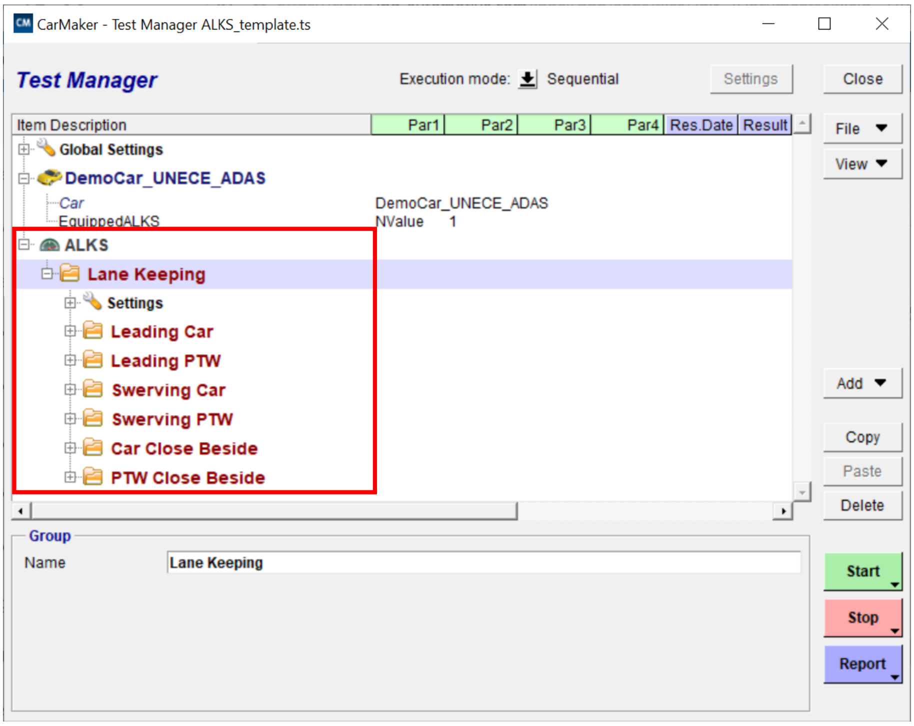

Figure 7 - Implemented ALKS – Lane Keeping test

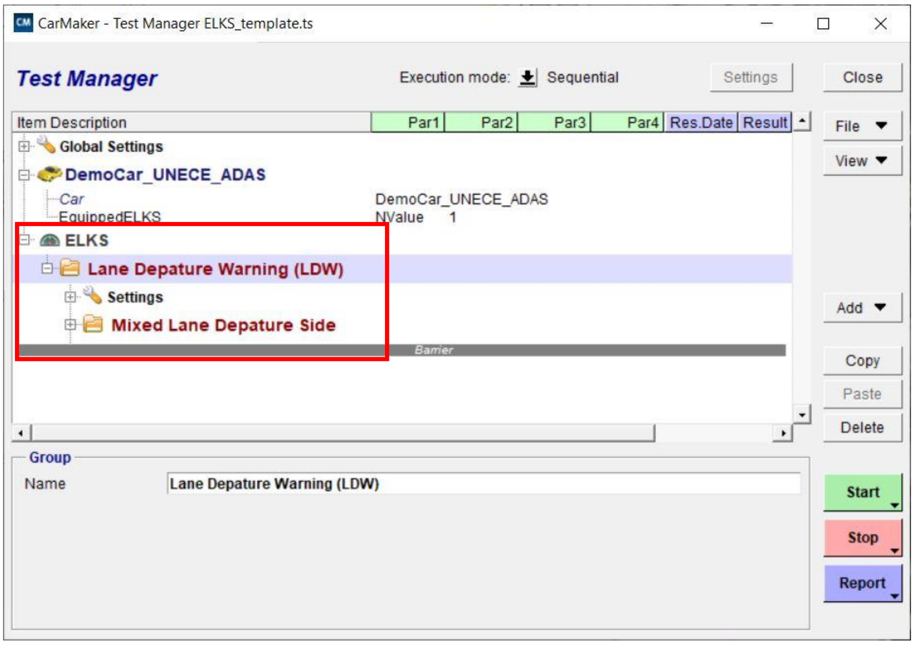

Figure 8 - Implemented ELKS – Lane Depature Warning test

1.2 Vehicle

The exact execution and evaluation of some tests depends on the vehicle width and length. Therefore the vehicle width is calculated either using the parameter *Vehicle.OuterSkin* or using the position of the wheel carriers and the width of the unloaded wheels. If the largest lateral component of the defined parameter *Vehicle.OuterSkin* is bigger than the most outer position of the wheels, the vehicle width is calculated using the parameter *Vehicle.OuterSkin*, and otherwise the outermost position of the wheels and an estimated offset of 0.025 m for each side are used for the calculation.

Note: If you want to change the value of the offset, go to *Data/TestRun/TestWare/ALKS*, open the package folder. Then, go to the subfolder Scripts/ and look for a tcl script, named ALKS.tcl. Search for the following line of code and change the parameter WhlOffset.

```
set WhlOffset 0.025
```

For the vehicle length the x coordinate of the *Front upper right point* of parameter *Vehicle.OuterSkin* is taken into account.

If another car than the DemoCar should be tested, select the other car using the *Vehicle Configuration* item and perform the following steps carefully.

Since no example ALKS controller has yet been implemented in CarMaker, the DemoCar_UNECE_ADAS was equipped with the following controllers.

- Generic Longitudinal Control (Automatic Emergency Braking (AEB))
- Generic Lateral Control
- Acceleration Control + ACC

For the ELKS these controllers are used aswell.

1.3 Signal Mapping

The entire TestWare package can be used for different test environments, e.g. MIL, SIL or HIL, without high effort of renaming or changing parameters. All TestRuns contain NamedValues, which are mapped to the corresponding signals of the model during the start procedure of the TestRun.

The default setting is the usage of the CarMaker driver assistance systems. Adjust the name of the signals to be mapped in the SignalMapping infofile to your needs.

The mapping is based on an infofile named *SignalMapping*. This file consists of all required keys used for the name of the NamedValues which were implemented in the TestRuns. The value for each key shall be the name of the corresponding signal of the user-specific signals according to the systems under test.

Pay attention that the names of the signals are only mapped, if the defined conditions in the mini maneuver can't be used, for example other values are expected by the system under test. Those conditions have to be adapted too.

The *SimParameters* file contains the corresponding key to select the user-specific SignalMapping infofile.

SignalMapping = Path

This key holds the path to the SignalMapping infofile.

Default: Path = *Data/Config/SignalMapping_UNECE_ADAS*

Example: SignalMapping = C:/CMProjects/UNECE_ADAS/Data/Config/SignalMapping_UNECE_ADAS

1.3.1 Configuration File

Header information

FileIdent = CarMaker-SignalMapping Ver

Identifies the Infofile as SignalMapping parameters file of version Ver. Currently supported value for Ver is only 1.

Configuration parameters

NamedValueName = *SignalName*

Used for mapping the user-specific signal to NValues implemented in TestRun infofiles. NamedValue *NamedValueName* is set to *SignalName*.

Example: AEB_SwitchedOn = LongCtrl.AEB.SwitchedOn

An overview about all mapped signals and the expected values meaning those values are used in the TestRuns to realize or detected the mentioned action can be found below:

Table 1 - Overview of mapped signals

NValue_Name	Description	Unit	Expected Value
ALKS_AEB_SwitchedOn	Main switch of the AEB system	-	On = 1 Off = 0
ALKS_LatCtrl_SwitchedOn	Main switch of the LatCtrl system	s	On = 1 Off = 0
ALKS_LongCtrl_IsActive	Indicator that LongCtrl (ACC) system is active	-	inactive = 0 active > 0
ALKS_AEB_IsActive	Indicator that AEB system is active	-	inactive = 0 active > 0
ALKS_LongCtrl_Time2Collision	Time to collision with the target vehicle (ACC system)	s	s
ALKS_LongCtrl_Desired_Dist		m	-
ALKS_LongCtrl_MinDist	Value of minmal distant to traffic Object	m	
ALKS_LongCtrl_MinSpd	Value of minimal speed	- kph	>0
ALKS_LongCtrl_MaxSpdt	Value of maximal speed	kph-	60

ALKS_LongCtrl_Desired_Spd	Value of desired speed	kph -	0-60
ALKS_LongCtrl_Sensor_Forward_relvTgt_dtct	Indicator that the system detected an object in forward direction	-	detected=1 undetected = 0
ALKS_LongCtrl_Sensor_ForwardDist _x	Value of the object x-distance in the forward direction	m	-
ALKS_LongCtrl_Sensor_ForwardDist _y	Value of the object y-distance in the forward direction	m	-
ALKS_LongCtrl_Sensor_ForwardDist _p	Value of the object distance in the forward direction	m	-
ALKS_LongCtrl_Sensor_Backward_relvTgt_dtct	Indicator that the system detected an object in backward direction	-	detected=1 undetected = 0
ALKS_LongCtrl_Sensor_BackwardDist _x	Value of the object x-distance in the backward direction	m	-
ALKS_LongCtrl_Sensor_BackwardDist _y	Value of the object y-distance in the backward direction	m	-
ALKS_LongCtrl_Sensor_BackwardDist _p	Value of the object x-distance in the backward direction	m	On = 1 Off = 0
ALKS_LatCtrl_Sensor _ relvTgtLeft_dtct	Indicator that the system detected on the left	-	detected=1 undetected = 0
ALKS_LatCtrl_Sensor _ DistLeft_x	Value of the object x-distance on left side	m	--
ALKS_LatCtrl_Sensor _ DistLeft_y	Value of the object y distance on the left	m	-
ALKS_LatCtrl_Sensor _ DistLeft_p	Value of the object distance on the left	m	-
ALKS_LatCtrl_Sensor _ relvTgtRight_dtct	Indicator that the system detected an object on the right	-	detected=1 undetected = 0
ALKS_LatCtrl_Sensor _ DistRight_x	Value of the object x-distance on the right	m	-
ALKS_LatCtrl_Sensor _ DistRight_y	Value of the object y-distance on the right	m	-
ALKS_LatCtrl_Sensor _ DistRight_p	Value of the object distance on the right	m	-
ELKS_LDW_SwitchedOn	Main switch of the LDW system	-	On = 1 Off = 0
ELKS_LDW_IsActive	Indicator that LDW system is active	-	detected=1 undetected = 0
ELKS_CDCF_SwitchedOn	Main switch of the CDCF system	-	On = 1 Off = 0

ELKS_CDCF_IsActive	Indicator that CDCF system is active	-	detected=1 undetected = 0
ELKS_CDCF_WarnSignal_Visual	Indicator that the visual warn signal of the CDCF is active	-	On = 1 Off = 0
ELKS_CDCF_WarnSignal_Acousic	Indicator that the acoustic warn signal of the CDCF is active	-	On = 1 Off = 0
ELKS_CDCF_Assist_Steer_Trq	Value of the actual steer torque of the CDCF system	Nm	<50

In case, model signal values do not correspond to the values of the implemented controller, the infofile *SignalMapping* and the TestRuns can be expanded by the needed parameters.

1.4 Adaption of Tcl Scripts

1.4.1 Instruments UNECE ADAS

To start the Instruments dialog, go to *File > Instruments* in the main GUI and select *Instruments_UNECE_ADAS (Project)*. This instrument offers a view into the cockpit with all information about the driver assistance systems. Furthermore, the main switches of the corresponding controllers are realized.

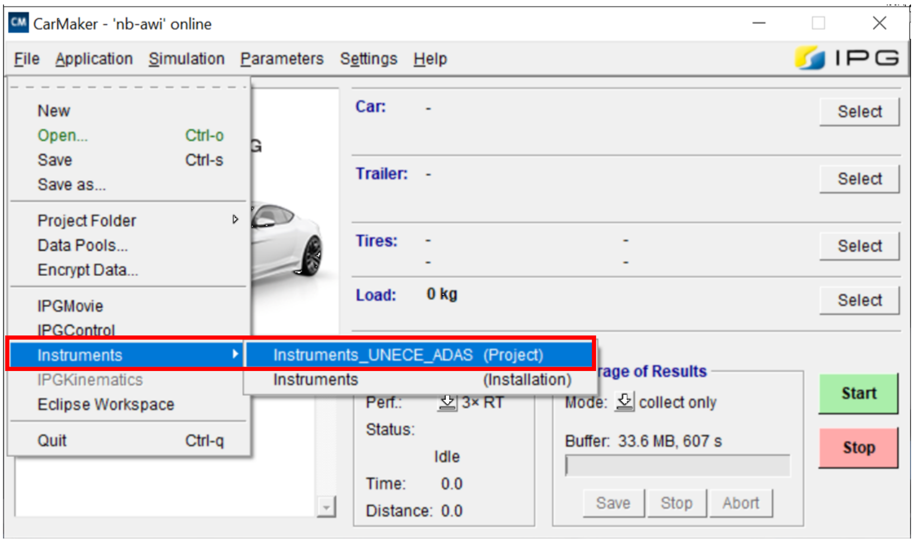

Figure 9 - Open Instruments UNECE ADAS

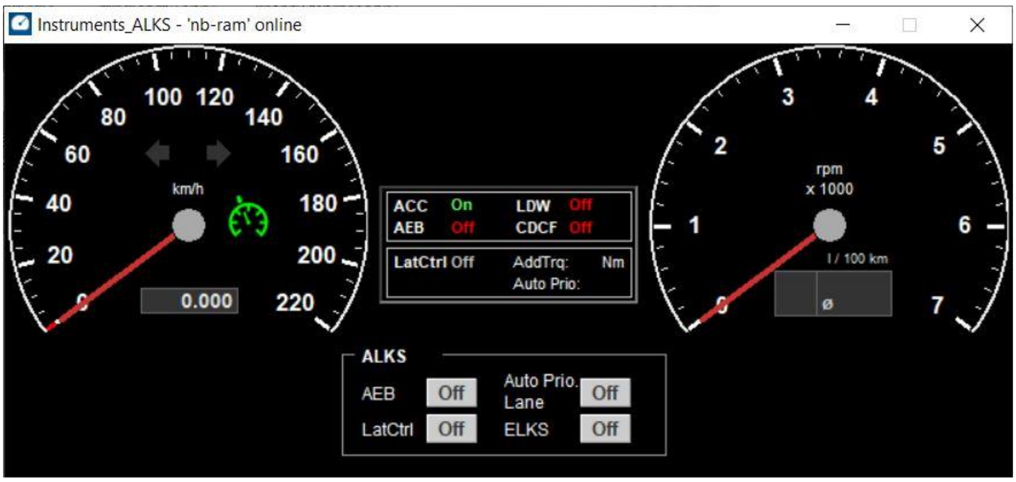

Figure 10 - Instruments UNECE ADAS

The delivered instruments refers to the UAQs of the CarMaker driver assistance systems. Some required changes have to be made in the file */bin/Instruments_UNECE_ADAS.tcl.* Replace the UAQs by the ones that refer to the tested system. The following lines show where the changes have to be made in the Tcl script.

```
set Subscription {
        {Qu(Distance)            Vhcl.Distance}
        {Qu(vCar)                IO.vCar                  Vhcl.v}
        {Qu(nEngine)             IO.nEngine               Vhcl.Engine.rotv}
        {Qu(Gas)                 VC.Gas                   DM.Gas}
        {Qu(Clutch)              VC.Clutch                DM.Clutch}
        {Qu(Brake)               VC.Brake }
        {Qu(GearNo)              DM.GearNo}
        {Qu(SelectorCtrl)        DM.SelectorCtrl}
        {Qu(PT.GearNo)           PT.GearBox.GearNo        DM.GearNo}
        {Qu(StWhlAngle)          Vhcl.Steer.Ang}
        {Qu(SpeedLimit)          DM.SpeedLimit}
        {Qu(Consump Abs)         PT.ECU.Consump Abs       PT.Engine.Consump Abs}
        {Qu(Consump_Avg)         PT.ECU.Consump_Avg       PT.Engine.Consump_Avg}
        {Qu(Consump Act)         PT.ECU.Consump Act       PT.Engine.Consump Act}
        {Qu(Kl15SW)              Kl15SW}
        {Qu(SelManShift)         DM.SelectorManualShift}
        {Qu(SetGearNo)           PT.GearBox.Auto.SetGearNo}
        {Qu(EngineSwitch)        DM.SST   DM.EngineSwitch}
        {Qu(IndL)                VC.Lights.IndL}
        {Qu(IndR)                VC.Lights.IndR}
        {Qu(LaLKS)               LatCtrl.LKAS.SwitchedOn}
        {Qu(LaLKSActive)         LatCtrl.LKAS.IsActive}
        {Qu(LaLKSAutoPrio)       LatCtrl.LKAS.UsePrioLines}
        {Qu(LaLKSTrq)            LatCtrl.LKAS.AssistTrq}
        {Qu(LoAEB)               LongCtrl.AEB.SwitchedOn}
        {Qu(LoAEBActive)         LongCtrl.AEB.IsActive}
        {Qu(LoACCActive)         AccelCtrl.ACC.IsActive}
        {Qu(LoACCTTC)            AccelCtrl.ACC.Time2Collision}
        {Qu(LoLDW)               LatCtrl.LDW.SwitchedOn}
        {Qu(LoLDWActive)         LatCtrl.LDW.IsActive}
        {Qu(LoCDCF)              LatCtrl.LKAS.SwitchedOn}
        {Qu(LoCDCFActive)        LatCtrl.LKAS.IsActive}
        {Qu(ELKSvisual)          LatCtrl.LDW.IsActive}
        {Qu(ELKSsound)           LatCtrl.LDW.IsActive}
}
```

1.5 Best Practices

1.5.1 TestWareDesigner ALKS

As mentioned in the previous sections, there are parameters for which no fixed values are prescribed in the regulation text. These can be freely selected by the manufacturer (or freely within a certain framework). The *TestWareDesigner* can be used to adjust the values of these parameters quickly and easily. Here are all those parameters for which no fixed values are specified as NamedValues defined. For example, if the user wants to change the parameters of the Cutout test, first open the Test Configurator as shown in chapter Quick Start. Here you make a right click on the item of the test and then select *Modify Test*. Then, the TestWareDesigner opens.

In the TestWareDesigner go to *Edit → Test Parameters*. In the lower part of the *TestWareDesigner* window you can now change the parameters or enter additional values.There are two different modes for filling in the table:

- In **Standard** mode each column of the table represents a single variation with its own parameter set. For complex tasks a parameter assistant is available which can be usedfor creating large consecutive ranges of parameter values in a row. [1]

- In the **Combinatorial** mode the resulting set of variations is formed by combining all values of the different parameters with each other. Note: This quickly leads to a very high number of variations! [1]

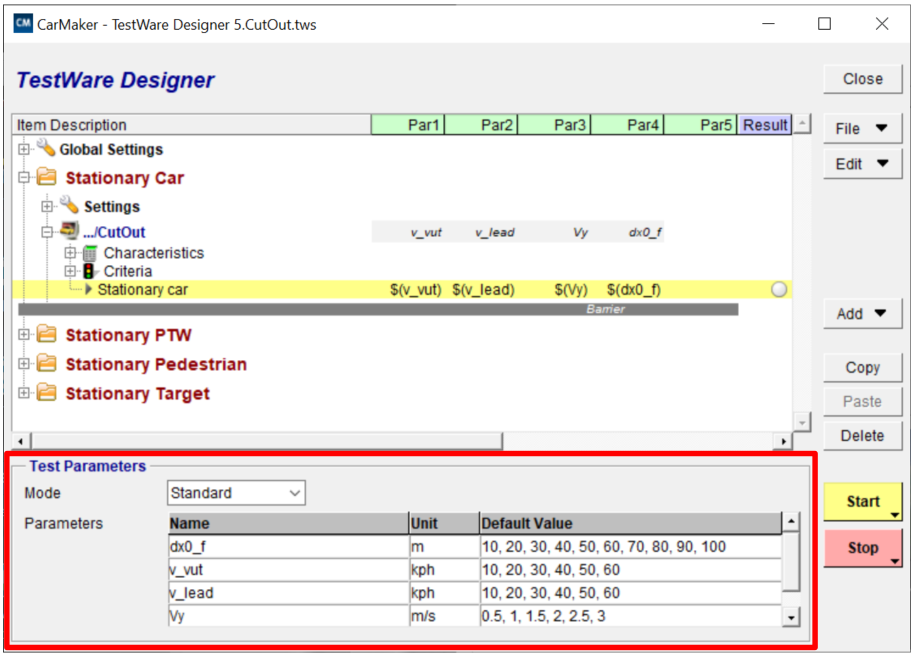

Figure 11: TestWare Designer with TestParameter view

Go back to the TestConfigurator. To reduce this number it is possible to exclude certain variations whose parameter sets hold non-reasonable combinations by applying one or more exclusion filter rules. Such filter rules are formed by Boolean expressions and can be defined in the available Exclusion Filter dialog. In the Test Configurator, click on the Filter item (see Figure 12). The Filter dialog box opens (Figure 13). A right-click in the box gives access to the pre-defined parameter names and to the commonly used Logical Operators AND, OR, NOT. Mind, to put strings to be evaluated in double quote

It is recommended not to overwrite the example file and to save changes in an extra file.

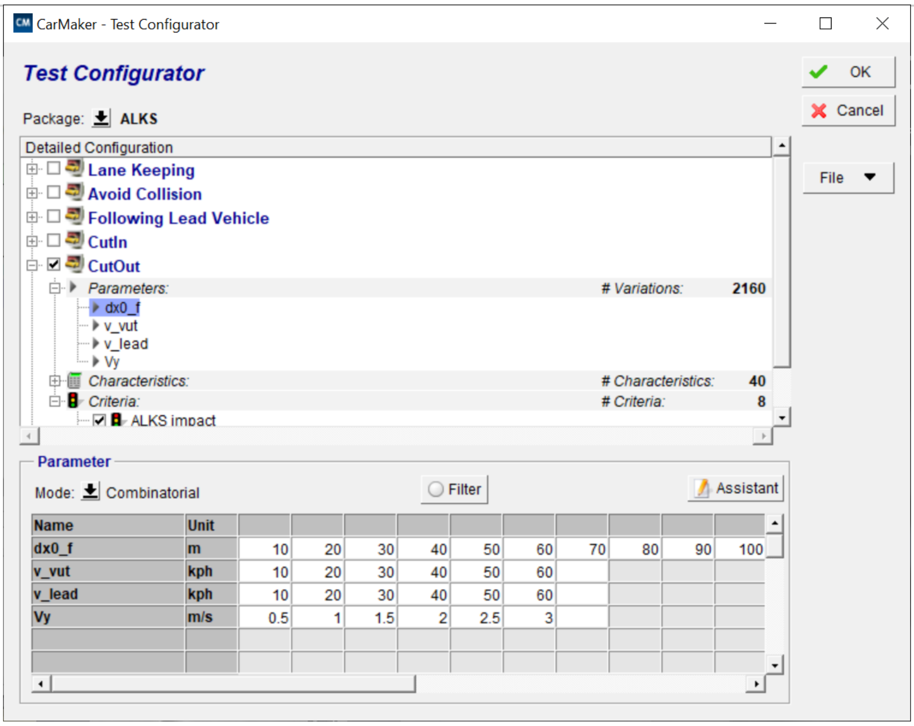

Figure 12: Parameters shown in Test Configuration

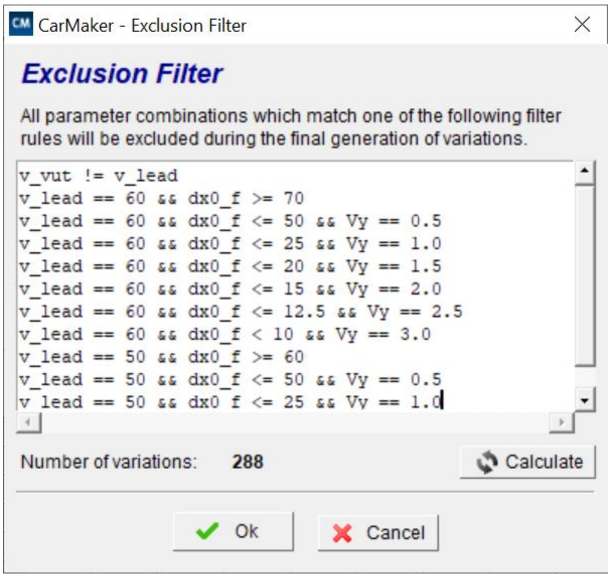

Figure 13: Exlusion Filter window

1.5.2 Combination with TestWare Package *NCAP*

The TestWare packages *NCAP* and *UNECE ADAS* can be used in together in the same project directory. Both files are compatible with each other and can be extracted in the same CarMaker project directory, as long as the CarMaker version is correct.

However, using the *DemoCar_NCAP* with the *UNECE ADAS* TestWare package or vice versa will lead to errors. Therefore, please ensure that the correct TestSeries file (*.ts) is selected in the TestManager.

2 Harmonized Technical UN Regulations

The World Forum for Harmonization of Vehicle Regulations, hosted by UNECE, is the intergovernmental platform responsible for the regulatory frameworks regarding the safety and environmental performance of vehicles, their subsystems and parts.

Countries from across the globe have been working under the World Forum since 2014 to develop internationally harmonized regulations resolutions and guidelines governing automated driving functionalities.

To accomplish autonomous driving under the highest levels of safety and social acceptance, experts from the World Forum for Harmonization of Vehicle Regulations under the leadership of China, the European Union, Japan and the United States, have developed a Framework Document to guide the future normative work of the United Nations on this strategic area for the future of mobility. [2]

2.1 ALKS – Automated Lane Keeping System

2.1.1 Overview

Automated Lane Keeping Systems (ALKS) for passenger vehicles are systems that, once activated, have primary control over the vehicle, i.e. manage all situations including failures, and shall not endanger the safety of the vehicle occupants or any other road users. However, the driver can override such systems and can be requested by the system to intervene at any time. The UNECE's World Forum for the Harmonization of Vehicles passed the first binding international regulation on the so-called level 3 vehicle automation on June 23, 2020. It came into force in January 2021. [3]

The system can only activated if the vehicle is on roads where pedestrians and cyclists are prohibited. In addition, the road must be designed with a physical separation that divides the lanes into the direction of travel and oncoming traffic and prevents the traffic from crossing the vehicle's path. In this first edition, the operational speed is limited to 60 km/h maximum and passenger cars (M1 vehicles)

The most important technical requirements are listed in chapters 5 to 9 of the regulation text.

Chapter 5 "System Safety and Fail-safe Response" includes general requirements regarding the system safety and the failsafe response. Requirements relating to the "Dynamic Driving Task (DDT)" are also formulated here .DDT means the control and execution of all longitudinal and lateral movements of the vehicleIn addition, requirements are formulated for the system, such as how it has to carry out the Minimum Risk Maneuver (MRM) and the Emergency Maneuver (EM).

- An MRM is defined in the regulation text as follows: " MRM means a procedure aimed at 19oolean19ng risks in traffic, which is automatically performed by the system after a transition demand without driver response or in the case of a severe ALKS or vehicle failure."
- An EM is defined in the regulation text as follows "EM is a manoeuvre performed by the system in case of an event in which the vehicle is at imminent collision risk and has the purpose of avoiding or mitigating a collision"

Chapter 6 "Human Machine interface/operator information" formulates requirements for the interaction between the system and the driver. For example, how it needs to record and monitor the presence and attention of the driver. Or how it is activated or deactivated by the driver. In addition, specifications are formulated as to what information the system must provide to the driver and how.

The Chapter 7. “Object and Event Detection and Response” lists the requirements for the forward detection and lateral detection ranger of the installed sensors.

In Chapter 8. “Data Storage System for Automated Driving” it is formulated how the system should save which data in which form and how the data can be accessed.

Chapter 9. “Cybersecurity and Software-Updates” stipulates that the effectiveness of the security measures shall be demonstrated by compliance with UN Regulation No. 15Z. und es 20oolea Anforderungen an die Software identification gestellt.

In addition, the text contains administrative provisions that are suitable for type approval, testing and reporting provisions as well as testing provisions. [4]

Test scenarios with the purpose to verify the technical requirements on ALKS are defined in Annex 5 of the regulation text. These test scenarios are the content of this TestWare package.The requirements that are formulated in chapters 6, 8 and 9 are not the subject of this Testware package.

The regulation text is available at: *https://undocs.org/ECE/TRANS/WP.29/2020/81*

2.1.1 Definitions

The individual tests are explained in the following chapters. The following abbreviations are used in describing the tests.

- **vut**: Vehicle under Test → ego vehicle
- **v_vut**: Vut velocity [kph]
- **GVT**: Globel Vehicle Target
- **v_GVT**: GVT velocity [kph]
- **Vy**: GVT lateral velocity [m/s]
- **TTC**: Time to Collision [s]
- **THW**: Time Head Way [s]
- **PTW**: Powerd Tow-Wheeler Target → combination of a motorcycle and motorcyclist
- **v_lead**: Leading car velocity [kph]
- **dx0**: Longitudinal distdance [m]
- **dx0_f**: Front of lead distance [m]

3 TestWare Package ALKS

The TestWare package *ALKS* includes the six test scenarios to rate the performance of the system with regard to the dynamic driving task.

The Test Configurator allows the user to select between the different implemented test scenarios which are part of so-called TestWare package. The TestWare package is a catalogue of several tests.

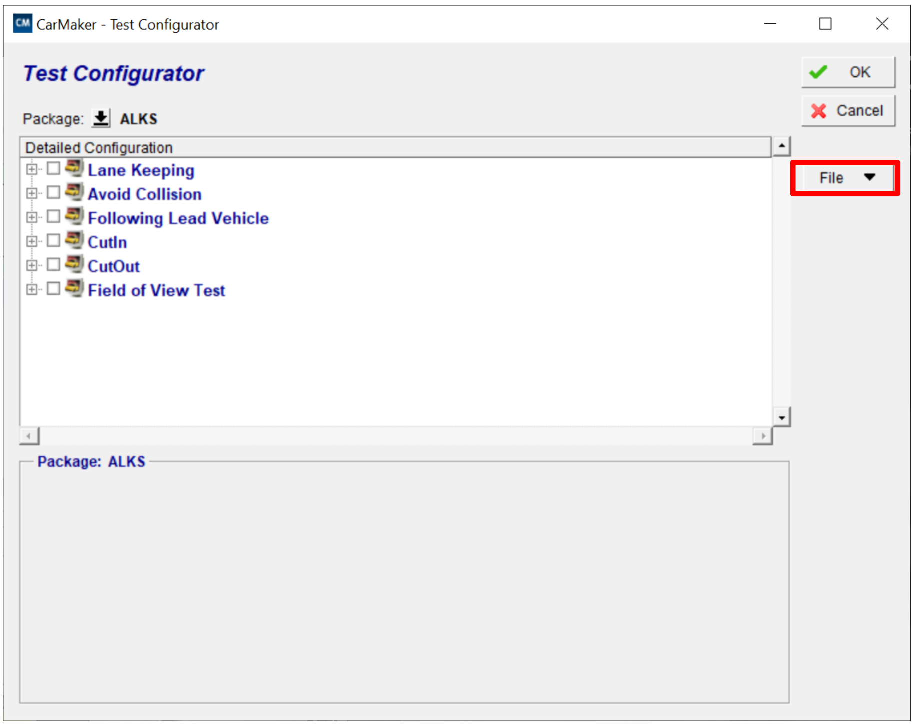

Figure 14 – TestWare Package *Euro ALKS*

Befor the user select all desired tests he/she have to open the predefined Parameter Settings File. For this open the *Parameter Settings* by clicking on *File -> open*. The *Load Parameter Settings* window opens. Select the *example_config* file an click okay This is necessary because in some tests the respective parameters have to be combined with each other. Exclusion filter conditions were formulated for a correct combination of the parameters. These filters conditions are saved in the example_config file. It is therefore important to load this file. This must be done every time the user opens the TestConfiguration. More information on this in the chapter "TestWareDesigner*"*.

By selecting all desired test and clicking on the Ok button, a TestSeries of the selected tests is automatically generated. The user can immediately begin evaluating the system while performing the predefined TestRun and the variation without requiring detailed knowledge of how the tests are built or what variations are needed.

The tests are discussed in the following sections. The descriptions from the regulation text are compared with the implementation in CarMaker.

3.1 Lane Keeping

In the regulation text the test is described as follows:

“The test shall demonstrate that the ALKS does not leave its lane and maintains a stable position inside its ego lane across the speed range and different curvatures within its system boundaries”. [4]

Furthermore, the following four minimum criteria are set for the execution of the test:

- With a minimum test duration of 5 minutes;
- With a passenger car target as well as a PTW target as the lead vehicle /other vehicle;
- With a lead vehicle swerving in the lane; and
- With another vehicle driving close beside in the adjacent lane [4]

3.1.1 Test Scenarios

In the test description, the test route is not given in more detail, so the following test route has been created according to the requirement to have straight and curved sections. The route consists of three lanes in the direction of travel and three lanes in the opposite direction. The separation takes place with a 2.75 m wide lane on both sides which is of the type Traffic Island and each with a traffic barrier. The route starts with a 7000 m long straight flown by a 90° right curve with a 500 m radius, a 500 m long intermediate straight, a 90° left curve with a 500 m radius, a 500 long intermediate straight, a 45° left curve with a 500 m radius and a direct following 45° right-hand curve with a 500 m radius and a 1000 m long final straight. The starting position of ego vehicle and the leading vehicle is calculated in the tcl-script ALKS.tcl as a function of the speed and route length. The starting position, speed and length of the route result in a test duration of 5 minutes for each speed.

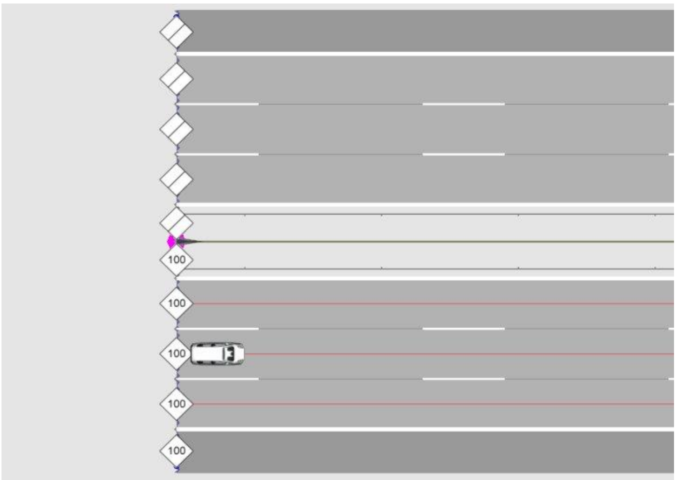

Figure 15: Test-Road for Lane Keeping

3.1.2 Test Parameter

Using information from the Regulation text, the test was created with the following parameter variations:

- The test speed range is set from 10 to 60 kph in 10 kph steps

- Note: The lower limit of 10 kph and the 10 kph steps were freely chosen. The regulation text only specifies the maximum speed of 60 kph

- As the Lead/other passenger car the IPG_CompanyCar_2018_Yellow.mobjmovie geometrie was choosen. It has the following dimensions (length x width x height): 4.47 m x 1.97 m x 1.19 m
  - Note: No information about the target car is given in the regulation text.
- As the lead/other PTW the Honda CBR600 movie geometrie was choosen. It has the following dimensions (length x width x height): 2m x 0.6m x 1.3m
  - Note: No information about the target PTW is given in the regulation text.
- Distance between ego vehicle and leading vehicle: $THW * V_{Vut}$ with THW: 2 sec.
  - The time 2 sec is in Appendix 3 of the regulation text specified as the maximum Time Head Way (THW) for which it was concluded that there is a danger in longitudinal direction
- Swerving movement: Sinus with amplitude 0.7m and peroide 6 s
  - Note: No additional information about the“Swerving movement” in the Regulation text. This is why a sinus movement with the parameters mentioned was chosen. Other vehicle driving close beside on the left side lane

Based on the variation of the other vehicle (car or PTW) and its driving behavior (leading, swerving, close beside), the test is divided into the following six groups. Leading Car, Leading PTW, Swerving Car, Swerving PTW, Car Close Beside and PTW Close Beside. Each group is carried out with the mentioned speed variations (Figure 16).

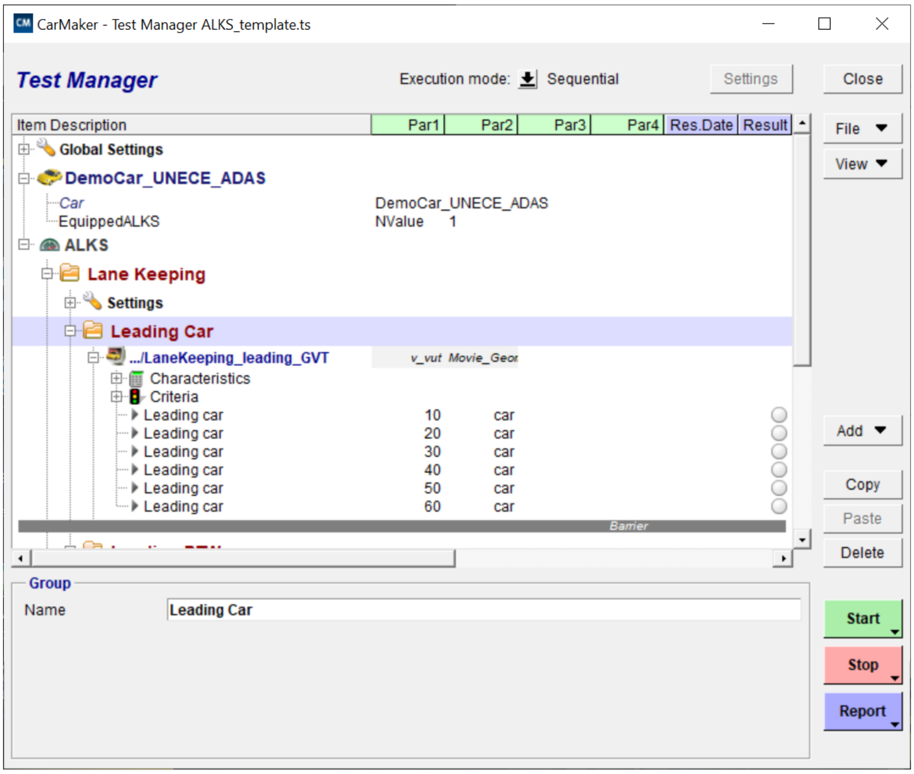

Figure 16: TestManger with the test “Lane Keeping”

3.1.3 Characteristics

The following tables provide an overview about all implemented characteristics .These characteristics are not included in the regulation text but have been added as helpful information..

Table 2 – Overview Characteristics

Characteristic –					
Name	**Identifier**	**Unit**	**Description**	**Calculation**	
Steering wheel velocity VUT	AEB.MaxSWV	°/s	max. Steering wheel velocity between T_0 and T_{AEB}	Rtexpr	AEB.MaxSWV
Speed deviation VUT	AEB.MaxDev_vx	kph	max. Vehicle speed deviation between T_0 and T_{AEB}	Rtexpr	AEB.MaxDev_vx
Lateral deviation VUT	AEB.MaxDev_t	m	max. Lateral deviation from test path between T_0 and T_{AEB}	Rtexpr	AEB.MaxDev_t
Yaw velocity VUT	AEB.MaxYawV	°/s	max. Yaw velocity between T_0 and T_{AEB}	Rtexpr	AEB.MaxYawV
AEB On	AEB.On	-	Flag if AEB system is active	Rtexpr	AEB.On
Impact	AEB.Impact	-	Flag if VUT impacts GVT	Rtexpr	Sensor.Collision.Vhcl.Fr1.Count
Speed when VUT impacts GVT	AEB.v_imp	kph	Relative impact speed	Rtexpr	AEB.v_imp
Speed reduction	AEB.v_red	kph	Speed reduction between vehicle speed and impact speed	Rtexpr	AEB.v_red

3.1.4 Criteria

For the assessment of whether the vut successfully passed the test, the following two criteria were identified in the regulation text:

Table 3 – Overview Criteria

Criteria – AEB			
Name	**good**	**warn**	**bad**
ALKS impact	0 (no impact)	-	1 (impact)
ALKS in lane	0 (vut didn't leave the lane)	-	1 (vut left the lane)

3.2 Avoid Collision

In the regulation text the test is described as follows:

"The test shall demonstrate that the ALKS avoids a collision with a stationaryvehicle, road user or fully or partially blocked lane up to the maximum specified speed of the system." [4]

Furthermore, the test is executed with the following variations:

- With a stationary passenger car target

- With a stationary powered two-wheeler target
- With a stationary pedestrian target
- With a pedestrian target crossing the lane with a speed of 5 km/h
- With a target representing a blocked lane
- With a target partially within the lane
- With multiple consecutive obstacles blocking the lane (e.g. in the following order: ego – vehicle – motorcycle – car)
- On a curved section of a road [4]

3.2.1 Test Scenarios

The route consists of three lanes in the direction of travel and one lane in the opposite direction.The separation takes place with a a traffic barrier. The route starts with a long straight path, which is 550 m, followed by a 180° right curve with a 500 m radius. The starting position of ego vehicle and the leading vehicle is calculated in the tcl-script *ALKS.tcl*.

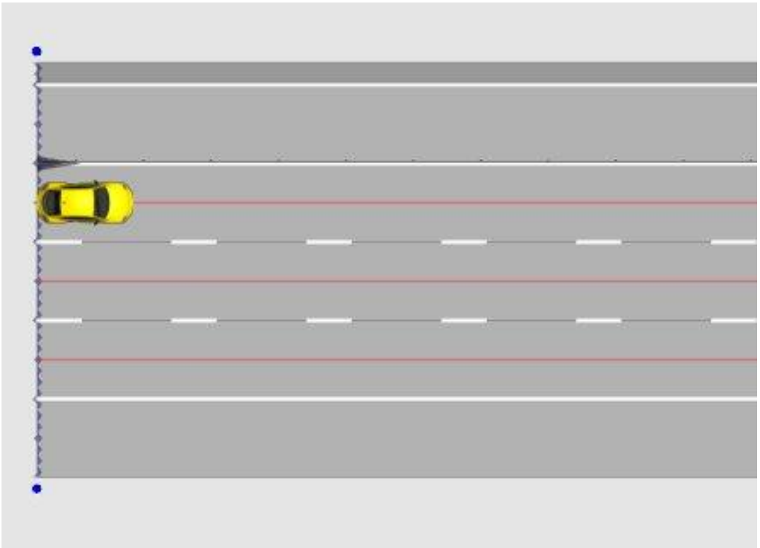

Figure 17 Test-Road for Lane Keeping

3.2.2 Test Parameters

Using information from the Regulation text, the test was created with the following parameter variations:

- The test speed range is set from 10 to 60 kph in 10 kph steps
    - Note: The lower limit of 10 kph and the 10 kph steps were freely chosen. The regulation text only specifies the maximum speed of 60 kph.
- With the IPG_CompanyCar_2018_Yellow movie geometry as the stationary passenger car target.
    - Note: No information about the target car is given in the regulation text.

- With the Honda CBR600 movie geometry as the stationary PTW
    - Note: No information about the target PTW is given in the regulation text.
- With the Pedestrian_Adult_EuroNCAP movie geometry (dimension (length x width x hight) 0.8m x 0.6m x 1.81m) as stationary pedestrian target
    - Note: No information about the Pedestrian target is given in the regulation text.
- With a pedestrian target crossing the lane with a speed of 5 km/h;
    - Note: The regulation text shows the following condition: "…the anticipated impact point is displaced by not more than 0.2 m compared to the vehicle longitudinal center plane,…" [4].

      For this reason, the existing Car-to-Pedestrian Farside Adult 50% (CPFA-50) maneuver was adopted at this point. The maneuver is described as follows**:**. A collision in which a vehicle travels forwards towards an adult pedestrian crossing it's path running from the farside and the frontal structure of the vehicle strikes the pedestrian at 50% of the vehicle's width when no braking action is applied. [5]

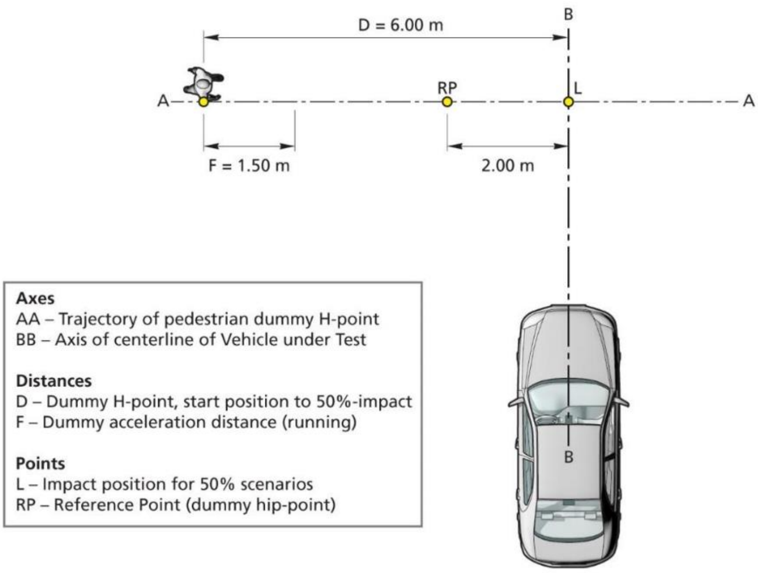

Figure 18: Test scenario CPFA-50, Adult running from Farside [5]

- With multiple consecutive obstacles blocking the lane
    - Note: The example order (ego-vehicle -motorcycle – car) has been implemented at this point .
- With a target partially within the lane,
    - Note: The Regulation text does not contain any information about the target itself (vehicle, object, etc.) and about the displacement of the target in the lane. Therefore, the IPG_CompanyCar_2018_Yellow movie geometry was taken as the target again and placed in the ego lane with an offset of -1.65 m.
- A 90° right curve with radius 500 m was choosen as "curved section"

- Note: No informations (such as radius) about the “curved section” is given in the regulation text.

Based on the variation of the Target (Car, PTW, Pedestrian and multiple Obstacles) plus the case of the Crossing Pedestrian the test is divided into the following five groups:

- Stationary Car
- Stationary PTW
- Stationary Pedestrian
- Crossing Pedestrian
- Multiple Obstacles.

Each group is divided in straight and curved Section (except for Crossing Pedestrian). The Crossing Pedestrian group contains three TestRuns for straight section crossing from left and right and one TestRun for Crossing in curved section. All of these variations are performed at the given speed variations.

3.2.3 Characteristics

The same characteristics, as described in chapter 3.1.3 are used.

3.2.4 Criteria

The same criteria, as described in chapter 3.1.4 are used.

3.3 Following Lead Vehicle

In the regulation text the test is described as follows:

“The test shall demonstrate that the ALKS is able to maintain and restore the required safety distance to a vehicle in front and is able to avoid a collision with a lead vehicle which decelerates up to its maximum deceleration.” [4]

Furthermore, the following minimum criteria are set for the execution of the test:

- Across the entire speed range of the ALKS
- For a passenger car target as well as a PTW target as lead vehicle, provided standardized PTW targets suitable to safely perform the test are available
- For constant and varying lead vehicle velocities (e.g. following a realistic speed profile from existing driving database)
- For straight and curved sections of road
- For different lateral positions of lead vehicle in the lane
- With a deceleration of the lead vehicle of at least 6 m/s^2 mean fully developed deceleration until standstill.[2]

3.3.1 Test Scenarios

The same road as described in chapter 3.1.1 is used.

3.3.2 Test Parameter

- The test speed range is set from 10 to 60 kph in 10 kph steps
  - Note: The lower limit of 10 kph and the 10 kph steps were freely chosen. The regulation text only specifies the maximum speed of 60 kph
- With a IPG_CompanyCar_2018_Yellow as the stationary passenger car target
  - Note: No information about the target car is given in the regulation text.
- With the Honda CBR600 movie geometry as the stationary PTW
  - Note: No information about the target PTW is given in the regulation text.
- For varying lead vehicle velocities
  - Note: No further information on the “varying speeds” is given in the regulation text. Therefore, the speed profile from the IPG example TestRun “TrafficJam” (→ *Examples/BasicFunctions/Traffic/TrafficJam*) was used. For straight and curved sections of road
- The leading vehicle is placed either at the center of the lane or 1m to the right of the center.
  - Note: The position deviation is not specified precisely in the regulatory text
- The minimum of 6 m/s² is selected for the deceleration of the lead vehicle
- Distance between vut and leading vehicle : $THW * V_{Vut}$ with THW: 2 sec.

3.3.3 Characteristics

The same characteristics, as described in chapter 3.1.3 are used.

3.3.4 Criteria

The same criteria, as described in chapter 3.1.4 are used.

3.4 Cut In

This test is referred to as “Lane change of another vehicle into lane” in the ALKS regulation. [4]

The test is described as shown below:

“The test shall demonstrate that the ALKS is capable of avoiding a collision with a vehicle cutting into the lane of the ALKS vehicle up to a certain criticality of the cut-in manoeuvre.” [4]

Furthermore, the following minimum criteria are set for the execution of the test:

- For different TTC, distance and relative velocity values of the cut-in manoeuvre, covering types of cut-in scenarios in which a collision can be avoided and those in which a collision cannot be avoided;

- For cutting-in vehicles travelling at constant longitudinal speed, accelerating and decelerating;
- For different lateral velocities, lateral accelerations of the cut-in vehicle;
- For passenger car as well as PTW targets as the cutting-in vehicle, provided standardized PTW targets suitable to safely perform the test are available [4]

3.4.1 Test Scenarios

The route consists of three lanes in the direction of travel and one lane in the opposite direction. Each lane is 3.5 m wide.The separation takes place with a a traffic barrier. The route is a 4000 m long straight. The starting position of ego vehicle and the CutIn vehicle is calculated in the tcl-script *ALKS.tcl* as a function of the speed. The ego vehicle is placed on the left lane and the CutIn vehicle starts on the middle lane.

3.4.2 Test Parameter

- The test speed range is set from 10 to 60 kph in 10 kph steps
    - Note: The lower limit of 10 kph and the 10 kph steps were freely chosen. The regulation text only specifies the maximum speed of 60 kph
- With the IPG_CompanyCar_2018_Yellow movie geometry as the stationary passenger car target
    - Note: No information about the target car is given in the regulation text.
- With the Honda CBR600 movie geometry as the stationary PTW
    - Note: No information about the target PTW is given in the regulation text.
- For different TTC
- distance and relative velocity values of the cut-in manoeuvre
    - The distance dx0 results from the TTC and the lateral speed of the CutIn Vehicle: $dx0 = TTC * V_y$
- Since no precise values are specified for Vy, the values 2 $\frac{m}{s}$,3 $\frac{m}{s}$, 4 $\frac{m}{s}$,5.4 $\frac{m}{s}$ und 5 $\frac{m}{s}$ were chosen. These values were selected using the graphics on page 46 of the regulations [4] and the condition that the test should be “*covering types of cut-in scenarios in which a collision can be avoided and those in which a collision cannot be avoided*.”

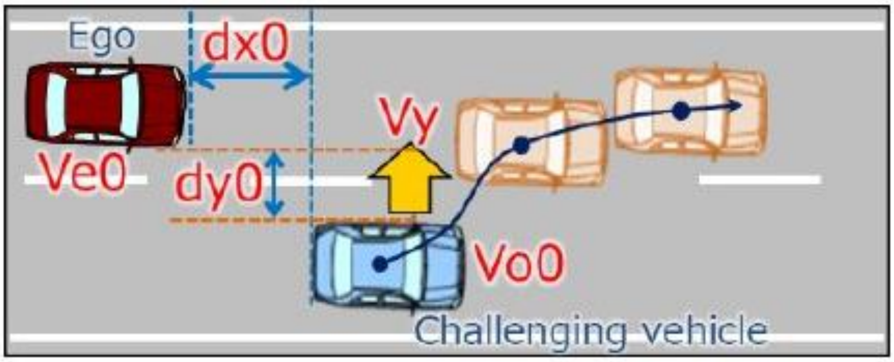

Figure 19: CutIn scenario [4]

In order to reduce the number of test variations resulting from the combination of the parameters TTC, v_vut, v_GVT and Vy an exclusion filter with the following 30oolean expressions was set in the Test Configurator:

- v_GVT == v_vut
- (v_vut – v_GVT) < 0
- (v_vut – v_GVT) > 40
- (v_vut – v_GVT) == 10 && ((v_vut – v_GVT)/3.6 * TTC) > 13
- (v_vut – v_GVT) == 20 && ((v_vut – v_GVT)/3.6 * TTC) > 20 && Vy>=1.0
- (v_vut - v_GVT) == 30 && ((v_vut - v_GVT)/3.6 * TTC) > 40
- (v_vut - v_GVT) == 40 && ((v_vut - v_GVT)/3.6 * TTC) >40 && Vy>1.0

These exclusion conditions reduce the number of test variants to 114 .When setting the filter, the graphs in [3] in the corresponding subchapter were used as a basis. Here were to exclude "unnecessary" test variants. More about the exlusion filters can be read in chapter 1.5.1.

3.4.3 Characteristics

The same characteristics, as described in chapter 3.1.3 are used.

3.4.4 Criteria

The same criteria, as described in chapter 3.1.4 are used.

3.5 Cut Out

This test is referred to as “Stationary obstacle after lange change of the lead vehicle” in the ALKS regulation [4]. There the test is described as shown below:

“The test shall demonstrate that the ALKS is capable of avoiding a collision with a stationary vehicle, road user or blocked lane that becomes visible after a preceding vehicle avoided a collision by an evasive manoeuvre” [4].

The test shall be executed at least:

- With a stationary passenger car target centred in lane
- With a powered two-wheeler target centred in lane
- With a stationary pedestrian target centred in lane
- With a target representing a blocked lane centred in lane
- With multiple consecutive obstacles blocking the lane (e.g. in the following order: ego – vehicle – lane change vehicle – motorcycle – car) [4]

3.5.1 Test Scenarios

The scenario is the same as described in chapter 3.4.1. The starting positions of the ego vehicle, the CutOut vehicle and the stationary target are calculated in the tcl-script *ALKS.tcl* as a function of the speed. All three test participants are placed on the left lane.

3.5.2 Test Parameter

- The test speed range is set from 10 to 60 kph in 10 kph steps
  - Note: The lower limit of 10 kph and the 10 kph steps were freely chosen. The regulation text only specifies the maximum speed of 60 kph
- With the IPG_CompanyCar_2018_Yellow movie geometry as the stationary passenger car target
  - Note: No information about the target car is given in the regulation text.
- With the Honda CBR600 movie geometry as the stationary PTW
  - Note: No information about the target PTW is given in the regulation text.
- With the TrafficDrum movie geometry as the stationary target
  - Note: No information about the stationary target is given in the regulation text.
- With the IPG_CompanyCar_2018_Blue movie geometry as the lead Car
  - Note: No information about the lead car is given in the regulation text.
- The distance dx0 results from the TTC and the lateral speed of the CutIn Vehicle: dx0= dx0 = $THW * V\_y$ with THW 2 s.
- Since no precise values are specified for Vy, the values 0,5 $\frac{m}{s}$, 1 $\frac{m}{s}$, 1,5 $\frac{m}{s}$, 2 $\frac{m}{s}$, 2, 5 $\frac{m}{s}$ 3 $\frac{m}{s}$ were chosen. These values were selected using the graphics in the ALKS regulation on page 34 [4].
- Since no precise values are specified for dx0_f, the values 10 to 100 m in 10 m steps were chosen. These values were selected using the graphics in the ALKS regulation on page 34 [4].

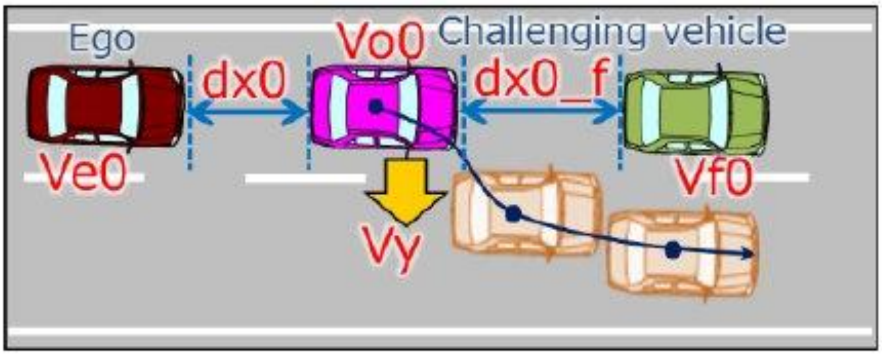

Figure 20: CutOut scenario [4]

In order to reduce the number of test variations resulting from the combination of the parameters TTC, v_vut, v_GVT and Vy, an exclusion filter with the following Boolean expressions was defined in the test configurator:

- v_vut != v_lead
- v_lead ==60 && dx0_f >= 70
- v_lead ==60 && dx0_f <= 50 && Vy== 0.5
- v_lead ==60 && dx0_f <= 25 && Vy== 1.0
- v_lead ==60 && dx0_f <= 20 && Vy== 1.5
- v_lead ==60 && dx0_f <=15 && Vy== 2.0
- v_lead ==60 && dx0_f <= 12.5 && Vy== 2.5
- v_lead ==60 && dx0_f < 10 && Vy== 3.0
- v_lead ==50 && dx0_f >= 60
- v_lead ==50 && dx0_f <=50 && Vy== 0.5
- v_lead ==50 && dx0_f <= 25 && Vy==1.0
- v_lead ==50 && dx0_f <= 15 && Vy== 1.5
- v_lead ==50 && dx0_f <=12 && Vy==2.0
- v_lead ==50 && dx0_f < 10 && Vy==2.5
- v_lead ==50 && dx0_f < 10 && Vy==3.0
- v_lead ==40 && dx0_f >= 50
- v_lead ==40 && dx0_f <= 50 && Vy== 0.5
- v_lead ==40 && dx0_f <= 25 && Vy== 1.0
- v_lead ==40 && dx0_f <= 15 && Vy== 1.5
- v_lead ==40 && dx0_f <=12 && Vy == 2.0
- v_lead ==40 && dx0_f < 10 && Vy== 2.5
- v_lead ==40 && dx0_f < 10 && Vy == 3.0

- v_lead ==30 && dx0_f >= 30
- v_lead ==30 && dx0_f <= 30 && Vy== 0.5
- v_lead ==30 && dx0_f <= 15 && Vy== 1.0
- v_lead ==30 && dx0_f < 10 && Vy== 1.5
- v_lead ==30 && dx0_f <10 && Vy== 2.0
- v_lead ==30 && dx0_f < 10 && Vy == 2.5
- v_lead ==30 && dx0_f < 10 && Vy == 3.0
- v_lead ==20 && dx0_f >= 20
- v_lead ==20 && dx0_f <= 15 && Vy== 0.5
- v_lead ==10 && dx0_f >= 20

These exclusion conditions reduce the number of test variants to 82.The graphs on page 46 of the ALKS regulation were used as a basis [4]. The "redundant" test variants were excluded. More about the exlusion filters can be found in chapter 1.5.1.

3.5.3 Characteristics

The same characteristics, as described in chapter 3.1.3 are used.

3.5.4 Criteria

The same criteria, as described in chapter 3.1.4 are used.

3.6 Field of View test

In the regulation text the test is described as follows:

“The test shall demonstrate that the ALKS is capable of detecting another road user within the forward detection area up to the declared forward detection range and a vehicle beside within the lateral detection area up to at least the full width of the adjacent lane.” [4]

The test for the forward detection range shall be executed at least:

- When approaching a motorcycle target positioned at the outer edge of each adjacent lane
- When approaching a stationary pedestrian target positioned at the outer edge of each adjacent lane
- When approaching a stationary motorcycle target positioned within the ego lane
- When approaching a stationary pedestrian target positioned within the ego lane [4]

The test for the lateral detection range shall be executed at least:

- With a motorcycle target approaching the ALKS vehicle from the left adjacent lane
- With a motorcycle target approaching the ALKS vehicle from the right adjacent lane [4]

3.6.1 Test Scenarios

The scenario is the same as described in chapter 3.4.1. The vut is placed in the center lane. In the forward detection test, the target is placed on the outer edges of the adjacent left or right lane and in the middle of the center lane.

In the lateral detection test the PTW starts on the left or right lane, the vut in the center lane.

3.6.2 Test Parameter

- The test speed of the vut in the forward detection test is set to a maximum of 60 kph and in the lateral detection test to 20 kph. The speed of the PTW in the lateral detection test is set to 50 kph.
  - Note: The regulation text does not indicate the speed for this test
- With the Honda CBR600 movie geometry as the stationary PTW
  - Note: No information about the target PTW is given in the regulation text.
- With the Pedestrian_Adult_EuroNCAP movie geometry (dimension (length x width x hight) 0.8m x 0.6m x 1.81m) as stationary pedestrian target
  - Note: No information about the Pedestrian target is given in the regulation text.

3.6.3 Characteristics

Characteristic –					
Name	**Identifier**	**Unit**	**Description**	**Calculation**	
ALKS_relv_Tgt_ds_x	ALKS_relv_Tgt_ds_x	m	distance to the target in x-direction	RTexpr	ALKS_relvTgt_ds_x
ALKS_relv_Tgt_ds_y	ALKS_relv_Tgt_ds_y	m	distance to the target in y-direction	RTexpr	ALKS_relvTgt_ds_y
ALKS_relv_Tgt_ds_p	ALKS_relv_Tgt_ds_p	m	distance to the target	RTexpr	ALKS_relvTgt_ds_p

3.6.4 Criteria

For the longitudinal test, the following criteria was defined:

Table 4 - Overview Criteria

Criteria - AEB			
Name	**good**	**warn**	**bad**
FoV longitudinal	ALKS_relvTgt_ds_p > 46	-	ALKS_relvTgt_ds_p < 46

4 TestWare Package ELKS

The TestWare package *ELKS* includes two test scenarios to rate the performance of the system with regard to the dynamic driving task.

These tests are divided in two groups where each group describes the system under test. Lane Departure Warning (LDW) and Corrective Directional Control Function (CDCF)

The Test Configurator allows the user to select between the different implemented test scenarios which are part of so-called TestWare package. The TestWare package is a catalogue of several tests.

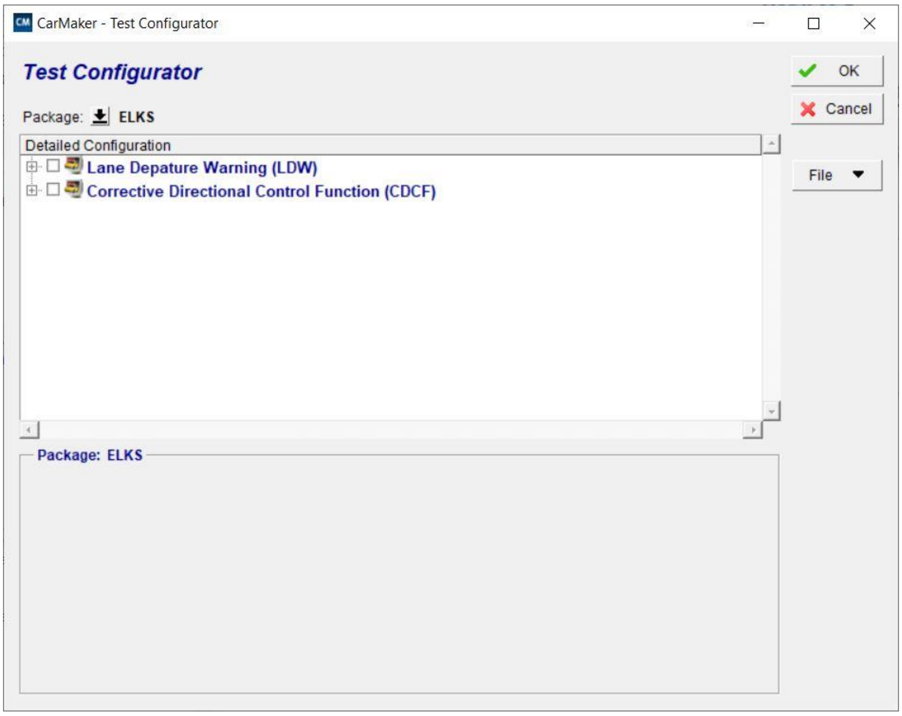

Figure 21 – TestWare Package *Euro ELKS*

4.1.1 Overview

The ELKS is a driver-assist system designed to warn the driver and correct the lane only if the driver leaves the lane unintentionally. This system consists of the LDW (Lane Departure Warning) and the CDCF (Corrective directional control function) [6].

Intervention of the corrective directional control function by the steering (CDCF) only takes place on solid lines and not on dashed lines, but a warning by the LDW takes place on all types of lines. The reason for this is to prevent the driver from switching off the system in case of unnecessary interventions, which would lead to a loss of safety benefits. However, the systems must be designed in such a way, that the steering intervention by the system can also be overridden by the driver [6].

The currently existing technologies for lane keeping systems are based on the detection of lane markings and the performance of these systems cannot be guaranteed in the absence of such markings. Therefore, lane departure warning systems should not be required to operate in the absence of lane markings [6].

The LDWS shall be active at least in the speed range between 65 km/h and 130 km/h (or the maximum speed of the vehicle if lower than 130 km/h), whereas the CDCF system shall be active between 70 km/h and 130 km/h (or the maximum speed of the vehicle if lower than 130 km/h) unless deactivated. However, if the vehicle reduces its speed from above 70 km/h to below 70 km/h, the system shall be active at least until the vehicle speed drops below 65 km/h. Both systems shall operate independently of the load [6].

When activated and operating within the prescribed speed range, the LDWS shall be capable of warning the driver at the latest when the vehicle crosses a visible lane marking for the lane it is in by more than a DTLM of - 0,3 m and at lateral departure speeds in the range 0,2 m/s to 0,5 m/s [6].

The CDCF shall be capable of preventing lane departure by crossing visible lane markings by more than a DTLM of - 0,3 m:

- at lateral turning speeds in the range 0.2 m/s to 0.5 m/s for vehicle speeds up to 100 km/h, and
- at lateral turning speeds in the range of 0.2 m/s to 0.3 m/s for vehicle speeds above 100 km/h and up to 130 km/h (or the maximum vehicle speed if this is below 130 km/h);
- and in good road, visibility and weather conditions (exact details can be found here: [6]).

4.1.2 Definitions

The individual tests are explained in the following chapters. The following abbreviations are used in describing the tests.

Vehicle under test (VUT) – means the vehicle tested according to the test protocol with a Lane Keep Assist and/or Lane Departure Warning system.

v_vut – Vut velocity [kph]

Corrective directional control function (CDCF) – means a control function within an electronic control system whereby, for a limited duration, changes to the steering angle of one or more wheels and/or braking of individual wheels in order to correct the lane departure, e.g. to avoid crossing lane markings or leaving the road [6].

Lane Departure Warning (LDW) – a warning that is provided automatically by the vehicle in response to the vehicle that is about to drift beyond a delineated edge line of the current travel lane.

Distance To Line Crossing (DTLE) – means the remaining lateral distance (perpendicular to the Lane Edge) between Lane Edge and most outer edge of the tire, before the VUT crosses Lane Edge, assuming that the VUT would continue to travel with the same lateral velocity towards it.

4.1.3 Lateral Velocity Calculation

For the calculation of the lateral velocity, a function from the NCAP Package is used and is described below:

4.1.3.1 Offset Calculation

The parameter d is the offset from lane marking and is calculated before the TestRun starts. It is the sum of the lateral distance travelled during Vlat steady state, lateral deviation during curve establishing yaw angle and the half of the vehicle width. The first two summands depend on the lateral velocity and are given in **Fehler! Verweisquelle konnte nicht gefunden werden.** and **Fehler! Verweisquelle konnte nicht gefunden werden.**. The calculation of the vehicle width is done in the same way that is described in section 1.2.

$$d = \mathrm{d1} + \mathrm{d2} + \frac{Vehicle\ width}{2} \qquad \textbf{(EQ 1)}$$

With:

$\mathrm{d1}$ Lateral distance travelled during curve establishing yaw angle [m]

$\mathrm{d2}$ Lateral distance travelled during V_{lat} steady state [m]

Table 5 - Parameter of offset calculation (unintentional lane changes)

Lateral velocity V_{lat} [m/s]	Radius r [m]	Yaw angle ψ_{vut} [°]	d1 [m]	d2 [m]
0.2	1200	0.57	0.06	0.70

0.3		0.86	0.14	0.90
0.4		1.15	0.24	0.80
0.5		1.43	0.38	0.75
0.6		1.72	0.54	0.60

Table 6 - Parameter of offset calculation (intentional lane change)

Lateral velocity V_{lat} [m/s]	**Radius r [m]**	**Yaw angle ψ_{vut} [°]**	**d1 [m]**	**d2 [m]**
0.5	800	1.43	0.25	0.75
0.6		1.72	0.36	0.60
0.7		2.01	0.49	0.53

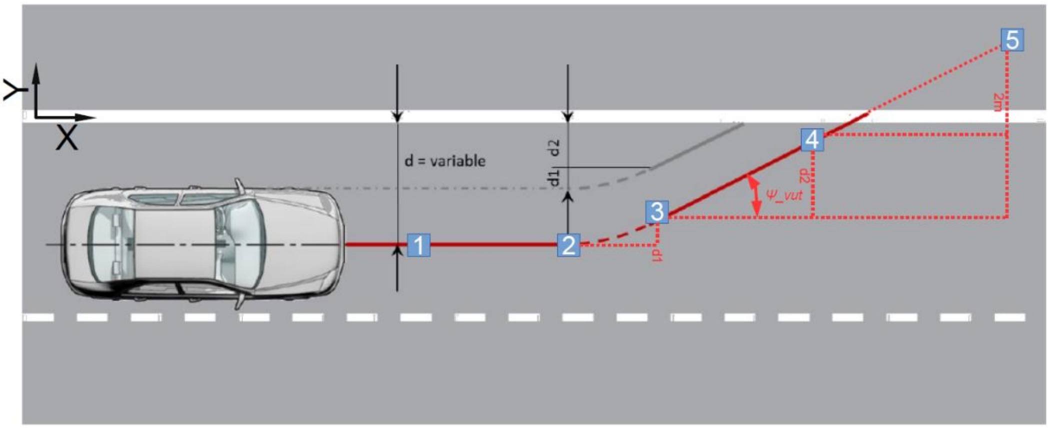

Figure 22 - Offset from lane marking

4.1.3.2 UserPath Calculation

The coordinates of the nodes used for the definition of the UserPath are calculated in the following way:

Table 7- UserPath nodes – calculation of coordinates

Node	Description	Longitudinal Offset	Lateral Offset
1	Lateral Offset	$X_1 = 690$	$Y_1 = -\left(d + \frac{LineWidth}{2}\right)$ $Y_1 = -\left(d1 + d2 + \frac{VehicleWidth}{2} + \frac{LineWidth}{2}\right)$
2	Lateral Offset	$X_2 = 710$	$Y_2 = Y_1$
3	Begin of Radius	$X_3 = X_2 + 2 * r * \sin(\frac{\psi_{vut}}{2})$ $X_3 \sim X_2 + r * \psi_{vut}$	$Y_3 = Y_2 + d1$
4	End of Radius	$X_4 = X_3 + \frac{d2}{\tan(\psi_{vut})}$	$Y_4 = Y_3 + d2 = Y_2 + d1 + d2$
5	End of Path	$X_5 = X_4 + \frac{2}{\tan(\psi_{vut})}$	$Y_5 = Y_4 + 2$

4.1.4 Calculation of distance to line edge

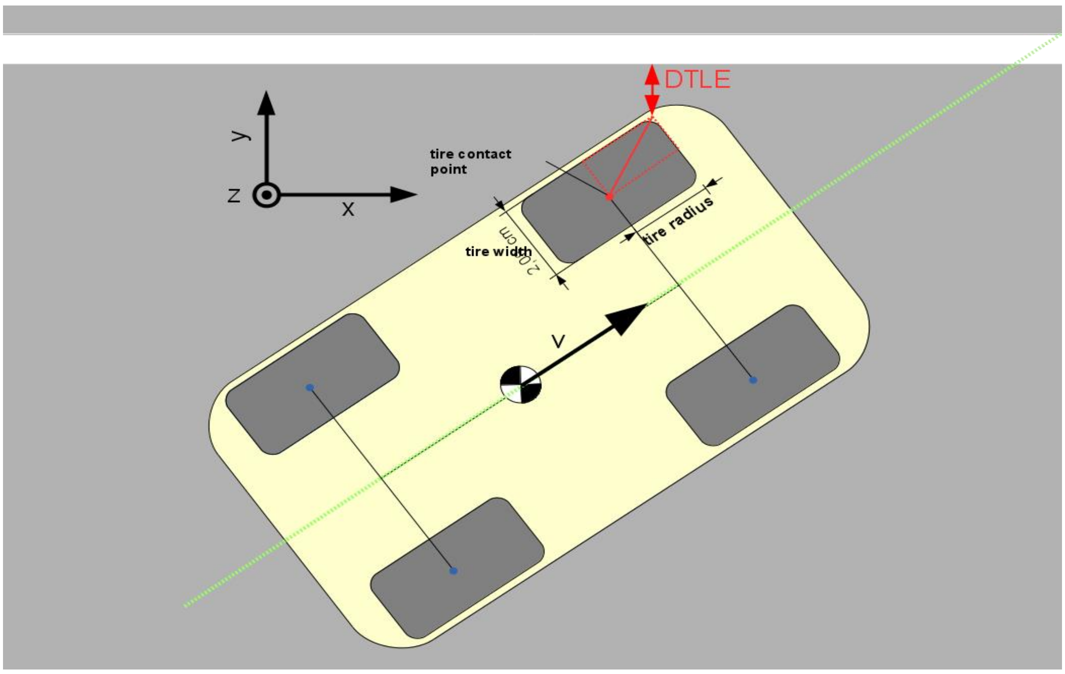

Figure 23 Calculation of Distance To Line Edge

4.2 Lane Departure Warning (LDW)

Lane Departure Warning (LDW) refers to a warning message, that is provided automatically by the vehicle in response to the vehicle drifting beyond an edge line of the current lane.

The LDW test scenarios include the left and right deviation from a solid line. [6]

For testing the Lane Departure Warning, the following test need to be performed:

4.2.1 Mixed depature side tests

The test checks whether the LDW system is capable to give a warinig indication to the driver, when the vehicle leaves the track at lateral accelerations between 0.2 and 0.5 m/s.

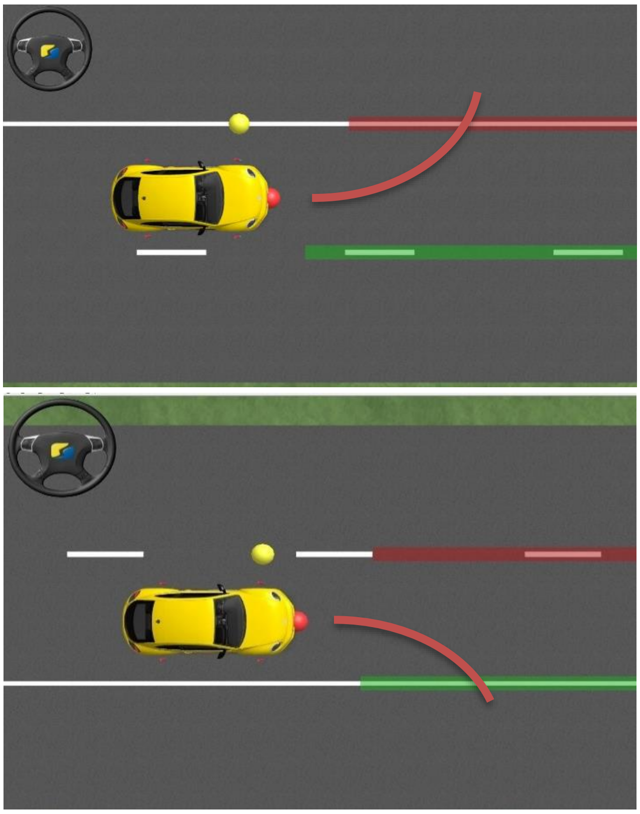

Figure 24 - LDW mixed depature side tests

The LDW test will be performed at the lateral velocities of 0.2 to 0.5 m/s in 0.1 m/s steps for departures at both sides of the vehicle.

4.2.1.1 Test Conditions

The test shall start at T0 and is valid when all boundary conditions are met between T_0 and T_{LDW}:

- Speed of VUT: 70 ± 3.0kph
- Lateral deviation from test path GVT: 0 ± 0.3m

- Lateral deviation from test path: 0 ± 0.05m
- Steady state lane departure lateral velocity: ± 0.05m/s

4.2.1.2 Test Parameter

Overview over the test parameter of the Lane Departure Warning (LDW)

Type	Name	Description
NValue	V_vut	Longitudinal velocity
NValue	DepartureSideNo	Flag for departure side 1:= left -1:= right
NValue	LateralVelocity	Lateral Velocity between 0.2 and 0.5 [m/s]

The path calculation is described in chapter 4.1.3.2

4.2.1.3 Characteristics

The following tables provide an overview about all implemented characteristics for the LDW system.

Overview Characteristics Lane Depature Warning

Characteristics					
Name	**Identifier**	**Unit**	**Description**	**UAQ**	
Speed deviation VUT	ELKS.MaxDev_vx	kph	max. vehicle speed deviation between T_0 and T_{LDW}	RTexpr	ELKS.MaxDev_vx
Lateral speed deviation VUT	ELKS.MaxDev_vlat	m/s	max. lateral speed deviation between T_0 and T_{LDW}	RTexpr	ELKS.MaxDev_vlat
Emergency Lane Keeping System On	ELKS.On	-	Flag if LSS system is active	RTexpr	ELKS.On
Distance To Line Edge LDW	ELKS.DTLE_LDW	m	Calculated Distance To Line Edge when LDW is actived	RTexpr	LSS.DTLE_LDW
Check Distance To Line Edge CDCF	CheckDTLE_CDCF	-	The test result is good, when the limit value for DTLE of -0.3 m is not exceeded	EndProc	CheckDTLE_CDCF
Result	ResultMixedLaneDepatureSide	-	The test result is good if the limit values for the characteristics were not exceeded	EndProc	:: ELKS:: ResultMixedLaneDepatureSide

4.2.1.4 Criteria

The test result is good, when all conditions are met between T_0 and T_{LDW} , the LDW System is activated and if the limit value for DTLE is not exceeded.

The limit value for DTLE for LDW is set to -0.3 meters, meaning that the LDW system must not permit the VUT to cross the inner edge of the lane marking by a distance greater than 0.3 meters.

For the calculation of the DTLE, the outermost tire edge is used. The calculation of this point is described in chapter 4.1.4

Table 8 - Overview Criteria Lane Depature Warning

Criteria			
Name	**good**	**warn**	**bad**
Check Conditions	ELKS.MaxDev_v < 3.0 && ELKS.MaxDev_vlat < 0.05	-	ELKS.MaxDev_vx > 3.0 || ELKS.MaxDev_vlat > 0.05
Check LSS On	ELKS.On > 0.5	-	ELKS.On < 0.5
Check DTLE_LDW	CheckDTLE_LDW > 0	-	CheckDTLE_LDW < 0

4.3 Corrective Directional Control Function (CDCF)

The Corrective Directional Control Function (CDCF) is a driver support function that warns the driver when a lane marking is crossed and intervenes in an emergency, e.g. by steering intervention.

The CDCF test scenarios include the left and right deviation from a solid line.

For testing the Lane Departure Warning, the following test need to be performed:

Test Scenarios

4.3.1 Warning Indication 3 Interventions

In this test, the Vut is controlled by the driver, so that the lanes are crossed three times within an roll interval of 180 seconds. The driver steers the vehicle in the direction of the lane markings (it is always steered in the direction of the solid line) until the system has been activated and the vehicle has steered back to the centre of the road, then the driver steers again in the direction of the lane markings. This is repeated three times.

The aim is to test whether the visual and acoustic warnings of the ELKS correspond to the regulations of UNECE.

4.3.1.1 Characteristics

The following tables provide an overview about all implemented characteristics for the CDCF System

Overview Characteristics Emergency Lane Keeping Systems

Characteristics					
Name	**Identifier**	**Unit**	**Description**	**UAQ**	
Emergency Lane Keeping System On	ELKS.On	-	Flag if ELKS system is active	RTexpr	ELKS.On
Time CDCF is active	CDCF_System_ac_time	s	Active time of the CDCF System	RTexpr	CDCF_visual_warn_ac_time
Acoustic warn signal time for second intervention	CDCF_acoustic_warn_ac_time_interv_2	s	Shows the active time of the acoustic warn signal of the second intervention	RTexpr	CDCF_acoustic_warn_ac_time_interv_2
Acoustic warn signal time for third intervention	CDCF_acoustic_warn_ac_time_interv_3	s	Shows the active time of the acoustic warn signal of the third intervention	RTexpr	CDCF_acoustic_warn_ac_time_interv_3
Visual warn signal time for first intervention	CDCF_visual_warn_ac_time_interv_1	s	Shows the active time of the visual warn signal of the first intervention	RTexpr	CDCF_visual_warn_ac_time_interv_1
Visual warn signal time	CDCF_visual_warn_ac_time_interv_2	s	Shows the active time of the visual	RTexpr	CDCF_visual_warn_ac_time_interv_2

for second intervention			warn signal of the second intervention		
Visual warn signal time for third intervention	CDCF_visual_warn_ac_time_interv_3	s	Shows the active time of the visual warn signal of the third intervention	RTexpr	CDCF_visual_warn_ac_time_interv_3
Result	ResultWarningIndication3Interventions	-	The test result is good if the limit values for the characteristics were not exceeded	EndProc	:: ELKS:: ResultWarningIndication3Interventions

4.3.2 Criteria

The test result is good when all conditions are met, when the CDCF System and the minimum time values for the visual and acoustic warn signals are reached.

Table 9 - Overview criteria corrective controlling system

Criteria			
Name	**good**	**warn**	**bad**
Check ELKS On	ELKS.On > 0.5	-	ELKS.On < 0.5
Check CDCF visual warn signal time for second intervention	CDCF_visual.._2 >= 1	-	CDCF_visual.._2 < 1
Check CDCF visual warn signal time for third intervention	CDCF_visual.._3 >= 1	-	CDCF_visual.._3 < 1
Check CDCF acoustic warn signal time for first intervention	CDCF_acoustic.._1 >= 1	-	CDCF_acoustic.._1 < 1
Check CDCF acoustic warn signal time for second intervention	CDCF_acoustic.._2 >= 1	-	CDCF_acoustic.._2 < 1
Check CDCF acoustic warn signal time for third intervention	CDCF_acoustic.._3 >= CDCF_acoustic.._2+10s	-	CDCF_acoustic.._3 < 1 CDCF_acoustic.._2+10s

4.3.3 Warning Indication 10 seconds

In this test, the VUT is controlled by the driver so that the VUT is on the solid lane for a minimum of 10 seconds with an active CDCF.

In the case of an intervention longer than 10 seconds, an acoustic warning signal shall be provided until the end of the intervention unless there is a driver action which indicates an intention to depart from the lane [8].

4.3.3.1 Test Parameter

Overview over the test parameter of the 4.3.1 Warning Indication 10 seconds (CDCF)

Type	Name	Description
NValue	DepartureSideNo	Flag for departure side 1:= left -1:= right

4.3.3.2 Characteristics

The following tables provide an overview about all implemented characteristics for the CDCF System

Overview Characteristics Correcitve Directional Control Function (CDCF)

Characteristics					
Name	**Identifier**	**Unit**	**Description**	**UAQ**	
Emergency Lane Keeping System On	ELKS.On	-	Flag if ELKS is active	RTexpr	ELKS.On
Check if acoustic warn signal appears	CDCF_acoustic_warn_ac	-	Shows if the acoustic warn signal of the CDCF System appears	RTexpr	CDCF_acoustic_warn_ac
Check time when acoustic warn signal appears	CDCF_acoustic_warn_ac_time	s	Shows the time when the acoustic warn signal of the CDCF System appears	RTexpr	CDCF_acoustic_warn_ac_time
Result	ResultWarningIndication10s	-	The test result is good if the limit values for the characteristics were not exceeded	EndProc	:: ELKS:: ResultWarningIndication10s

4.3.4 Criteria

The test result is good, when all conditions are met, when the CDCF System and the minimum time values for the visual and acoustic warn signals are reached.

Overview criteria Correcitve Directional Control Function (CDCF)

Criteria			
Name	**good**	**warn**	**bad**
Check ELKS On	ELKS.On > 0.5	-	ELKS.On < 0.5
Check if acoustic warn signal appears	CDCF_acoustic_warn_ac >= 1	-	CDCF_acoustic_warn_ac < 1
Check when acoustic warn signal appears	CDCF_acoustic_warn_ac_time >= 10	-	CDCF_acoustic_warn_ac_time < 10

4.3.5 Steering Override

In this test, the intervention of the CDCF system should be override by the driver. The VUT is controlled by the driver so that it leaves the lane and is steered in the direction of one of the two solid lane markings. When the CDCF system has been active for 0.5 seconds, the driver should bring the VUT back into the lane, to override the CDCF system. This driver intervention evaluates parameters such as the steering torque of the driver that led to the deactivation of the CDCF system or the loss of steering assistance after CDCF deactivation.

4.3.5.1 Test Parameter

Overview over the test parameter of the Steer Override (CDCF)

Type	Name	Description
NValue	DepartureSideNo	Flag for departure side 1:= left -1:= right

4.3.5.2 Conditions

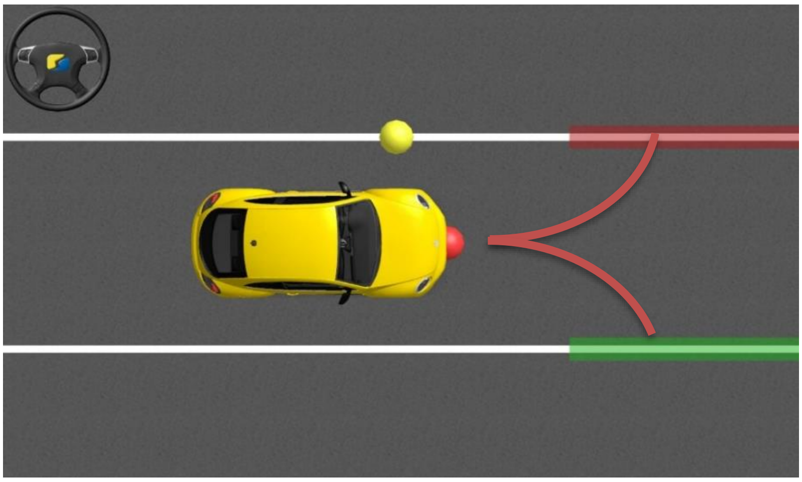

Figure 25 Lane Markings for steer override test

4.3.5.3 Characteristics

The following tables provide an overview about all implemented characteristics for the CDCF System

Overview Characteristics Correcitve Directional Control Function (CDCF)

Characteristics					
Name	**Identifier**	**Unit**	**Description**	**UAQ**	
Emergency Lane Keeping System On	ELKS.On	-	Flag if ELKS system is active	RTexpr	ELKS.On
Flag if CDCF system is deactivated	ELKS_deactivate	-	Check whether the CDCF is switched off by the driver's intervention	RTexpr	ELKS_deactivate
Steer override torque from the driver	Steer override torque	Nm	Shows the value of the steer torque to override the CDCF System	RTexpr	Steer_override_trq
Avg steering loss trq	Avg_Steer_trq_support_ELKS	Nm	Average steer trq by the CDCF after deactivation of the system	RTexpr	Avg_Steer_trq_support_ELKS
Driver steer angle	ELKS_deactivation_steer_whl_ang	deg	Steering wheel angle at the time, where the CDCF is deactivated	RTexpr	ELKS_deactivation_steer_whl_ang
Result	ResultSteeringOverride	-	The test result is good if the limit values for the characteristics were not exceeded	EndProc	:: ELKS:: ResultSteeringOverride

4.3.6 Criteria

The test is passed if all the values described in the next table are within or below the tolerances described.

Overview Characteristics the Correcitve Directional Control Function (CDCF)

Criteria			
Name	**good**	**warn**	**bad**
Check ELKS On	ELKS.On > 0.5	-	ELKS.On < 0.5
Check ELKS turned off	ELKS_deactivate >= 1	-	ELKS_deactivate< 1
Check driver steering trq	Steer_override_trq <= 50	-	Steer_override_trq > 50

Loss of steering support	Avg_Steer_trq_support_ELKS > 0	-	Avg_Steer_trq_support_ELKS == 0
Check driver steer angle	ELKS_deactivation_steer_whl_ang <= 25	-	ELKS_deactivation_steer_whl_ang > 25

4.3.7 Lane Keep

The test checks whether the CDCF system is capable of keeping the vehicle on track at lateral accelerations between 0.2 m/s and 0.5 m/s.

4.3.7.1 Test Conditions

The test shall start at T0 and is valid when all boundary conditions are met between T0 and TLDW:

- Speed of VUT: 72 ± 1.0kph
- Steady state lane departure lateral velocity: ± 0.05m/s

4.3.7.2 Test Parameter

Overview over the test parameter of the Correcitve Directional Control Function (CDCF)

Type	Name	Description
NValue	DepartureSideNo	Flag for departure side 1:= left -1:= right
NValue	LateralVelocity	Lateral Velocity between 0.2 and 0.5 [m/s]

The path calculation is described in chapter 4.1.3.2

4.3.7.1 Characteristics

The following tables provide an overview about all implemented characteristics for the CDCF system.

Overview Characteristics the Corrective Directional Control Function (CDCF)

Characteristics					
Name	**Identifier**	**Unit**	**Description**	**UAQ**	
Speed deviation VUT	ELKS.MaxDev_vx	kph	max. Vehicle speed deviation between T_0 and T_{LDW}	RTexpr	ELKS.MaxDev_vx
Lateral speed deviation VUT	ELKS.MaxDev_vlat	m/s	max. Lateral speed deviation between T_0 and T_{LDW}	RTexpr	ELKS.MaxDev_vlat

Emergency Lane Keeping System On	ELKS.On	-	Flag if LSS system is active	RTexpr	ELKS.On
Distance To Line Edge CDCF	ELKS.DTLE_CDCF	m	Calculated Distance To Line Edge when CDCF is active	RTexpr	LSS.DTLE_CDCF
Check Distance To Line Edge CDCF	CheckDTLE_CDCF	-	The test result is good, when the limit value for DTLE of -0.3 m is not exceeded	EndProc	CheckDTLE_CDCF
Result	ResultLaneKeep	-	The test result is good if the limit values for the characteristics were not exceeded	EndProc	:: ELKS:: ResultLaneKeep

4.3.7.2 Criteria

The test result is good when all conditions are met between T_0 and T_{CDCF} , the CDCF System is activated and if the limit value for DTLE is not exceeded.

The limit value for DTLE for CDCF is set to -0.3 meters, meaning that the CDCF System must not permit the VUT to cross the inner edge of the lane marking by a distance greater than 0.3 meters.

For the calculation of the DTLE, the outermost tire edge is used. The calculation of this point is described in chapter 4.1.4

Overview Criteria Correcitve Directional Control Function (CDCF)

Criteria			
Name	**good**	**warn**	**bad**
Check Conditions	ELKS.MaxDev_v < 1.0 && ELKS.MaxDev_vlat < 0.05	-	ELKS.MaxDev_vx > 1.0 || ELKS.MaxDev_vlat > 0.05
Check LSS On	ELKS.On > 0.5	-	ELKS.On < 0.5
Check DTLE_CDCF	CheckDTLE_CDCF > 0	-	CheckDTLE_CDCF < 0

5 Version History

Version	Changes
1.0	• Initial version • Support ALKS • Support ELKS

6 References

[1] IPG Automotive GmbH, *CarMaker User's Guide.*

[2] UNECE, "Safety at core of new Framework to guide UN regulatory work on autonomous vehicles," 3 September 2019. [Online]. Available: https://unece.org/transport/press/safety-core-new-framework-guide-un-regulatory-work-autonomous-vehicles#:~:text=%E2%80%9CThe%20level%20of%20safety%20to,or%20death%20that%20are%20reasonably.

[3] UNECE, "UN Regulation on Automated Lane Keepnig Systems is milestone for safe introduction of automated vehicles in traffic," January 2021. [Online]. Available: https://unece.org/transport/press/un-regulation-automated-lane-keeping-systems-milestone-safe-introduction-automated.

[4] UNECE, "Uniform provisions concerning the approval of vehicles with regard to Automated Lane Keeping Systems," 22 January 2021. [Online]. Available: https://unece.org/sites/default/files/2021-03/R157e.pdf.

[5] Vulnerable Road User Protection - AEB VRU Test Protocol v3.0.3, June 2020. [Online]. Available: https://cdn.euroncap.com/media/58226/euro-ncap-aeb-vru-test-protocol-v303.pdf.

[6] UNECE, „EU Regulation Emergency-Lane-Keeping-Systems (ELKS),“ https://safetywissen.com/object/A11/A11.uei737915iuxm50bzkh58719jn09uf63755828319/safetywissen?prev=%2Fnews%2FSAFETYNEWS%2F, 2020.

[7] C-NCAP Management Regulation Appendix C - Test Methods for Active Safety of ADAS System, 2021. [Online]. Available: http://www.c-ncap.org.cn/cms/picture/357347723784007680.pdf.

[8] C-NCAP Management Regulation, 2021. [Online]. Available: http://www.c-ncap.org.cn/cms/picture/357347311580393472.pdf.

[9] Safety Assist - LSS Test Protocol v3.0.2, 16 August 2019. [Online]. Available: https://cdn.euroncap.com/media/53143/euro-ncap-lss-test-protocol-v302.pdf.

7 Illustration Directory

8 List of Tables