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Lane Departure Warning and Lane Keep Assist Assessment based on Southeast Asian Environmental Conditions: Preliminary Investigation

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Abstract – *Lane Departure Warning (LDW) and Lane Keep Assist (LKA) systems are part of the Advanced Driver-Assistance Systems (ADAS), which are equipped in the latest passenger vehicles sold in the Southeast Asia (SEA) countries. Both technologies are very beneficial to gain improved safety performance for vehicle occupants and benefiting other road users such as pedestrians and cyclists by alerting the driver and making automatic trajectory correction when the vehicle is deviating away from the correct path while in motion. Nevertheless, there is yet any test protocol established by the New Car Assessment Program for Southeast Asian Countries (ASEAN NCAP) to evaluate both technologies tailored to the SEA's environmental conditions. Hence, this is a preliminary investigation of the new test protocol developed for LDW and LKA based on SEA's environmental conditions. The proposed protocol incorporated the effect of both dry and wet conditions, which is unique to simulate the main weather elements in the region. On-road tests using actual passenger vehicles were conducted using a rain simulator to simulate the rainy weather. The preliminary tests were performed on straight road conditions. Results show that the proposed protocol was able to assess the effectiveness of LDW and LKA in both dry and wet conditions. Further actions shall be carried out in the later stage of this project to validate the proposed protocol using other vehicle models sold in SEA that equipped with similar technologies.*

Keywords: Lane Departure Warning (LDW), Lane Keep Assist (LKA), test protocol, dry and wet condition

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1.0 INTRODUCTION

World Health Organization's (WHO) global status on road safety report of 2018 stated that the Southeast Asia (SEA) region recorded the second-highest regional rate of road deaths, which is higher than the global rate, with 20.7 death per 100,000 populations (global rate 18.2 per 100,000 populations) (WHO, 2018). The region's rate of road death has also increased compared to the previous year (19.8 per 100,000 populations). For SEA, the majority of road accidents death (43 %) are among riders of two- and three-wheelers while 16 % involved driver/passenger of four-wheeled vehicles (WHO, 2018). In terms of sales, a total of 7,610,826 units of motorcycles and 2,603,871 units of four-wheelers were sold in ASEAN countries in 2018 (JKJR, 2018). While for Malaysia, the majority of road deaths in 2018 were the motorcyclists (61.7 %), and car driver/passenger (20.1 %). The causes of road accidents are human negligence (80.6 %), road conditions (13.2 %) and vehicle condition (6.2 %) (JKJR, 2018).

The Advanced Driver-Assistance Systems (ADAS) is a valuable active safety assist technology developed to help drivers avoid on-road collisions, hence significantly improving road safety. Safety assist technology help to reduce fatality occurrence due to human negligence while driving such as error at intersections and when making turns, failure to yield right of way, failure to comply with signs and signals, failure to see objects, improper turns and lane changes, low driving skill level, inexperience and unnecessary risk-taking behaviours, traffic violations, reckless driving, driving under influence of alcohol and drugs, poor visibility, physical fatigue and defective eyesight (Rolison et al., 2018). Recently, more latest models are sold in the SEA countries equipped with many ADAS systems such as Lane Departure Warning (LDW), Lane Keep Assist (LKA), Automatic Emergency Braking (AEB), Adaptive Cruise Control (ACC) and Satellite Navigation (SAT) system such as from BMW, Mercedes, Proton, Toyota, Honda, Hyundai etc. (MRC, 2019; Abu Kassim et al., 2019).

ADAS systems' performance have been tested based on protocols produced by many established organizations such as the Euro NCAP, Japan NCAP (JNCAP), Australian NCAP (ANCAP), and US NCAP. Nevertheless, there is yet any test protocol established in ASEAN NCAP to evaluate the ADAS performance tailored to the SEA's environmental and road conditions (Abu Kassim et al., 2019). The SEA region experienced unique and have different environmental and road conditions as compared to other parts of the regions in the world, due to its geographical location near the equator and bordering sea. Many SEA countries were recorded to experience heavy rain up to 27 days within a month and subjected to many tropical yearly storms (Jawi et al., 2010; USDA, 2018). The overall climate is wet and humid throughout the year. Moreover, road conditions also vary from other regions. Road length in SEA countries is estimated stretching up to 27,300 km, covering motorway, primary and secondary roads (ESCAP, 2019), consist of many curves and winding roads, hillsides, road junctions and intersections due to its natural topography. Driving behaviour in SEA countries is also different compared to developed countries, due to varying regulations, driving style and varying types of vehicles dominating the market (two- and three-wheelers are the majority). Hence, as more ADAS equipped vehicles entered the SEA market, it is crucial that improvement needs to be made on any ADAS system test protocol to be adopted by ASEAN NCAP which will include considerations of its countries actual environmental and road conditions. Based on the tailored ASEAN NCAP test requirement, actual ADAS system performance can be successfully evaluated with consideration of the environmental and road conditions parameters, to provide higher road safety performance to all type of ASEAN road users (two-, three- and four-wheelers' drivers; pedestrians; cyclists; and others).

Based on the aforementioned situations, in this project, new comprehensive test procedures for evaluating the safety assist systems, i.e. Lane Departure Warning (LDW) and Lane Keep Assist (LKA), were developed based on Southeast Asia's environment and road conditions. The LDW and LKA test protocols are later evaluated by performing preliminary on-road evaluation using a selected vehicle model available in the region. The project activities performed include developing on-road test facilities based on the selected environment and road parameters, setting up data collection equipment, as well as the data analysis. Results obtained from the preliminary investigation is very beneficial to evaluate how well the new test protocols may be adopted in real on-road situations and identify further improvements for the next stage of the project.

2.0 LITERATURE REVIEW

LDW and LKA systems are part of the ADAS systems in assisting the drivers. There is a slight difference in the definition of these systems. LDW can be described as a system that continuously monitors the position of the vehicle to be within the lane markers (Narote et al., 2018). It alerts the driver by using visual, vibration or sound warnings when the vehicle is moving outside the lane marker boundaries. On the other hand, LKA is the improvement of the LDW system, in which the vehicle can automatically steer itself to the pre-determined location. It uses a variable combination of steering control and differential braking (Chen et al., 2018).

In recent years, various researches are focusing on both systems. For LDW, most studies are now concentrating on the driver behaviours such as the study regarding the influence of LDW on driver's behaviour with and without auditory warning (Navarro et al., 2017), and driver's mental model and insufficient knowledge in using the LDW system (Aziz et al., 2013). Researchers are also putting more effort into accumulating statistical data regarding the users of the system. Examples of the studies are the reported crash of LDW due to drivers' age (Cicchino, 2018) and the effectiveness of heads-up LDW for younger and older drivers (Aksan et al., 2017). The concentration of research regarding the LDW system itself has become less attractive due to the passivity of the system's feedback (Sandstrom et al., 2017). In addition, there is also limited publication regarding the influence of the environment on the LDW system and it is generally focusing on specific geographical locations. One of the examples of this study is regarding the use of a real-time detection vision system during testing in rainy and foggy weather and also inside the tunnel (Nguyen et al., 2018).

For the LKA system, research studies are still wide-spreading in multiple disciplines. It includes the study regarding the system itself, the system's performance due to environmental influence and statistical data regarding the utilization of the system. Examples of the studies focusing on the system are control algorithm using differential braking (Lee et al., 2014), and control based on the safe envelope of steering wheel angle (Tan et al., 2017). There is also a statistical study of forecasting the system's efficiency when utilizing this technology in the market (Penmetsa et al., 2018). With regards to the system's performance, some studies focusing on the influence of environmental illumination to the system operation such as the different illumination when driving in the tunnel (Son et al., 2015), and also due to the foggy weather (Das et al., 2019).

Based on the available publications, there are limited studies regarding the environmental and road condition effects on LDW and LKW performance. The accessible research outputs of this discipline is merely concentrating on a specific geographical location. Most of the studies are referred to in Europe and North America. Because of that, it provides the opportunity to carry out research works in evaluating both systems' performance due to environmental factors and road conditions, particularly for the SEA region. It is because this region has a unique climate and road terrain which surely produce different system's performance as compared to the published research.

Based on statistical data from the Malaysia Metrological Department (MET) in 2018, the highest rainfall recorded in Malaysia for an hour and a single day is 95 mm (Bintulu, Sarawak) and 296.6 mm (Mersing, Johor), respectively. MET also reported that most of the places in West Malaysia (the peninsular) recorded a mean rainfall value of 3,000 mm per year, while Sarawak was the wettest state in Malaysia with mean rainfall value between 3,000 mm to 5,000 mm per year. The rain in Malaysia is also categorised into six types depending on the rainfall received per day, namely light rain, moderate-heavy rain, heavy rain, light downpour rain, moderate downpour rain, heavy downpour rain and very heavy downpour rain (pouring rate more than 50 mm per hour) (MET, 2018).

3.0 METHODOLOGY

Overall, the project methodology shall cover six main stages, with a focus is on the environmental and road conditions parameters as described below. The overall research framework is shown in Figure 1. Details of the research methods implemented are described in the subsequent sub-sections.

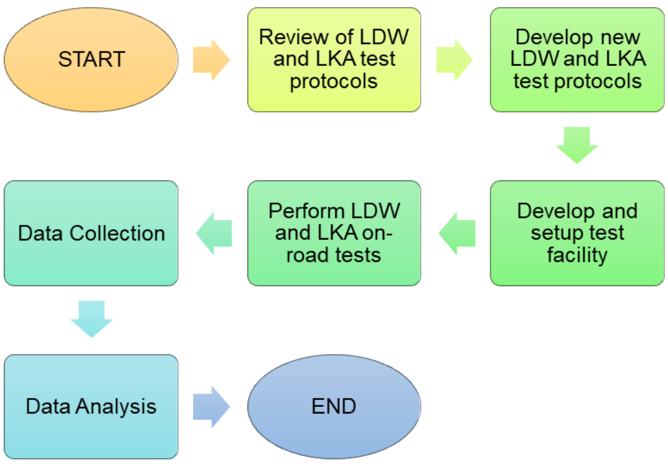


Figure 1: Overall research methodology applied

3.1 New ASEAN NCAP Test Protocol Development for LDW and LKA – Environment and Road Condition Parameters

In this stage, planning and development for new LDW and LKA performance test protocols were conducted. The new test protocol incorporated selected environment and road condition parameters that reflect ASEAN conditions, such as weather (dry/wet), light intensity (day/night) and road profile (straight and curve roads). Previous information gathered from the review on existing test protocols were used as a reference to execute the performance test. Euro

NCAP's Lane Support System (LSS) test protocol was used as the primary reference for the newly proposed ASEAN NCAP LSS test protocol (Euro NCAP, 2018). Besides, the Japanese National Agency for Automotive Safety and Victim's Aid (NASVA) Lane Departure Prevention System test protocol was also used as the secondary reference while developing the new test protocol for this study (NASVA, 2018). In this preliminary study, the ASEAN unique parameters investigated in the new test protocol was focused on weather condition (dry and wet), while the light intensity is fixed for daytime and straight road profile. Evaluation of the weather condition is significant to the new test protocol, as it is never being done before in any lane-keeping assist test protocols developed based on literature review. Furthermore, in this study, two test scenarios were included for the straight road profile, which is road test with edge line and road test with the dashed line, as most of the roads in Malaysia are constructed with a similar profile. The performance evaluation plan for both LDW and LKA systems is also based on real-time graphical images with the aid of selected qualitative data such as ambient temperature and light intensity. Table 1 summarized some important evaluation parameters involved in this on-road preliminary study on LDW and LKA systems for the proposed new ASEAN NCAP LSS system protocol.

Table 1: Summary of evaluation parameters used for preliminary study on the proposed new ASEAN NCAP LSS system protocol

ADAS System Evaluated	Evaluation Parameters	
	Variable	Fix
LDW and LKA	• Environment condition: Weather • Type of weather: Dry and Wet (Rain)	• Light intensity: Day time • Test location: State road, Melaka, Malaysia • Test car model: Volkswagen Passat 2.0 TSI High-line • Road condition: straight • Test scenario: (i) road test with edge line, (ii) road test with the dashed line • Total road length: 2.5 km • Test section distance: 200m • Vehicle test speed: 72 ± 2 km/h (or 20 m/s) • Vehicle lateral speed: 0.2 – 0.5 m/s (0.72 – 1.8 km/h) • Visual sensor (camera): 3 units (1x outer side of car, 1x on the dashboard, 1x steering looking at display panel) • Data acquisition system: VBOX Racelogic • Rain simulation method: lorry moving with car • Interior load= 200k kg • Fuel capacity: minimum 90% full tank (max. capacity for VW Passat 2.0 TSI = 66 litres) • Three repetitions per test

3.2 Test Facility Development and Setup

Based on the new test protocols formulated for LDW and LKA, the subsequent testing facility was developed and setup. Performance evaluation was carried out based on field tests (on the road test) using actual test vehicles. Since both LDW and LKA systems activate at the same vehicle speed and using the same sensors, the test vehicle selected shall have both LDW and LKA systems equipped to it. Therefore, the systems can be evaluated concurrently hence saving valuable resources. In this preliminary study, the test vehicle selected was a Volkswagen Passat 2.0 TSI (high-line variant).

3.3 Test Track and Test Matrix

In this preliminary study, the test track and test matrix used are summarized in Figure 2. The test matrix was adapted from Euro NCAP LSS test protocol, encompassing two test scenarios for the straight road condition which are left and right vehicle departure directions, and for solid line and dash line road markings (Euro NCAP, 2018). Furthermore, some improvements were made for the proposed new ASEAN NCAP LSS protocol as compared to the Euro NCAP LSS test protocol which are creating designated areas within the whole test track, which are start area (marked from cone number 1 to cone number 2), vehicle stabilization area (marked from cone number 2 to cone number 3), test section area (marked from cone number 3 to cone number 4) which represent the steering area of the test vehicle, and test termination area (marked from cone number 4 to cone number 5).

For the wet test (rain simulation), two vehicles are involved which are the test vehicle and rain vehicle (termed given to the vehicle carrying the rain simulator machine). The wet test is started by moving the vehicle first, then followed by the test vehicle. Both vehicles must enter the stabilization area at the same speed. The rain vehicle shall dispense the water once it entered the stabilization area and keep on dispensing until the end of the test section area.

Cone markings are also recommended to be included in test track preparation as it provided visual aid for the driver in systematically executing the test procedure. This visual marking was adapted from the NASVA LDW test method, including recommended the test section distance of 300 m (NASVA, 2018). However, the NASVA test method also mentioned that the distance proposed is considered arbitrary in nature as a yardstick to carry out the deviation test, hence it may be amended based on the actual test situation.

Meanwhile, Figure 3 shows the summary of the track path for the test vehicle to perform the deviation test, which includes dimensions of the lane markings. The track path configuration applied in this study was adapted from the Euro NCAP LSS test protocol (Euro NCAP, 2018). The Vehicle Under Test (VUT) must be manoeuvred with the maximum lateral speed of 0.5 m/s towards the intended lane marking. All on-road tests were carried out at a vehicle speed of 72 ± 2 km/h (based on GPS speed measurement).

3.4 Test Location and Traffic Management Plan (TMP)

In this preliminary study, the selected test location was a 2.6 km straight State Road in Melaka, Malaysia. The road is administrated by the Public Works Department (PWD/JKR) Malaysia. Since it is a public road, approval to close the road for the testing purpose must be obtained from the PWD. The approval is enabled through the Traffic Management Plan (TMP) document, which is prepared in accordance to the 2017 JKR regulation on “Standard Specification for Road Works – Section 19: Traffic Management at Work Zones” (JKR/SPJ/2017-S19) (PWD, 2017) and 1985 JKR regulation on “Manual on Traffic Control Devices: Temporary Signs and Work Zones Control” (*Arahan Teknik (Jalan) 2C/85*) and approved by the District PWD for official road closure (PWD, 1985). Approval then must be disseminated to all road stakeholders through printed and/or electronic media sources before the test. Figure 4 and Figure 5 show the location of the test track selected in this study and the summary of the TMP developed and approved, respectively.

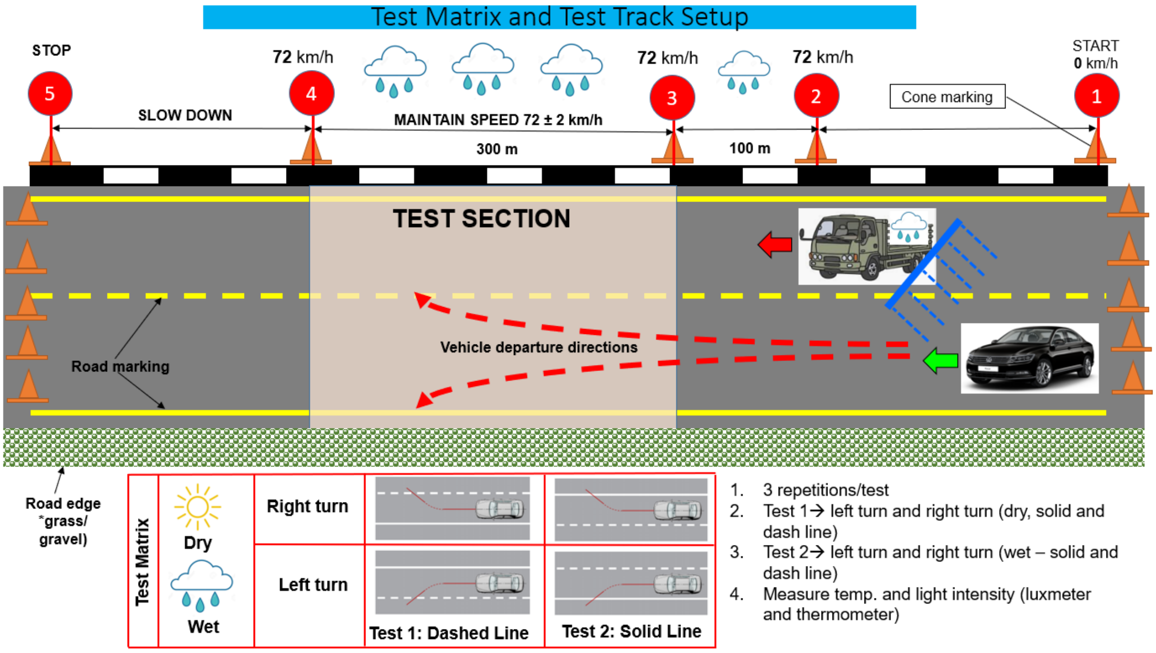


Figure 2: Summary of LDW and LKA testing track setup for straight road profile and test matrix

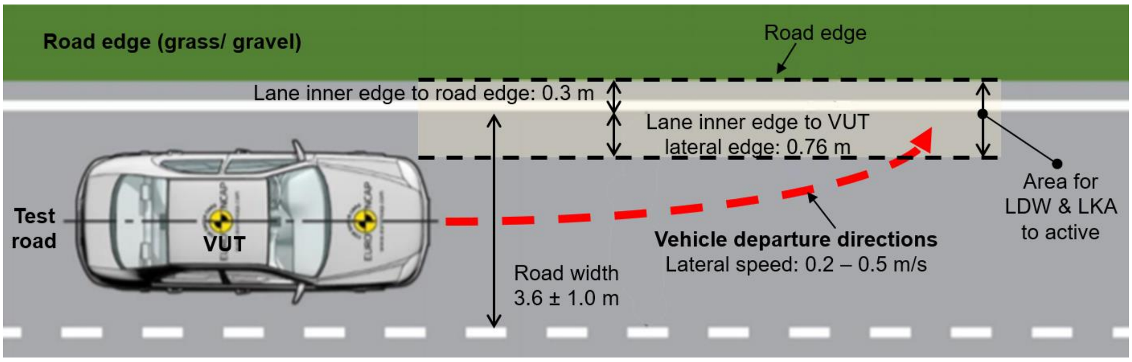


Figure 3: Summary of LDW and LKA test path

Figure 4: Test track location in Melaka, Malaysia

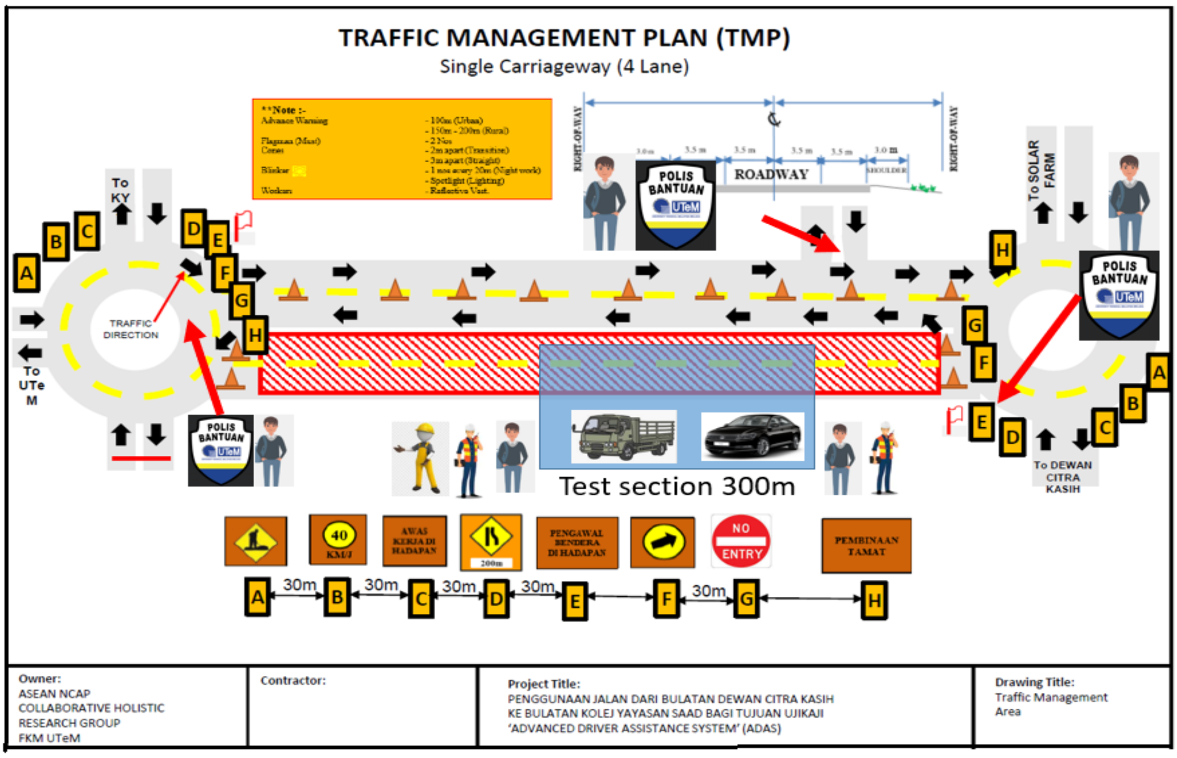


Figure 5: Summary of TMP for test track setup

3.5 Rain Simulator

In this study, a customized test-rig was designed and fabricated to simulate the effect of ASEAN weather (rainy condition) on the LDW and LKA systems as shown in Figure 6. The customized rain simulator test-rig is capable to be used for both straight and curve road conditions. The rain machine is mounted on a moving vehicle, and the spraying mechanism is operated manually. The customized weather simulator machine provides an advantage to the development of a comprehensive environment and road condition testing capabilities to this project. Among the advantages of this rain simulator machine is design simplicity, able to dispense high and low volume of water with a simple control mechanism, lightweight, portable and low cost. In addition, the water inside the plastic industrial-grade water tank can also be easily refilled. However, the design requires a skilled operator to dispense the water to the desired VUT surface location accurately. Detail specifications of the rain simulator machine developed in this project are summarized in Table 2.

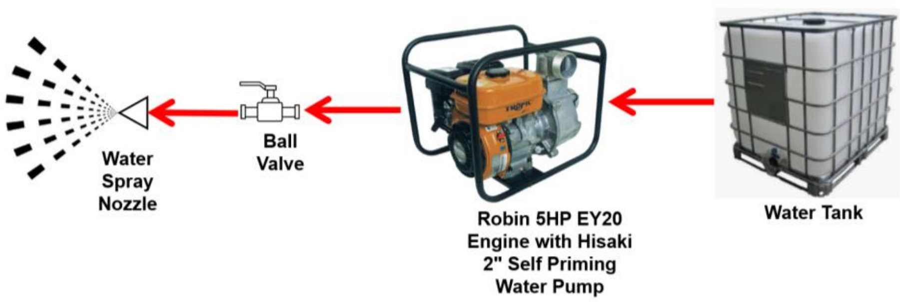


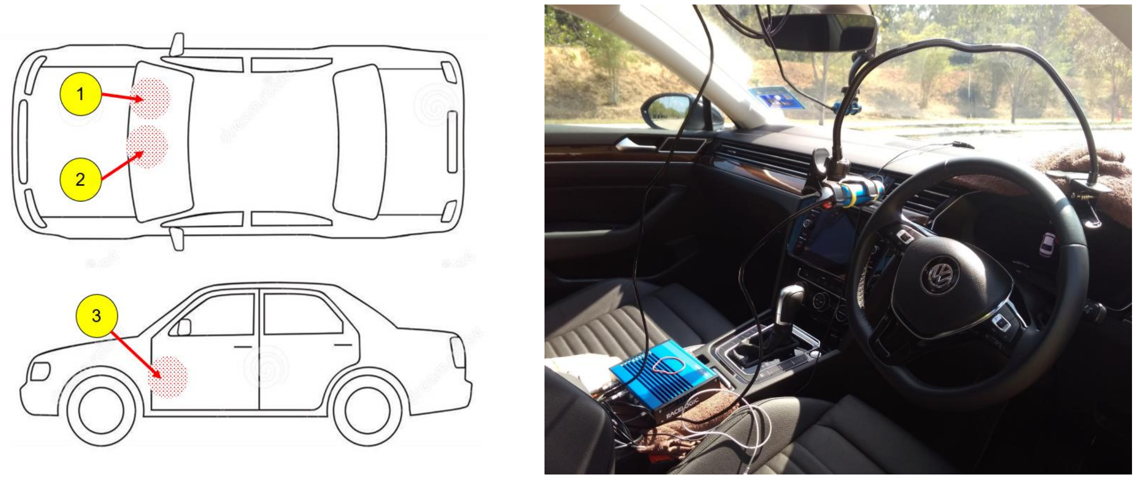
Figure 6: Basic diagram of rain simulator machine

Table 2: Specifications for rain simulator machine

Water Source: • Intermediate bulk containers (IBC) water tank – capacity 1000 litres **Water spray specification:** • Valve type: ball valve (cast iron) • No. of nozzle: Single nozzle • Dispensing mechanism: Manually operated	**Engine specification:** • Model: ROBIN 5HP EY20 Engine • Engine fuel: Gasoline **Water pump specification:** • Model: Built-in Hisaki 2" self-priming water pump • Spray capacity: 600 litres/minute (or 36 m^3/hour) • Water pump total head: 30 m • Maximum suction head: 8 m • Pump inlet and outlet size: 2 inch

3.5 Data Collection and Data Analysis

In this stage, the on-road test using the selected vehicle model shall be performed for both LDW and LKA systems, based on the pre-determined environment and road conditions. Three repetitions were executed for each environment and road condition parameters and the results were recorded as shown in Figure 7. Specialized on-board data acquisition system with two cameras from VBOX Racelogic and one independent high-resolution camera (GoPro brand) were installed to the test vehicle for data collection purposes. The visual data are used to capture the performance for both LDW and LKA systems. Meanwhile, the vehicle speed is measured based on GPS data from the on-board data acquisition system, whereas the ambient temperature and light intensity during the test are measured using light intensity meter with built-in thermometer (Figure 8).



(a) (b)

Figure 7: (a) Camera location setup (1: interior display panel, 2: front view from interior, 3: exterior side body panel); (b) VBOX camera location inside the car

Similar to the Euro NCAP LSS test protocol, the performance of the LDW and LKA system is based on the pass-fail criteria. Furthermore, four types of performance category are also proposed for the new ASEAN NCAP LSS protocol, namely its ability to make a correction and stay within lane, make correction but touch the lane, vehicle went over lane (no correction made by the LKA system), and LKA system disengage (did not function), as illustrated in Figure 9. The evaluation category for the LKA system was adapted from the recent research method published by the Insurance Institute for Highway Safety (IIHS, 2018). Finally, the performance measurement for the LDW system is ended when the system warning commences, whereas the LKA system measurement is ended when either system fails to maintain the vehicle within the permitted lane departure distance or the system intervenes to maintain the vehicle within permitted lane departure distance (manoeuvre vehicle back to the lane) (Euro NCAP, 2018). The proposed test sheet is shown in Appendix I.

(a) (b)

Figure 8: (a) Go-Pro camera location on the exterior; (b) Light intensity meter with built-in thermometer

Figure 9: Data collection plan at the varying environment and road conditions for a frequency of LKA system performance experiment to (1) stay within lane, (2) went over lane, (3) touch lane, and (4) system disengage

4.0 RESULTS AND DISCUSSION

The overall results in this preliminary investigation on the new ASEAN NCAP LDW and LKA test protocols are shown in Appendix II. For the vehicle test model used in this study, both LDW and LKA system is designed to activate at a minimum speed of 65 km/h. For all test scenario and all three repetitions, the test vehicle LDW and LKA system was found to perform successfully in providing the warning to the driver and make an automatic correction when the test vehicle was manoeuvred out of its safe trajectory. Figure 10 shows the visual images from the on-board camera during vehicle testing process. The findings showed that both new ASEAN NCAP LDW and LKA the proposed test protocol is viable to be implemented in the real on-road test condition. LDW and LKA assessment methods were only performed by visual data, and further validation was not able to be conducted since all the visual sensors were not synchronized to the same data capture time.

(a)

(b)

(c)

Figure 10: (a) Front view from the display panel and front view obtained from VBOX system during a dry test, (b) vehicle exterior view from the rear side obtained from Go-Pro system during dry test, (c) Front view from the display panel and front view obtained from VBOX system during a wet test

5.0 CONCLUSION AND RECOMMENDATIONS

In conclusion, preliminary investigation on the proposed new ASEAN NCAP's LDW and LKA protocols was successfully conducted. The protocols were proved viable to be implemented in a real on-road test setting especially to test the LSS performance in both dry and wet weather conditions, with consideration on the existing constraint especially with regards to the test facility and data collection equipment.

Furthermore, the preliminary investigation also highlighted many challenges and potential improvement works for a later stage in this study. Among the recommendations noted are as follows:

- To perform the on-road test at secured test track for safety during testing, to eliminate the risk of other road users from entering the test section. The secured test track should also not consist of any permanent obstacles on any road edges such as concrete kerb, lamp posts, trees, etc. which may impose further safety threat to the driver and test vehicle, and have adequate space besides both road edges, to compensate for LKA system malfunction during testing and ensure driver/vehicle safety.
- To use a dedicated data acquisition system which able to be operated using a minimum three cameras, and all cameras must be synchronized together to enable result validation especially on the time taken.
- To consider the "stabilization time" for the LDW and LKA system during test track design. This means that it required some time for the LDW and LKA system to fully activated after the recommended vehicle speed is achieved. Hence, this "stabilization time" will result in requiring additional track distance for the testing purpose.
- The LDW and LKA normally provide an audio and visual signal to the driver when the system is activated, respectively. However, for the Passat model, no audio signal is produced when the car deviates from the lane. The audio signal was replaced by a vibration signal on the steering wheel. Hence, to verify the system performance, it is recommended to use an auxiliary verification system to record when the LDW and LKA systems have become active. Such auxiliary system captured acoustic and optical alerts and signals generated by the LSS and produced a CAN or digital signal when recognising changes of the shapes and colours of defined icons or when audible signals are identified. The output of the auxiliary system can later be used as data by the same data acquisition system and synchronized to log the exact moment the vehicle safety message is displayed to the driver.
- To develop and use steering robots to accurately provide steering and throttle input (such as steering angle and lateral speed) when making lane departure. This will provide higher data accuracy and consistency during the test.
- To develop and use proper camera mounting arms to enable an uninterrupted view for the cameras, as well as not interrupting the driver's movement while driving the test vehicle (for enhanced safety purpose).
- To develop a rain simulator machine able to be activated remotely as well as explore other methods of dispensing the water with better control and mechanism.

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Appendix I. Proposed Test Sheet for New ASEAN NCAP LDW and LKA Evaluation

ANCHOR II

LANE DEPATURE WARNING (LDW) AND LANE KEEP ASSIST (LKA) TEST RESULTS

Vehicle Model: ______________________________

	Left Departure			**Right Departure**		
Test Number	**1**	**2**	**3**	**1**	**2**	**3**
Road Line (Dash/Solid)						
Weather condition (Dry/Wet)						
Date (d/m/y)						
Test Time (e.g. 0800)						
Ambient Temperature (°C)						
Light Intensity (Lux)						
Test speed (km/h)						
Steering angle (< 1°/s)						
Departure rate (0.2 – 0.5 m/s)						
LDW active (Yes/No)						
LKA active (Yes/No)						
Remarks: *e.g. car (1) stay within lane; (2) went over line; (3) touch line; (4) system disengage*						

Appendix II. Overall Results for LDW and LKA Tests

	Left Departure				Right Departure			
Test Number	-	-	-	-	-	-	-	-
Road Line (Dash/Solid)	Solid	Dash	Solid	Dash	Solid	Dash	Solid	Dash
Weather condition (Dry/Wet)	Dry	Dry	Wet	Wet	Dry	Dry	Wet	Wet
Test Time (e.g. 0800)	0934	0957	1635	1403	1124	1059	1547	1612
Ambient Temperature (°C)	31.8	31.8	36.8	38.1	38.8	35.1	37.4	37.1
Light Intensity (Lux)	12920	12920	56540	85570	22800	26980	55460	57830
Test speed (km/h)	74	73	73	71	74	73	73	74
Steering angle (< 1°/s)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Departure rate (0.2 – 0.5 m/s)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
LDW active (Yes/No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
LKA active (Yes/No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Remarks: *e.g. car (1) stay within lane; (2) went over line; (3) touch line; (4) system disengage*	1	1	1	1	1	1	1	1