EVALUATION OF VEHICLE LANE KEEPING ASSISTANCE (LKA) AND LANE DEPARTURE WARNING (LDW) SYSTEM FOR ADVANCED DRIVER ASSISTANCE SYSTEM (ADAS) TECHNOLOGY UNDER MALAYSIAN ENVIRONMENT CONDITIONS

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This report is submitted

in fulfillment of the requirement for the degree of

Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2020

DECLARATION

I declare that this project report entitled “Evaluation of Vehicle Lane Keeping Assistance (LKA) and Lane Departure Warning (LDW) system for Advanced Driver Assistance System (ADAS) Technology under Malaysian Environment Conditions” is result of my own work except as cited in the references.

Signature	:	....
Name	:	....
Date	:	....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of Degree of Bachelor of Mechanical Engineering.

Signature	:	....
Name of Supervisor	:	....
Date	:	....

DEDICATION

It is a dream in doing something big in my life and this project is a big part of my life. I dedicate this to my mama and abah for giving me a chance in pursuing degree and following my dream.

ABSTRACT

Lane Departure Warning (LDW) and Lane Keeping Assistance (LKA) systems are part for the Advanced Driver Safety Assist (ADAS) technologies which is equipped in latest passenger vehicle models sold in South-East Asia (SEA) countries. Both technologies are very beneficial to gain improved safety performance for vehicle occupants and surrounding road users (such as other vehicle occupants, pedestrians and cyclists), by alerting the driver and making automatic trajectory correction when the vehicle deviate away from the correct path while the vehicle moves. Nevertheless, there is yet any test protocol established by ASEAN New Car Assessment Programme (ASEAN NCAP) to evaluate the LDW and LKA performance tailored to SEA environmental conditions. Hence, in this project, preliminary investigation on the new test protocol developed for LDW and LKA based on SEA environment condition was conducted. The new protocol incorporated the effect of both dry and wet environment condition, which is unique to simulate the driving conditions in this region. The new test protocol is derived using EURO NCAP Lane Support System test procedure v.2.0.2 2018 as the benchmark. On-road test using actual passenger vehicle was conducted, using a dedicated rain simulator to simulate the rainy weather. The preliminary test was also performed on straight road condition. Results showed that the new test protocol was able to assess the effectiveness of the LDW and LKA system, at both dry and wet weather conditions.

ABSTRAK

Lane Departure Warning (LDW) dan Lane Keeping Assistance (LKA) adalah sebahagian daripada teknologi Advanced Driver Safety Assist (ADAS) yang dilengkapi dengan model kenderaan penumpang terkini yang dijual di negara-negara Asia Tenggara (SEA). Kedua-dua teknologi ini sangat bermanfaat untuk memperoleh peningkatan prestasi keselamatan bagi penghuni kenderaan dan pengguna jalan raya di sekitarnya (seperti penghuni kenderaan lain, pejalan kaki dan penunggang basikal), dengan memberi amaran kepada pemandu dan membuat pembetulan lintasan automatik ketika kenderaan menyimpang dari jalan yang betul semasa kenderaan bergerak. Walaupun begitu, masih ada protokol ujian yang ditetapkan oleh New Car Assessment Programme dalam kawasan negara ASEAN (ASEAN NCAP) untuk menilai prestasi LDW dan LKA yang disesuaikan dengan keadaan persekitaran SEA. Oleh itu, dalam projek ini, penyelidikan awal mengenai protokol ujian baru yang dikembangkan untuk LDW dan LKA berdasarkan keadaan persekitaran SEA telah dilakukan. Protokol baru menggabungkan kesan keadaan persekitaran kering dan basah, yang unik untuk mensimulasikan keadaan pemanduan di wilayah ini. Protokol ujian baru dihasilkan menggunakan prosedur ujian Sistem Sokongan Lorong EURO NCAP v.2.0.2 2018 sebagai penanda aras. Ujian di jalan menggunakan kenderaan penumpang sebenar telah dilakukan, menggunakan simulator hujan khusus untuk mensimulasikan cuaca hujan. Ujian awal juga dilakukan pada keadaan jalan lurus. Hasil kajian menunjukkan bahawa protokol ujian baru dapat menilai keberkesanan sistem LDW dan LKA, baik pada keadaan cuaca kering dan basah.

ACKNOWLEDGEMENT

First and foremost, I would like to express my gratitude to Allah S.W.T., as I am able to complete my final year project with His blessing. It is a great opportunity to carry out this final year project as I have learned a lot of new things. This final year project work is part of the international research grant ANCHOR II project funded by New Car Assessment Program for Southeast Asian Countries (ASEAN NCAP) 2019, involving Universiti Teknikal Malaysia Melaka (UTeM), Motordata Research Consortium (MRC) Malaysia, Bina Nusantara University Indonesia and Malaysian Institute of Road Safety Research (MIROS).

I would like to express my deepest appreciation to Ts. Dr. Muhd Ridzuan bin Mansor as my supervisor for giving me this opportunity to do final year project with him. He always gave me a full support, and never hesitated to give me advice and guidance whenever I needed the most. He is so brilliant in giving fruitful ideas and I am thankful for his wisdom and patience while leading me in this project. Special thanks as well to my faculty, Fakulti Kejuruteraan Mekanikal, Universiti Teknikal Malaysia Melaka for the great facilities, FKM lecturers for valuable knowledge and Malaysian Institute of Road Safety Research (MIROS) for giving me an opportunity to be involved in this big project.

Next, would be my mother, Anita Binti Zakaria, my father, Arshad Bin Ahmad and my siblings who always give me an endless support and love. Those morale supports are really precious and it does give me a major boost in finishing my project successfully. I would like to thank my course mates for giving me their support, patience and encouragement. Finally, I would like to thank to my closest friend who always with me through thick and thin.

CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ADAS	Advance Driving Assistance System
LKA	Lane Keeping Assistance
LDW	Lane Departure Warning
NCAP	New Car Assessment Program
MIROS	Malaysian Road Safety Research Institute
AOP	Adult Occupant Protection
COP	Child Occupant Protection
SATs	Safety Assist Technologies
ESC	Electronic Stability Control
SBR	Seatbelt Reminder
AEB	Autonomous Emergency Braking
DAQ	Data Acquisition
ACC	Adaptive Cruise Control
BSM	Blind Spot Monitoring
DLC	Distance to lane crossing
TLC	Time to lane crossing
SW	Southwest
NE	Northeast
NHTSA	National Highway Traffic Safety Administration
LSS	Lane Support System
VUT	Vehicle Under Test

GVT	Global Vehicle Target
DGPS	Differential Global Positioning System
PBC	Peak Braking Coefficient
UNESE	United Nations Economic Commission for Europe
LIDAR	Light Detection and Ranging
OEM	Original Equipment Manufacturer
SAE	Society of Automotive Engineers
ABS	Antilock braking system
3D CAD	Three-dimensional computer-aided design
PDS	Product Design Specifications
PVC	Polyvinyl Chloride

CHAPTER 1

INTRODUCTION

1.1 Background

Advance Driving Assistance System (ADAS) is a system designed to assist the driver when driving. It has become an essential technology for vehicles equipped to reduce road accidents and fatalities. Lane Keeping Assistance (LKA) and Lane Departure Warning (LDW) are some of the feature examples provided by ADAS. Those examples are also known as Lane Support System. Lane Support Systems can support and alert the driver if they leave the road lane suddenly or switch the lane without providing a signal. The negligence conduct of the driver is enough to stray the vehicle from its lane. The systems monitor the vehicle's position on the road and while LDW warns the driver if the vehicle inadvertently drives off the road, LKA helps them to correct the course of their vehicle. (www.euroncap.com, 2019).

1.1.1 Lane Departure Warning

LDW is a camera-based system that recognizes lane markings and is activated when a driver is about to leave a lane without using the turning signal being used. A driver can drift inadvertently towards the line identifying the edge of the lane on a long highway journey. Very often, the driver will not be aware that the car is in a potentially dangerous situation until such time as the situation becomes severe, for example, the car's tires may be on the grass or gravel on the side of the road or, in extreme cases, the car may find itself in the path of oncoming. This sudden, late realization may trigger a panic response that causes the driver to lose control over the vehicle, sometimes resulting in a crash.

Several manufacturers have developed technologies that warn the driver as the car approaches a lane marking. Various systems use different warnings: some give an audible signal while others use a vibrating steering wheel to simulate the car's feeling running over a 'rumble strip'. The intention is simply to inform the driver that there is a danger that the car will cross the line. Many systems only need a line on one side of the vehicle, while other systems depend on different lines on either side.

Manufacturers take great care to ensure that the signal does not irritate drivers unnecessarily irritate drivers and is always in control. Most systems operate at above 60 km/h and, if the direction indicator is used, it suppresses the warning signal

A camera is usually positioned at the top of the windscreen, behind the rear view mirror. A computer continually analyses the images of this camera to identify the lane markings and, in some cases, an unmarked edge of the road. At the same time, the steering input of the driver is monitored along with the vehicle's speed and trajectory. These parameters are combined to determine whether or not the car is about to depart the lane of travel.

LDW rely on distinct lane markings that will reduce their efficiency if lines cannot be clearly distinguished, such as in heavy rain or fog, or if the road markings are obscured by mud or snow. In such cases, the driver is given an indication that the system could not assist.

1.1.2 Lane Keeping Assistance

LKA systems tackle LDW related accident circumstances. Although alert systems, however, depend on the driver for corrective action, LKA also proactively steers the car back into the lane. The machine gently steers the car away from the line until it is safely inside the lane when the vehicle is close to the lane marking. The system can control the car either by applying gentle braking on one wheel or by applying a direct steering input in the case of electrical steering systems.

Drivers however should not rely on LKA to do their driving for them. Some systems deactivate if they sense that the driver is no longer steering the vehicle. In any case, the systems can take corrective action only if the lane marking is being approached very gradually which that more rapid departures cannot (and should not) be corrected by LKA systems.

1.2 Problem Statement

Models with innovative safety features were quickly adapted by manufacturers to remain competitive and comply with strict regulatory reform. Somehow, these features are quite new and their safety could not be fully guaranteed. To verify that the features are sufficiently safe, the car should be tested. The New Car Assessment Program is responsible for these tests. For this scope of project, the NCAP is Southeast Asia based, and it is known as ASEAN NCAP.

ASEAN NCAP is an automotive safety rating program established jointly by the Malaysian Road Safety Research Institute (MIROS) and the Global New Car Assessment Program (Global NCAP). It is also a new addition to the NCAP family and is aimed at evaluating vehicle safety standards, raising awareness among consumers and thus promoting the region's market for safer vehicles. The ASEAN NCAP rating plate consists of important information of the crash tested vehicle; make and model, star ratings of Adult Occupant Protection (AOP) and Child Occupant Protection (COP), side impact test result, crash test date and fitment status of Safety Assist Technologies (SATs) (www.aseancap.org, 2019). Adult Occupant Protection is determined from frontal impact, side impact and whiplash tests, which are carried out to evaluate the protection of adult driver and passengers offered by the vehicle while the assessment of Child Occupant Protection covers three aspects which are the protection offered by the child restraint systems in the frontal and side impact tests, the vehicle's ability to accommodate child restraints of various sizes and designs and the availability of provisions for safe transport of children in the car.

For Safety Assist Technologies, Electronic Stability Control (ESC) and Seatbelt Reminder (SBR) system have been considered in the rating system as a prerequisite for tested vehicle to obtain a 5-Star rating. This requirement is valid until end of 2016. For the ASEAN NCAP new rating system for 2017–2020, Safety Assist requirement has changed and improved considerably. Apart from ESC and SBR, which dominantly affect the scoring, new technologies such as Blind Spot Indicator, Autonomous Emergency Braking (AEB) and other up to date devices have been considered in the rating system. (www.aseancap.org, 2019).

The Table 1.1 below shows the selected NCAP whether they have conducted the test protocol for Safety Assist System specifically for LDW and LKA. Based from the Table 1.1, many NCAP have obtained their test protocol for evaluating the LKA and LDW except for ASEAN NCAP. Hence, ASEAN NCAP needs to develop new comprehensive test protocol for evaluating ADAS safety assist system, specifically LDW and LKA systems. This initiative is for making the rating system under Safety Assist to become more accurate. The test protocol should be based on South-East Asia environment and road conditions, to reflect current situation of ASEAN road users.

Table 1.1: Existence of test protocol of LDW and LKA for selected NCAP

NCAP	LDW	LKA
ASEAN NCAP	X	X
Euro NCAP (www.euroncap.com, 2019)	✓	✓
JNCAP (Japan) (www.nasva.go.jp, 2019)	✓	✓
ANCAP (Australasia) (www.ancap.com.au, 2019)	✓	✓
National Highway Traffic Safety Administration (United States of America) (www.safercar.gov, 2019)	✓	✓

1.3 Objectives of Study

The main objectives of this research are:

i. To develop new test protocol for LDW and LKA systems based on selected environment and road conditions parameters.

ii. To test the car equipped with LDW and LKA Safety Assist Systems under simulated dry and rainy weather conditions

1.4 Research Scopes

i. To design and develop on-road test facilities to run the test protocol based on the selected environment and road conditions parameters.

ii. To perform on-road test for the LDW and LKA systems using selected vehicle models.

iii. Data gathering using on-board Data Acquisition (DAQ) system and data analysis.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

This chapter mainly discusses on the concept of LDW and LKA, which are among the ADAS. Based from the concept, it will clearly show on how does the mechanism of the systems works. Besides that, it will show on how the climate and weather affects the performance of the systems. This chapter then briefly introduces on the test protocols that have been done from the benchmarked NCAP from abroad.

2.1 Advanced Driver Assistance Systems

Kannan et al. (2010) and Paul et al. (2016) states that every year, the road accidents cause 1.2 million death and up to 50 million injuries across the world due to the problems such as traffic congestion, rash driving and lane changing. According to Navarro et al. (2017), around 40 percent of all crashes in European countries because of lane departures. For South-East Asia countries with likes of Malaysia and Thailand have been ranked as the country with the highest fatalities per 100,000 populations in the world from year 1996 to 1999 (Jacobs et al., 1999).

ADAS systems are classified into information-based assistance systems and manipulation-based assistance systems where the information-based systems only provide the human driver with the appropriate information and warnings (Kala, 2016). The context-conscious ADAS focus to assist drivers and react to the setting as indicated to the change in environmental circumstances (Paul et al., 2016). By inputting sensors around the vehicle, driver support systems designed for assisting the driver by calculate some form of feedback (Narote et al., 2018). According to Werneke et al. (2008), Trübswetter et al. (2013) and You et al. (2015), ADAS are available for driver safety, comfort and convenience. Types of driver assistance systems are Adaptive Cruise Control (ACC), Blind Spot Monitoring (BSM), LDW and LKA (Stanton et al., 2001) (Suzuki, 2003) (Navarro et al., 2017).

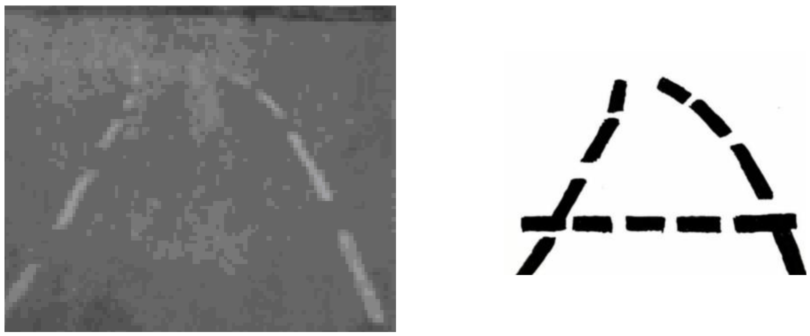
2.2 Lane Departure Warning System

According to Faulks et al. (2009), Xu et al. (2012) and Haupt et al. (2013), LDW is a device designed to alert the driver when the car starts to approaching out of its lane unless there is a turning signal in that direction. Shiller et al. (2010), Li et al. (2015) and You et al. (2015) states that the system will against the attempt of a risky lane change maneuver and prevent the driver from possible front collision based on the concept of velocity obstacles. If the car shows up within a distance of a marker, the driver will be notified and corrective action takes place. LDW continually keep track of the vehicle's position on both sides of the lane markers (Barickman, 2005) (Narote et al., 2018). The alert from the system will be in form of sound and warning display (Tseng et al., 2009) (Mahajan et. al., 2015) (Yoshida et al., 2015).

Involuntary lane departure due to inattention of the driver, distractions and fatigue can be minimized and collision can be prevented by using LDW (Rudin et al., 2018) (Narote et al., 2018). LDW can reduce road accidents caused by drowsiness and disturbance (Xu et al., 2015) (Solaz et al., 2016). The warning can expect the drivers would make immediate changes to their direction, speed, or both to avoid accidents, which was considered an integral part of the driver assistant program (Xu et al., 2015).

2.2.1 System Overview of LDW

According to Yu et al. (2008) and Zhang et al. (2012), the key modules that made out of LDW is lane detection module. Figure 2.1 shows (a) normal lane picture and (b) lane model to express the lane detection module.



(a) (b)

Figure 2.1: (a) normal lane picture and (b) lane model (Yu normal lanes were picked up from Figure 2.1(a) and from Figure 2.1(b), it shows the image of the normal lanes. To get the image of Figure 2.1(b), the Figure 2.1(a) is to be calculated by using specific equation (Yu et al., 2008). The equation used is:

$$f(x) = \begin{cases} a + bx, \ if \ x > x_m & (2.1) \\ c + dx + ex^2, \ if \ x \leq x_m & (2.2) \end{cases}$$

Where:

i. x_m represents border between near and far fields

ii. a, b, c, d, and e are constants

By using suitable x_m, the image will be split into two as shown in Figure 2.1(b) and Figure 2.2 below. The split image has 2 areas to be seen on the image dividing which are for the top area, it does not have the lane information as it is more to the object image while for the bottom area, it has the lane information to be read (Yu et al., 2008). Figure 2.2 shows the image dividing on the screen.

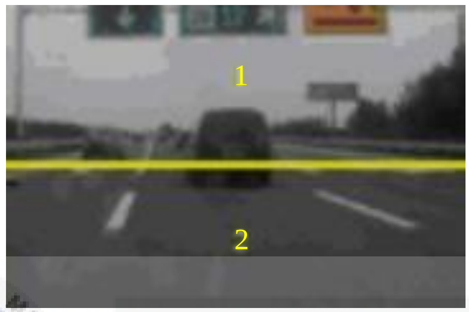


Figure 2.2: The image dividing on the screen (Yu et al., 2008)

There are a lot of LDW are being introduced in this decade and exist in the marketplace (Habeeb et al., 2018). Figure 2.3 shows one of the LDW available in the marketplace.

Figure 2.3: One of the LDW available in the marketplace (Habeeb et al., 2018)

The LDW camera capable of capturing the scene at the front of the car as the forward- facing camera positioned in the rear-view mirror inside the windscreen. This camera can read the information of lane positions (Britt et al., 2009). Figure 2.4 shows the images captured by LDW during (a) the straight-line road, (b) left-curved road and (c) right-curved road with object detection (Habeeb et al., 2018).

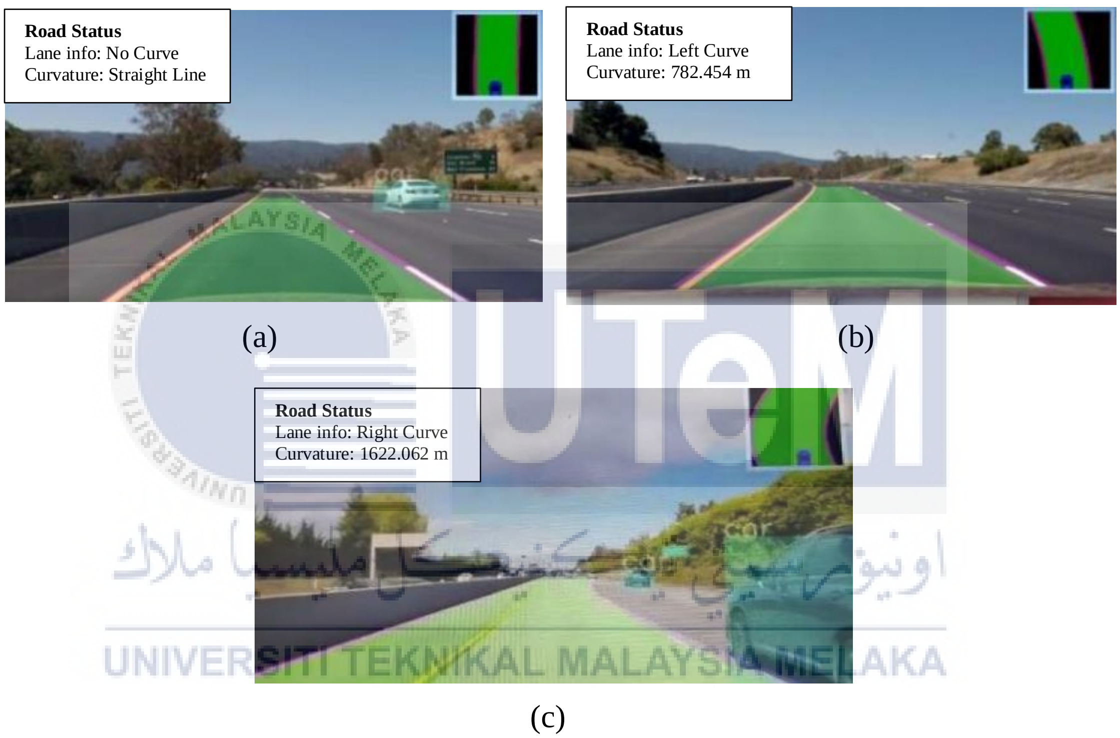


Figure 2.4: The images captured by LDW during (a) the straight-line road, (b) left-curved road and (c) right-curved road with object detection (Habeeb et al., 2018)

2.3 Lane Keeping Assistance

According to Jermakian (2011), it could save up to 3 percent of serious collisions, 5 percent of medium or moderate injury collisions and 23 percent of passenger car fatal collisions if every passenger car in the United States was equipped with lane-keeping technology. According to Sternlund et al. (2017), as the car is about to drive beyond the lane edge of the current travel lane, the driver will be alerted by the system to encourage the process of returning to normal driving position. The system will keep the vehicle within the lane by applying steering torque (Madas et al., 2013). According to Leelavansuk et al. (2003), LKA is designed to control the vehicle as human driver in lane-keeping task. Figure 2.5 shows the process of LKA system behaves.

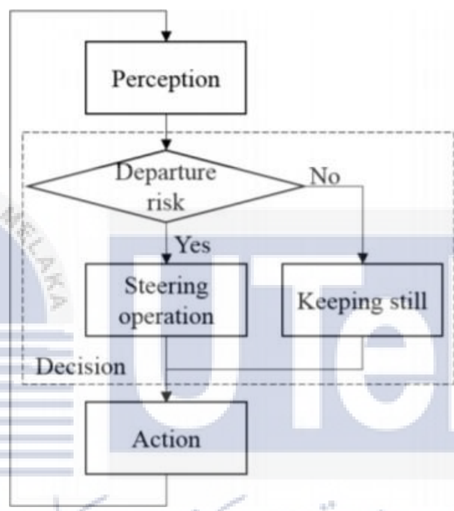


Figure 2.5: The process of LKA system behaves (Lan et al., 2017)

Based from the Figure 2.5 above, the driver interprets the state and surrounding around the car, which can be defined as perception. The driver will then assess the risk of the lane departure. If there is a risk, the driver will give command of steering operation, or else it will give command of keeping still in mind, which is defined as decision. Finally, driver will perform the command, which is defined as action (Lan et al., 2017).

2.3.1 System Overview of LKA

According to Kim et al. (2013), Lee et al. (2014) and He et al. (2018), a common LKA algorithm is activated at a speed of more than 60 km/h. It is assumed that the slip angles of the left and right wheels are small enough to assume that the lateral tire force is proportional to the slip angle of the corresponding tire. Figure 2.6 shows a vehicle model that used to describe the error with respect to road. (Rajamani, 2005).

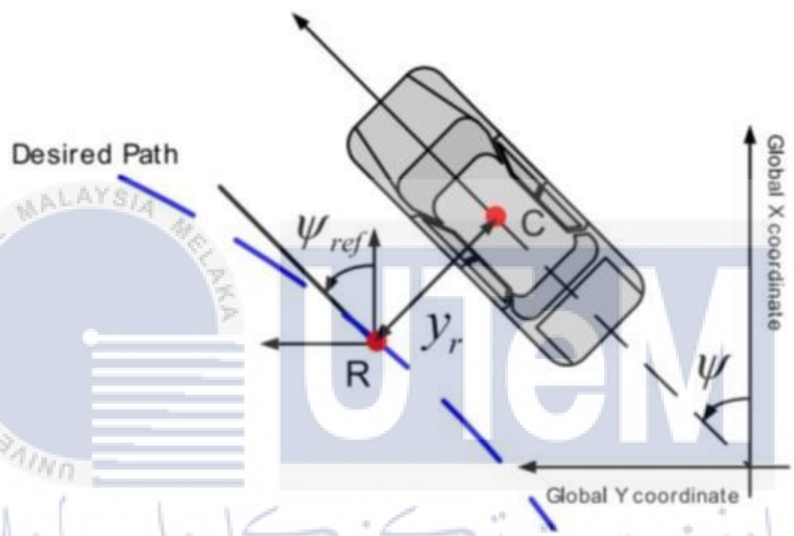


Figure 2.6: A vehicle model that used to describe the error with respect to road (Rajamani, 2005)

The probability of the lane departure can be calculated if it is known that a driver does not intend to change the lane. According to Mammar et al. (2006), to calculate the lane departure, the remainder distance to lane crossing (DLC) and the time to lane crossing (TLC) are used. As for DLC, it is the measurement of the car's remaining distance from the lane. While for TLC, it is the estimation of the remaining time before the car leaves the lane boundary. Analyzation of the collected driving data on a real road during lane processing is needed to determine the sufficient threshold for the lane departure decision with DLC (Lee et al., 2014). Table 2.1 shows the statistical characteristics of DLC in lane keeping situation. From the Table 2.1, disregarding the speed of the car, it shows that most of the driver usually keep a DLC more than 0.4 m in lane-keeping circumstances (Lee et al., 2014).

Table 2.1: Statistical characteristics of DLC in lane keeping situation

Speed (km/h)	DLC		
	Mean	σ	Mean - 3σ
60 – 70	0.6399	0.0408	0.5174
70 – 80	0.6343	0.0588	0.4580
80 – 90	0.6506	0.0526	0.4926
90 – 100	0.6490	0.0500	0.4992
100 – 110	0.6408	0.0733	0.4208

To find the TLC, assume that the lateral speed of a vehicle is constant for a short period of time. The lateral departure speed is determined by the product of longitudinal speed and relative heading angle between the vehicle and centre line of lane, e_ψ (Lee et al., 2014). The equation that can be used is:

$$TLC = \frac{DLC}{V_{lateral}} \simeq \frac{DLC}{V_x e_\psi} \qquad (2.3)$$

Where:

i. $V_{lateral}$ is lateral velocity of car

ii. e_ψ is desired yaw rate

iii. Vehicle longitudinal velocity

If either DLC or TLC is below a predefined threshold, there is a high probability of lane departure in the current driving state. Then, there is a need for active assistance. A DLC threshold of 0.4 m was selected based on the results of this study to determine the activation time of the lane-keeping assistance controller (Lee et al., 2014). Based on previous studies, a TLC threshold was chosen as 0.4 s (Pohl et al., 2007).

According to Lee et al. (2014), the lane departure should be avoided and the car should be directed into a lane boundary. According to Lan et al. (2017), the working process of lane departure can be divided into three parts, which are intervention timing, intervention process and intervention ending. Intervention timing is the timing when LKA begins to interfere in the regulation of the steering to return vehicle. Intervention process is how LKA returns vehicle back, and intervention ending is the timing when LKA completes the return maneuver. Figure 2.7 shows the working process of LKA.

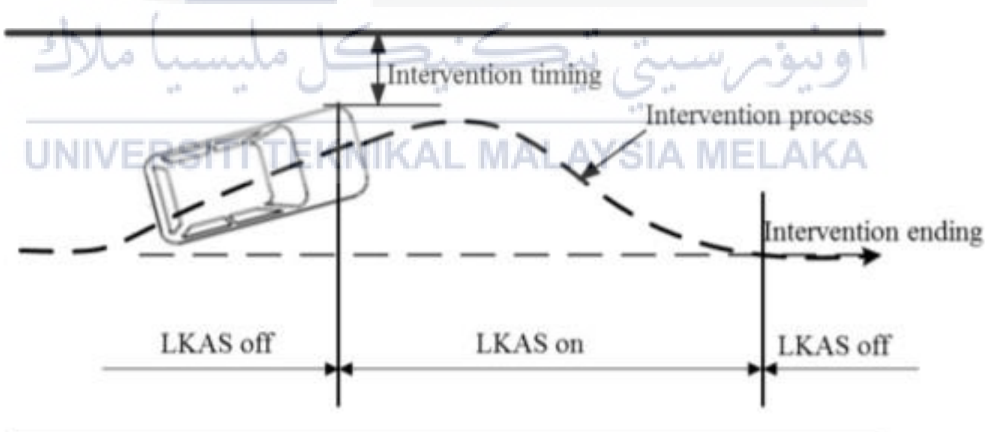


Figure 2.7: The working process of LKA (Lan et al. 2017)

2.4 The Effects of Climate and Weather

Based on data from National Highway Traffic Safety Administration, there are more than 5,760,000 vehicle accidents annually and a roughly of 22 percent of the accidents are weather-related with slick pavement. About 19 percent of the accidents left injured are from weather-related and 16 percent of crash fatalities are from weather-related (Hamilton, 2016). Figure 2.8 illustrates the data in pie chart form.

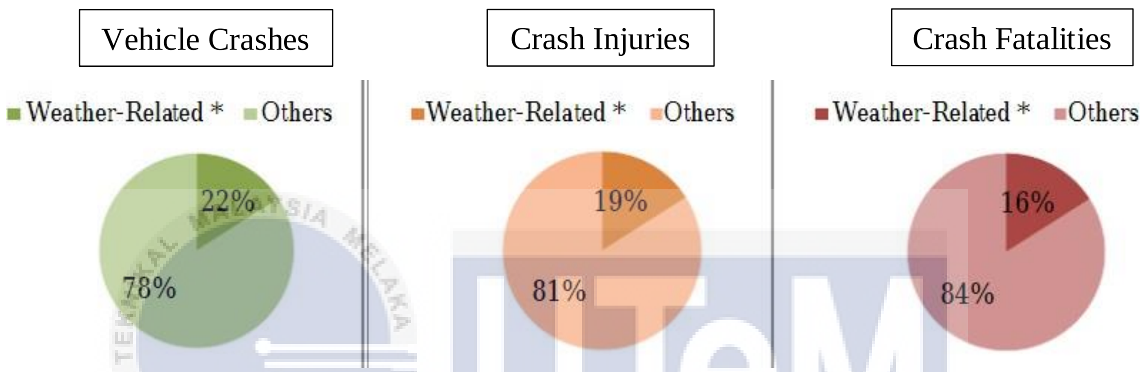


Figure 2.8: Data illustration in pie chart form (www.ops.fhwa.dot.gov)

Low visibility conditions such as fog and rain, have been found to increase the risk of an accident (Peng et al., 2017). More precisely, accidents involving three and more cars are common in rainy conditions (Bernardin et al., 2014). There are two rainfall weather categories, which are heavy rain and light rain. The rainy weather is rated on the basis of the road signs' visibility and readability, and the surrounding roadside (Ghasemzadeh et al., 2018). If the captured video shows a high rate of wiper swipe with limited sights of road markings, unclear road signs and cannot see the surroundings on the road clearly, it is a heavy rain. If the captured video is opposite from the description of heavy rain, it is a light rain (Ghasemzadeh et al., 2018). It is confirmed that the risk increase was greater in heavy rain than in light rain (Bernardin et al., 2014).

2.4.1 South-East Asia's Climate

There is a total of 11 countries situated at South-East Asia. One of the countries from South-East Asia is Malaysia. Malaysia is located near to Thailand, Singapore, Brunei and Indonesia and separated in two regions which are Peninsular Malaysia and East Malaysia. Malaysia's tropical climate is significantly different in terms of rainfall, temperature and wind across the country (Zulhaidi et at., 2010).

Malaysia's mean annual rainfall is relatively high at 2,500 mm, ranging from a low 1,500 mm up to over 4,000 mm. The wind pattern, which are Southwest Monsoon (SW) and Northeast Monsoon (NE), is very much determined by heavy rainfall. The SW monsoon takes effect from around the beginning of June to September, while the NE monsoon takes effect from November to March. The inter-monsoon period between the two prominent winds is relatively light and variable (Zulhaidi et al., 2010).

From 1997 to 2007, the total number of accident cases investigated was about 3 million, but the weather-related cases were only about 98,000. This figure accounted for only 3 percent of the total cases, with the highest annual performance in 2007 which is over 8 percent and the lowest in 2003 which is less than 4 percent. Most of road accidents took place on fine days. However, it was found that 20 percent of cases can be attributed to bad weather conditions, and nearly all of them were rain-related cases. It was also observed that some accidents occurred not only because of the single weather, but also in combination with other conditions such as rain and light fog (Zulhaidi et al., 2010). Figure 2.9 shows the annual mean monthly rainfall at Peninsular Malaysia and Figure 2.10 shows the annual mean monthly rainfall at East Malaysia.

Mean Monthly Rainfall (Annual)

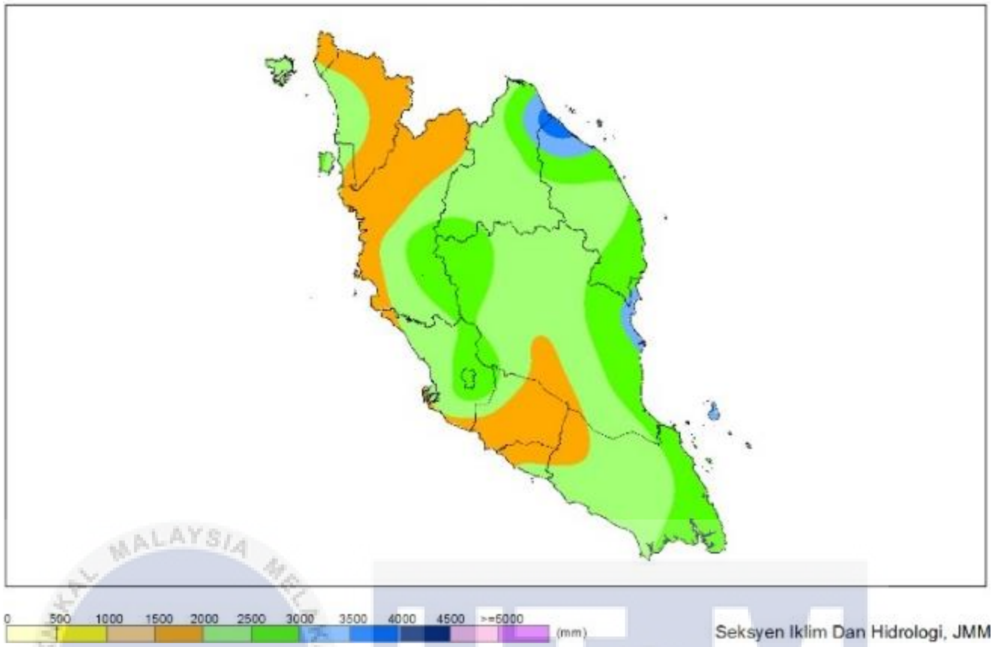


Figure 2.9: The annual mean monthly rainfall at Peninsular Malaysia (www.met.gov.my)

Mean Monthly Rainfall (Annual)

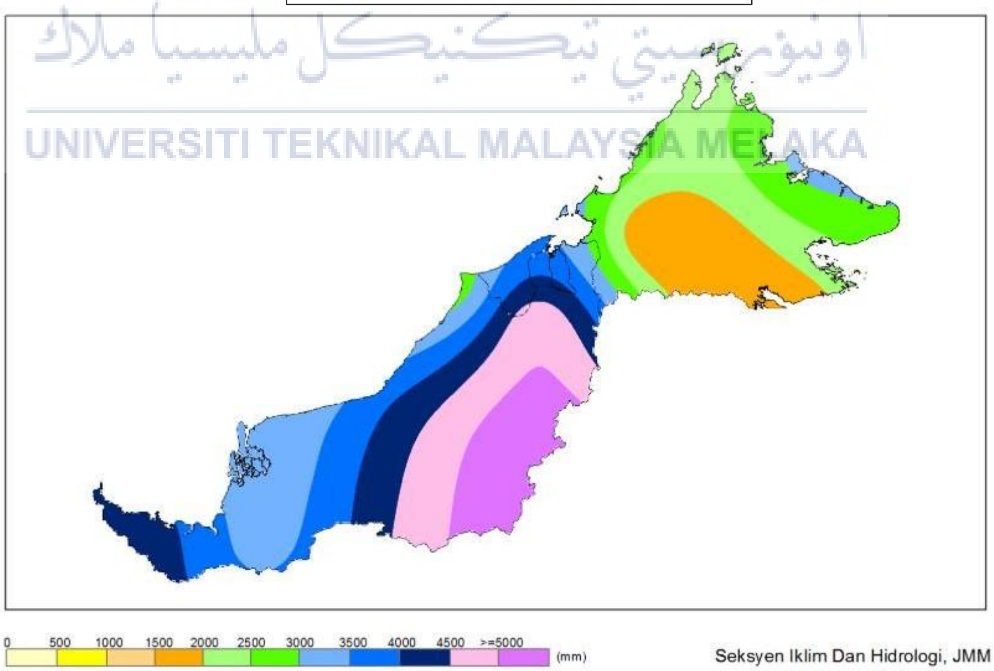


Figure 2.10: The annual mean monthly rainfall at East Malaysia (www.met.gov.my)

Malaysia's motorists are highly exposed to rain or wet pavement driving. High exposure to this condition could result in severe threats immediately or in the longer term. Heavy rain in the country has also been observed to create serious visibility problems (Zulhaidi et al., 2010). Due to poor visibility and slippery surface conditions, adverse weather conditions could exacerbate poor lane keeping. Learning driver behaviour and reaction in adverse weather conditions, specifically when visibility is reduced below a certain amount, can be helpful not only in reducing lane-departure collisions, but also in identifying an effective threshold for LDW systems in adverse weather conditions (Ghasemzadeh, 2018)

2.4.2 Limitation of the System Due to Weather Conditions

The type of road and the mixture of the two of lighting and precipitation greatly affected the availability of LDW (Wilson et al., 2007). According to Gayko (2012), the lane marker recognition setting and lighting conditions can differ in a wide range. Direct sunlight, tunnels, rainy weather, and other conditions must be taken into consideration as there may be disturbing reflections. Under certain circumstances, a white lane marker can appear darker than the pavement. Rain and wet weather conditions can make the markings unclear, particularly at night (Hadi et al. 2007). Moreover, according to Penmetsa et al. (2018) and Lee et al., (2018), the existed LDW systems does not work precisely if the lane markings are clearly not visible due to weather conditions, light conditions, or poor lane markings. The system also may be struggle to read the lanes due to the existence of shadow on the lane (Yoo et al., 2017). This shows that different lighting conditions may have an effect on the vision-based systems used in LDW (Kusano et al. 2012). According to

Gordon et al. (2010), the system availability of LDW is ranged of more than 90 percent during daylight condition and less than 20 percent during nighttime and wet roads.

2.5 Test protocols available for both LDW and LKA

Table 1.1 from Chapter 1, shows the existence of test protocol for LDW and LKA systems for selected NCAP. From that, it shows that there are many NCAP have conducted the test protocols before. From the findings at the web, there are some similarities of the test protocols from the selected NCAP, which are Euro NCAP, Japan NCAP, Australasia NCAP, and US NCAP, which is known as National Highway Traffic Safety Administration (NHTSA). Table 2.2 shows some similarities of the test protocols.

Based from Table 2.2, it shows that Australasia NCAP has the most similarities with Euro NCAP's test protocols. This can clearly show that Australasia have implemented the same test protocol as Euro NCAP. Other than that, there are a few similarities of some descriptions between Euro NCAP and Japan NCAP with NHTSA. This can be verified that almost all of the test protocols are the same as Euro NCAP's test standard.

Table 2.2: Similarities of the test protocols

DESCRIPTION	TEST PROTOCOL			
	Euro NCAP (euroncap.com)	Australasia NCAP (ancap.com.au)	Japan NCAP (nasva.go.jp)	NHTSA (nhtsa.gov)
200 kg of interior load	✓	✓	✓	X
Usage of Original manufacturer tires of the vehicle	✓	✓	✓	✓
Fuel tank	At least 90 %	At least 90 %	Full Tank	At least 75 %
Spare tire	✓	✓	✓	✓
Weather condition	Above 5 ºC below 40 ºC	Above 5 ºC below 40 ºC	Above 0 ºC below 40 ºC	Above 0 ºC below 38 ºC
Wind speed	Below 10 m/s	Below 10 m/s	Below 5 m/s	Below 10 m/s
External Camera	✓	✓	✓	✓
Lane requirement same as Euro NCAP		✓	X	X
Maximum 2000 Lux natural ambient illumination	✓	✓	✓	X

CHAPTER 3

METHODOLOGY

3.0 Overall Process Method

This chapter gives the layout of the research method followed throughout the research project. It provides the information on the method used to obtain the data of the on- road test. The function of the LKA and LDW systems are first studied. Then, the test protocol of LKA and LDW are being developed which can smoothen the flow of the test and helps for brainstorming the test facility needed. After the test protocol has been developed, the test facility that is rain simulator is being developed. After that, the on-road test for sunny and rainy weather, which is South-East Asia's weather, is being conducted. The rainy weather will use the Rain Simulator to simulate the rainy weather during the test. After test protocol has been successfully done, the analysis of data will be collected. Figure 3.1 shows the overall research flowchart on the test protocol data gathering and the Gantt chart for PSM 1 and PSM 2 are shown in the appendices.

3.1 Development of LDW and LKA Test Protocol

Typical accidents are usually caused by an accidental departure of the lane where the driver drives to and across the line identifying the edge of the lane. Quite often, the driver does not know that the car is in a potentially dangerous situation until the situation is critical: the tires of the car may be on the grass or on the side of the road or, in extreme cases; the car may be on the verge of oncoming or overtaking traffic. The late realization of the driver can cause a panic response: the driver loses control over the vehicle, which often leads to a crash. The seriousness of the injury is usually high, but this type of accident is easy to avoid with a lateral support system, resulting in potentially significant improvements in health.

This procedure specifies the test protocol for Lateral Support Systems, which is part of the assessment of the Safety Assist based from Euro NCAP. If applicable, LKA and LDW systems are tested. The vehicle are equipped with an ESC system, which met the regulatory requirements to qualify for lane support system (LSS) score points.

Figure 3.1: Overall research flowchart on the test protocol data gathering

3.1.1 Convention and Lateral Path Error

For the vehicle under test (VUT) the convention specified in ISO 8855:1991 is used in which the x-axis points to the front of the vehicle, the y-axis to the left and the z-axis upwards (right-hand system), originated at the most forward point of the VUT centre line for dynamic data measurements. Figure 3.2 shows the coordinate system and notation.

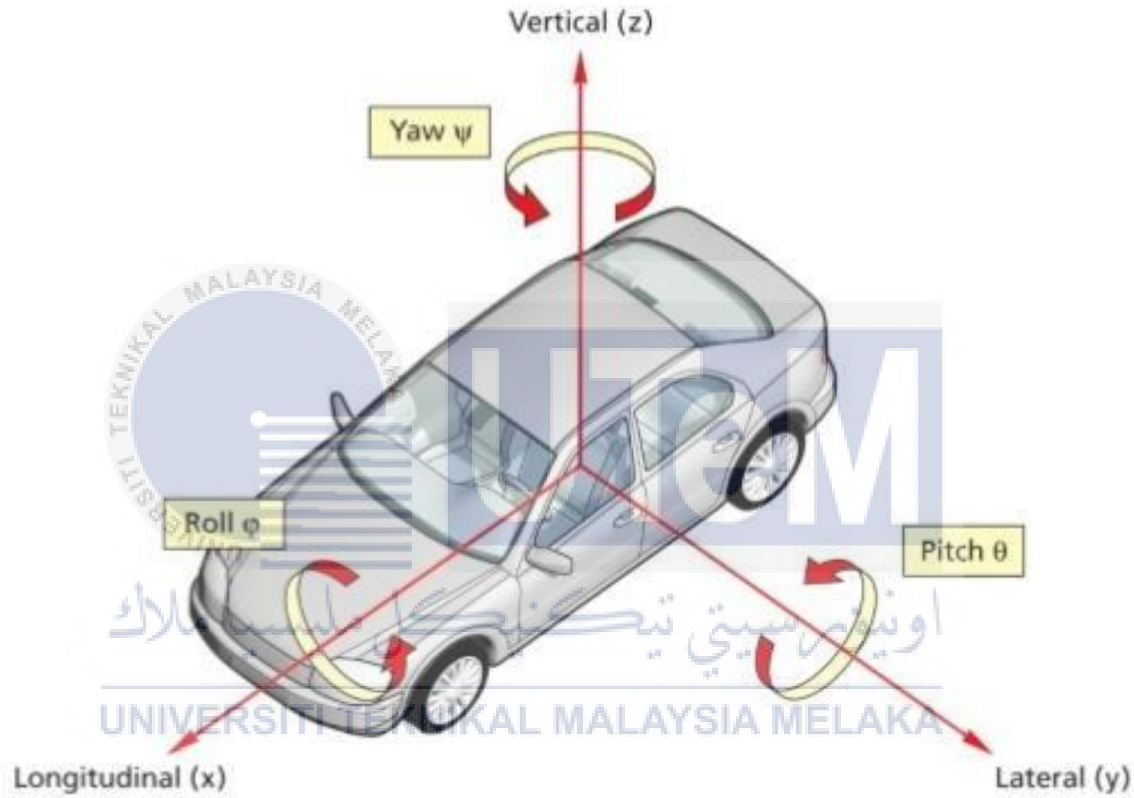


Figure 3.2: Coordinate System and notation (www.euroncap.com, 2019)

Based from Figure 3.2, Viewed from the origin, roll, pitch and yaw rotate clockwise around the x, y and z axes respectively. Longitudinal refers to the measurement component lateral along the y-axis, and the component vertical along the z-axis. This reference system should be used for both left and right-hand drive vehicles tested.

For the lateral path error, it was determined as the lateral distance between the centres of the front of the VUT when measured in parallel to the intended path. This measure applied during both the straight-line approach and the curve that established the lane departure. Lateral Deviation from Path is equalled to the Y_{VUT} error. Figure 3.3 shows the lateral path error.

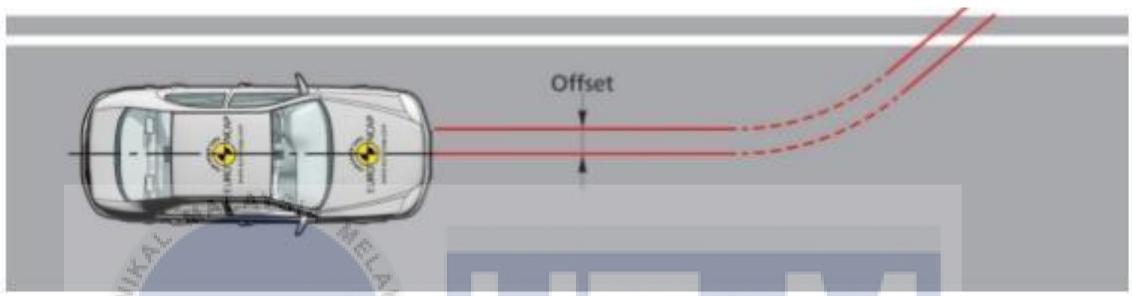


Figure 3.3: Lateral path error (www.euroncap.com, 2019)

3.1.2 Measuring Equipment

Noted that the dynamic data at a frequency was sampled and recorded of at least 100Hz. The data was synchronized by using the differential global positioning system (DGPS), time stamp the Global Vehicle Target (GVT) data with that of the VUT. For variables of the test, it was included:

For Time:

- T_0, time where maneuver starts with 2s straight path
- T_{LKA}, time where LKA activates (for calibration purposes only if required)

- T_{LDW}, time where LDW activates
- T_{steer}, time where VUT enters in curve segment
- $T_{crossing}$, time where VUT crosses the line or road edge Other specific variables that uses during the entire test:
- X_{VUT} and $Y_{VUT,}$ position of the VUT
- X_{GVT} and $Y_{GVT,}$ position of the GVT
- $V_{long,VUT}$ and $V_{lat,VUT,}$ speed of the VUT
- V_{GVT}, speed of the GVT
- $\boldsymbol{\Psi}_{VUT}$, yaw velocity of the VUT
- $\boldsymbol{\Psi}_{GVT}$, yaw velocity of the GVT
- Ω_{VUT}, steering wheel velocity of the VUT

The VUT was equipped with data measurement and acquisition equipment to sample and record data with an accuracy of at least:

- VUT and GVT longitudinal speed to 0.1km/h;
- VUT and GVT lateral and longitudinal position to 0.03m;
- VUT heading angle to 0.1°;
- VUT and GVT yaw rate to 0.1°/s;
- VUT longitudinal acceleration to 0.1m/s^2;
- VUT steering wheel velocity to 1.0°/s.

For filtered data, noted that the position and speed data are not filtered and was used in their raw state. Acceleration, yaw rate, steering wheel torque and steering wheel velocity with a 12-pole phase less Butterworth filter with a cut off frequency of 10Hz.

3.1.3 Track Preparation

For the test track, the test was conducted on a dried surface with no visible ground moisture. The track was a standard solid-paved surface with a maximum longitudinal slope of 1 percent, less than 2 percent for half a lane width on either side of the centreline and less than 3 percent for the lateral outer half of the trial lane. The test surface has a minimum peak braking coefficient (PBC) of 0.9, paved and does not contain any defects such as wide dips or cracks, manhole coverings or reflective studs at a lateral distance of 3 m to either side of the test lane core and a longitudinal distance of 30 m from the point after the test was completed.

For lane markings, two different types of lane markings conforming to one of the lane markings as specified in United Nations Economic Commission for Europe (UNECE) Regulation 130 was needed to mark a lane with a width between 3.5 m to 3.7 m and a road edge, which are:

i. Dashed line with a width between 0.10 and 0.25m (0.10 and 0.15m for centrelines)
ii. Solid line with a width between 0.10 and 0.25m
iii. Road Edge consisting of grass and/or gravel or any other approved surrogate

The inner edge of the marking of the lane was between 0.20 m to 0.30 m from the road edge. The lane markings or edge of the road should be sufficiently long to ensure that the marking remains at least 20 m ahead of the vehicle after the test was completed. Figure 3.4 displays the layout of the lane markings.

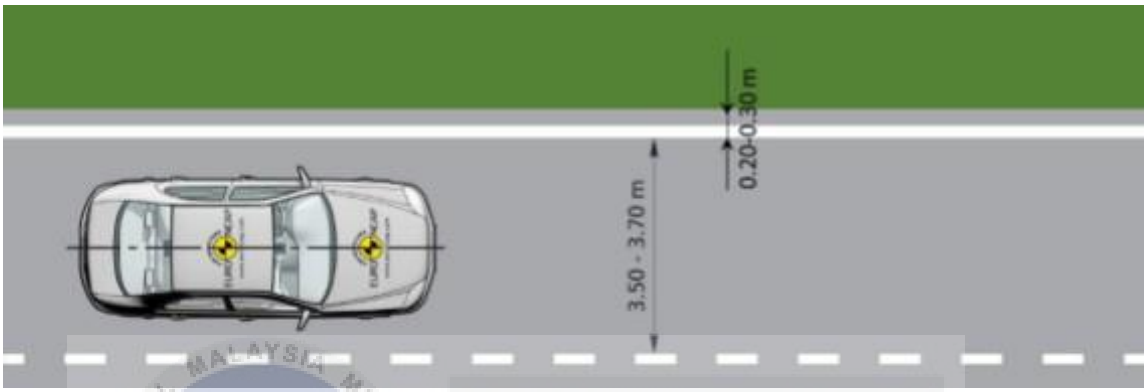


Figure 3.4: Layout of the lane markings (www.euroncap.com, 2019)

The experiments were carried out in dry conditions at ambient temperatures above 5°C and below 40°C for weather conditions. As to minimize the disruption of the vehicle under test (VUT), the wind speed was below 10 m/s. The natural ambient lighting must be homogeneous in the test area. The daytime test should have no heavy shadows spread through the test area except for the shadows created by the VUT in excess of 2000 lux.

The following parameters should be calculated and reported at the beginning of each single test or at least every 30 minutes:

i. Ambient temperature in °C;

ii. Track Temperature in °C;

iii. Wind speed in m/s;

iv. Wind direction in azimuth ° and/or compass point direction (monitoring);

v. Ambient illumination in Lux.

3.1.4 Vehicle Preparation

For GVT specification, the tests were conducted in this protocol using the GVT. The GVT replicates the visual, radar and Light Detection and Ranging (LIDAR) attributes of a typical M1 passenger vehicle. The GVT was designed to work with the sensors such as Radar (24 and 77 GHz), LIDAR, and a camera. Figure 3.5 shows one of the examples of the GVT.

Figure 3.5: Global Vehicle Target (www.euroncap.com, 2019)

Some driver-configurable system elements were set such as LDW timing or LKA in the middle or midpoint setting for VUT preparation and the next poorer performance setting was set afterwards. Figure 3.6 displays the system setting for testing. The lower performance environment should be identical to the one shown in Figure 3.6 below and the lane centering functions should be switched off.

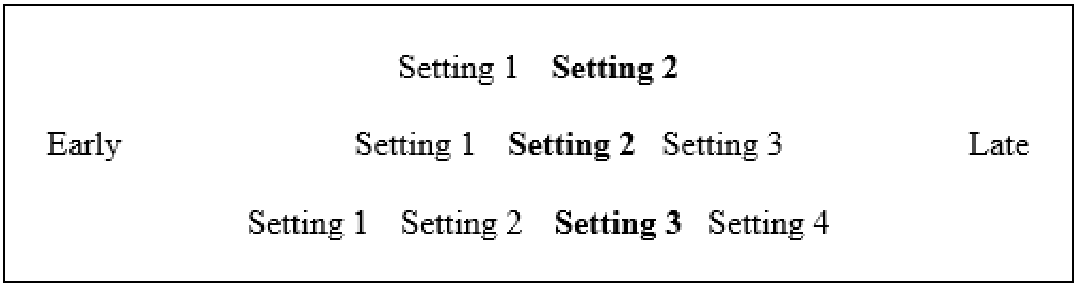


Figure 3.6: System setting for testing (www.euroncap.com, 2019)

As regards VUT tires, the vehicle to be used during testing should use the new original fitment tires, as specified by the vehicle manufacturer, of the make, model, size, speed and load rating. It was permissible to change the tires supplied by the manufacturer or acquired by an official dealer represented the manufacturer if those tires were identical to the original manufacturer, model, size, speed and load rating.

The wheel alignment measurement, the chassis should be subject to a geometry test of the wheels that in-line to document the original equipment manufacturer (OEM) wheel alignment. This should be included in the kerb weight of the car.

The tank was filled with fuel to at least 90 percent of the fuel capacity of the tank for the vehicle's unladen kerb mass. The level of oil was checked and lift it to its maximum level if appropriate. The levels of all other liquids will also be increased to their maximum levels if appropriate. In addition, the vehicle was ensured to fitted with its spare wheel and any supplies that the vehicle provided on board. There should be nothing else in the car. All tires were ensured to be inflated for the least loading condition according to the manufacturer's instructions. The weight of the front and rear axle was measured to calculate the vehicle's total weight. The total mass was the vehicle's ‘unloaded kerb masses. This mass was reported in the details of the test. Finally, get the necessary internal load of 200 kg, by subtracting the mass of the test driver and test equipment.

Equipment and vehicle instrumentation were mounted on-board monitoring. Any associated cables, boxes for cabling and power sources were installed. After that, weights were attached with a ballast mass. Any additional objects should be securely attached to the car. The front and rear axle loads of the vehicle were weighed with the driver in the car and then those loads was equated with the 'unloaded kerb masses'. This step was repeated until the loads of the front and rear axle and the total vehicle weight were within the set limits. The total vehicle weight was greater than or less than 1 percent of the unloaded kerb weight plus 200 kg. The load distribution of the initial unladen kerb mass plus full fuel load should be within 5 percent of the load distribution of the front/rear axle. If the vehicle differed from the stated specifications, the vehicle can be excluded or objects that have no impact on its performance was attached. Any items added to increase the vehicle weight should be tightly secured to the vehicle.

With regard to the repeated steps as mentioned above, care must be taken when adding or removing weight in order to suit the vehicle's original inertial properties as closely as possible. The axle's final load was recorded in the test details. The weights of the VUT axle was recorded in 'as tested' condition.

Measurements were to be made of the vehicle dimensions. For the purposes of this test protocol, using the standard Society of Automotive Engineers (SAE) coordinate system, a two-dimensional polygon specified by the lateral and longitudinal dimensions relative to the centroid of the vehicle should represented vehicle dimensions. The lateral and longitudinal positions where the outer edge plane of each tire met the surface described the polygon corners. This plane was characterized by a perpendicular line running from the tire's outermost tip to the surface at the wheelbase. It was necessary to measure the wheelbase of the vehicle and the lateral and longitudinal locations. Figure 3.7 shows the vehicle dimensional measurements.

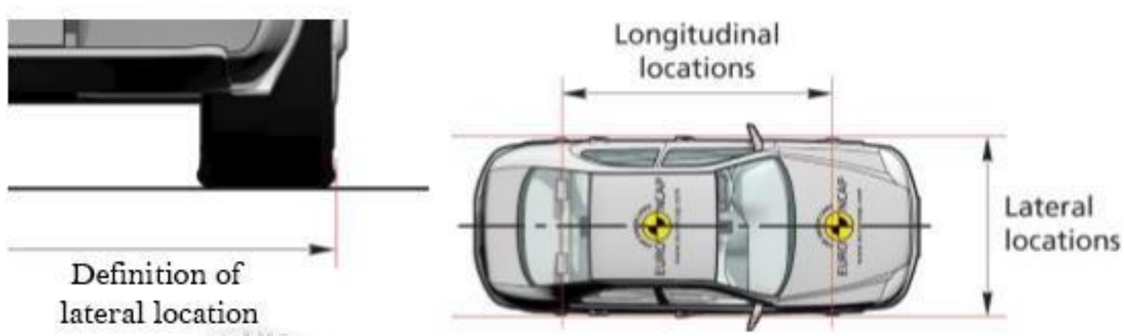


Figure 3.7: Vehicle dimensional measurements (www.euroncap.com, 2019)

3.1.5 Test Protocol

For VUT pre-test conditioning, a new car generally was used as delivered to the test laboratory; however, a car may have been used for other active safety tests. To ‘calibrate’ the sensor system, drive a total of 100 km on a mixture of urban and rural roads with other traffic and roadside furniture if requested by the vehicle manufacturer where it is not already done for.

In terms of brakes, condition the brakes of the vehicle as follows, if it was not done before or if the lab did not perform a 100 km of driving:

- Perform twenty stops from a speed of 56km/h with an average deceleration of approximately 0.5 to 0.6g.

- Immediately following the series of 56km/h stops, perform three additional stops from a speed of 72km/h, each time applying sufficient force to the pedal to operate the vehicle's antilock braking system (ABS) for the majority of each stop.
- Immediately following the series of 72km/h stops, drive the vehicle at a speed of approximately 72km/h for five minutes to cool the brakes.

In terms of tires, condition the vehicle's tires as follows to remove the mould sheen, if it was not done before for another test or if the lab did not perform a 100 km of driving:

- Drive around a circle of 30m in diameter at a speed sufficient to generate a lateral acceleration of approximately 0.5 to 0.6g for three clockwise laps followed by three anticlockwise laps.
- Immediately following the circular driving, drive four passes at 56km/h, performing ten cycles of a sinusoidal steering input in each pass at a frequency of 1Hz and amplitude sufficient to generate a peak lateral acceleration of approximately 0.5 to 0.6g.
- Make the steering wheel amplitude of the final cycle of the final pass double that of the previous inputs.

If the sinusoidal driving became erratic, the amplitude of the steering input was increased to an appropriately safe level and start the four passes. Before any testing begins, a maximum of ten runs was performed to ensure proper functioning of the system.

3.1.6 Test Scenarios

The performance of the VUT LSS was assessed in different scenarios that were applicable to the system:

- LKA
- LDW

There was no specific performance test for Blind Spot Monitoring Systems (warning only). Tests will be conducted with incremental steps of 0.1 m/s in all scenarios within the lateral velocities defined for the test scenarios. Assume an initial straight-line path followed by a fixed radius as defined for the test scenarios for testing purposes, followed again by a straight line, hereby known as the test path. The VUT was controlled with driver inputs or using alternative control systems that can modulate the controls of the vehicle as required for testing.

The vehicle manufacturer should provide the location definition when the direction and/or speed control of the closed loop was terminated so as not to interfere with the device interference for each test. Otherwise, two test runs were performed for each lateral velocity to determine when the system was triggered. The torque of the steering wheel, the velocity of the vehicle or the level of yaw of the two runs were measured and determine where there was a significant difference defining the direction of the action.

- Run 1: Complete the required test path with the system turned OFF and measure the control parameter
- Run 2: Complete the required test path with the system turned ON and measure the control parameter

The tests were completed while ending the closed loop control before system activation. In the case of calibration tests, steering control should be released on the test track and not less than 5 m longitudinally before the intervention spot. Table 3.1 shows the parameters that should be used to create the test paths:

Table 3.1: Parameters to be used

$V_{lat,VUT}$ [m/s]	**R [m]**	**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

Where the lateral offset d from the lane marking or road edge:

$d = d_1 + d_2 +$ Half of the vehicle width (m)

With:

d_1: Lateral distance travelled during curve establishing yaw angle (m)

d_2: Lateral distance travelled during V_{lat} steady state (m)

Figure 3.8 shows briefly, on where the d_1 and d_2 variables located in the test protocol.

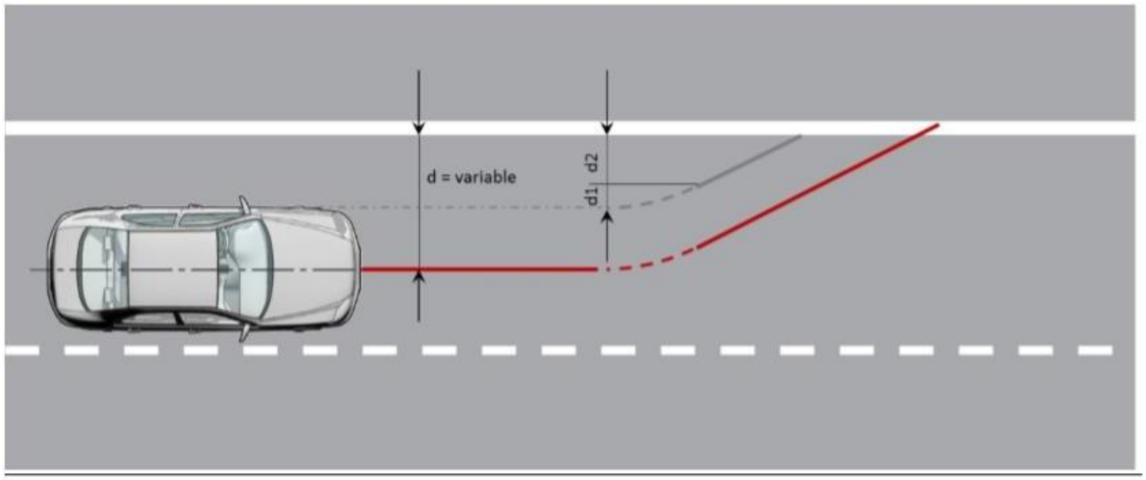


Figure 3.8: d_1 and d_2 variables location (www.euroncap.com, 2019)

3.1.7 LKA Test

For LKA test, it has three different tests that covers different criteria. The tests were road edge test, dashed line test and solid line test. For departures on the front passenger side only, LKA Road Edge tests will be performed with 0.1 m / s incremental steps within the lateral velocity range from 0.2 m/s to 0.5 m/s. Figure 3.9 shows the visual representation of road edge only and Figure 3.10 shows the visual representation of road edge with dashed or solid centreline.

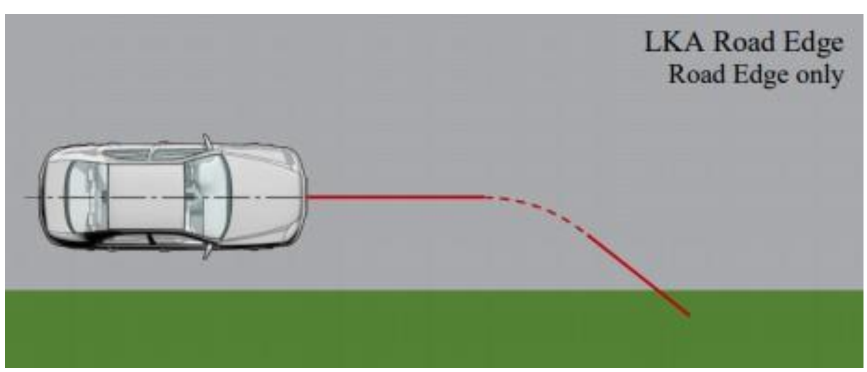


Figure 3.9: Visual representation of road edge only (www.euroncap.com, 2019)

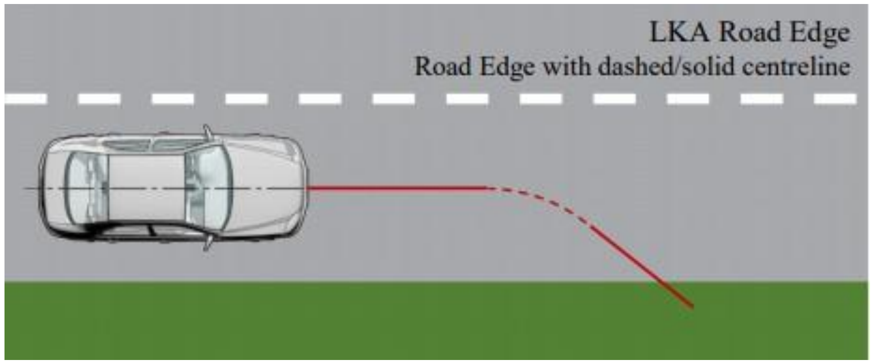


Figure 3.10: Visual representation of road edge with dashed or solid centerline (www.euroncap.com, 2019)

For departures on both sides of the vehicle, LKA dashed line test was conducted with incremental steps of 0.1 m / s within the lateral speed range of 0.2 m/s to 0.5 m/s. Figure 3.11 shows the visual representation of LKA dashed line test.

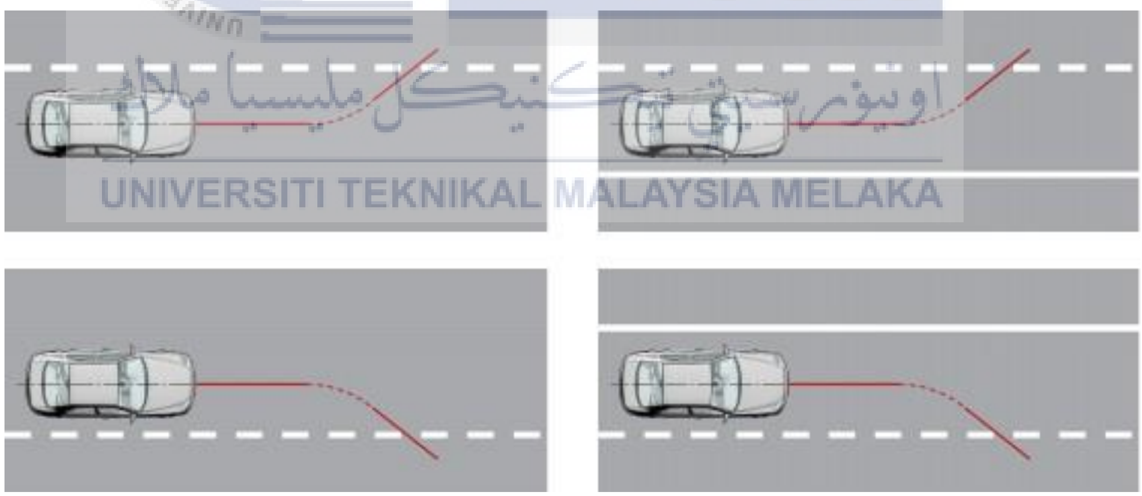


Figure 3.11: Visual representation of LKA dashed line test (www.euroncap.com, 2019)

For departures on both sides of the vehicle, LKA solid line test was conducted with incremental steps of 0.1 m/s within the lateral speed range of 0.2 m/s to 0.5 m/s. Figure 3.12 shows the visual representation of LKA solid line test.

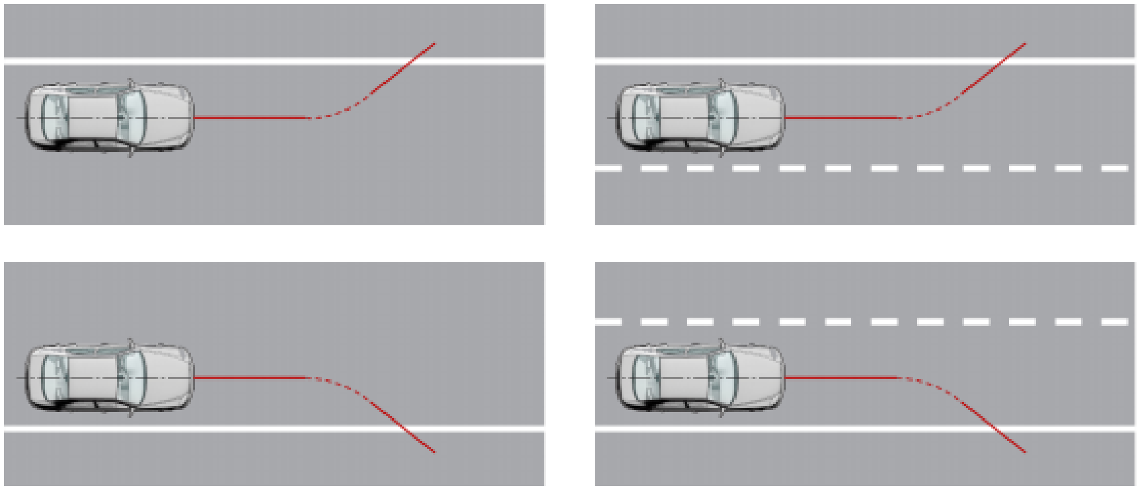


Figure 3.12: Visual representation of LKA solid line test (www.euroncap.com, 2019)

3.1.8 LDW Test

For LDW systems or systems only where LDW can be used as a stand-alone tool, the tests below were performed. The LDW output was assessed during LKA or ELK analysis, excluded the deliberate overtaking case, when paired with an LKA and/or ELK system. It has two different tests that covers different criteria. The tests were dashed line test and solid line test.

For departures on both sides of the vehicle, LDW dashed line test was conducted with incremental steps of 0.1 m/s within the lateral speed range of 0.2 to 0.5 m/s. Figure 3.13 shows the visual representation of LDW dashed line test.

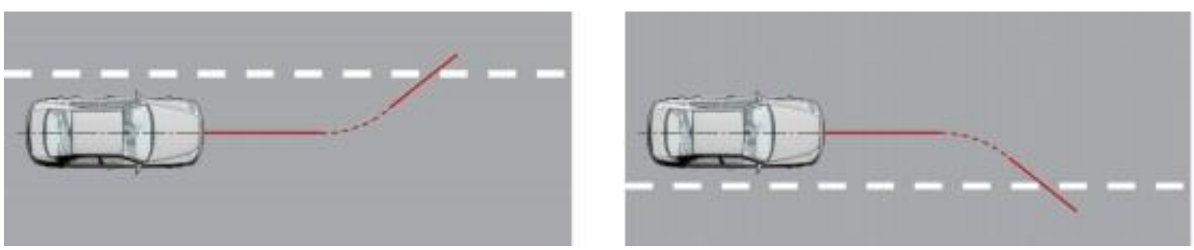


Figure 3.13: Visual representation of LDW dashed line test (www.euroncap.com, 2019)

For departures on both sides of the vehicle, LDW solid line test was conducted with incremental steps of 0.1 m/s within the lateral speed range of 0.2 to 0.5 m/s. Figure 3.14 shows the visual representation of LDW solid line test.

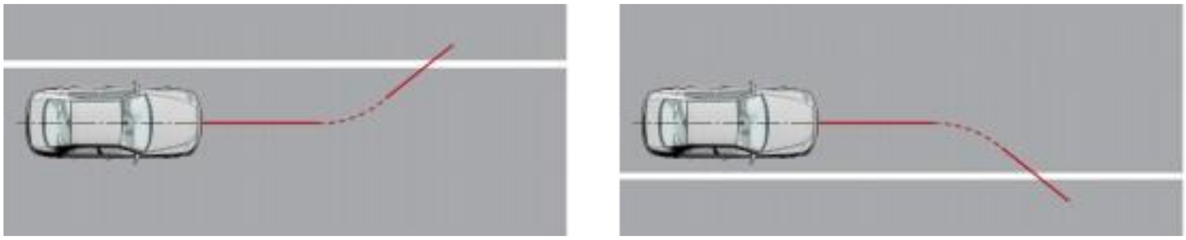


Figure 3.14: Visual representation of LDW solid line test (www.euroncap.com, 2019)

3.1.9 Test Conduct

The VUT was drove around a circle with a maximum diameter of 30 m at a speed of less than 10 km/h for one lap in the clockwise direction followed by one lap in the anti-clockwise direction and then manoeuvred the VUT in the test path position. Before each test run, an initialization run may be included if requested by the OEM.

For automatic transmission cars, D gear was picked. For manually transmitted cars, the maximum gear was picked where at the test speed the RPM will be at least 1500. Among tests, the VUT was move at a maximum speed of 50 km/h. Riding the brake pedal and rough acceleration, accelerating or turning were avoided unless a safe test environment was necessary.

3.1.10 Test Execution

The VUT was speed up to 72 km/h. Based on the test situation; the target vehicle was accelerated to 72 km/h or 80 km/h, when it is appropriate. The test started at T_0. It is accurate when the T_0 and T_{LKA} or T_{LDW} were fulfilled all boundary conditions:

ELK Road Edge, LKA and LDW scenarios:

- Speed of VUT (GPS-speed); 72 ± 1.0km/h
- Lateral deviation from test path VUT; 0 ± 0.05m
- Steady state lane departure lateral velocity; ± 0.05m/s
- Yaw velocity of VUT (upto T_{STEER}); 0 ± 1.0 °/s
- Steering wheel velocity (upto T_{STEER}); 0 ± 15.0°/s

ELK upcoming scenarios:

- Speed of GVT (GPS-speed); 72 ± 1.0km/h
- Lateral deviation from test path GVT; 0 ± 0.20m

ELK overtaking scenarios:

- Relative longitudinal speed; 0 or 8 ± 1.0km/h
- Relative longitudinal distance

  i. 0km/h relative velocity; 0 ± [0.20]m

  ii. 8km/h relative velocity; x ± [0.20].m

  iii. Lateral deviation from test path GVT; 0 ± 0.20m

The vehicle was steered as needed in a smooth controlled manner and with minimum overshoot to achieve the lateral velocity. The end of an LDW test is known as the start of the alarm. After one of the following happened, the end of an LKA / ELK Road Edge test was considered complete 2 seconds:

- The LKA / ELK system does not maintain the VUT within the allowed distance from the road.

- The LKA / ELK system intervenes to hold the VUT within the allowed lane departure range, thereby achieving a maximum lateral position that subsequently decreases allowing the VUT to turn back to the lane.

The end of an ELK oncoming or overtaking test was considered as one of the following:

- To avoid a collision between the VUT and the target vehicle, the ELK device intervenes.

- To avoid a collision between the VUT and the target vehicle, the ELK system failed to interfere (sufficiently). This can be expected if one of the following occurs:

  i. In the oncoming and overtaking case, the lateral distance between the VUT and the target vehicle is equal to < 0.3 m.

  ii. There is no interference in a TTC = 0.8s or a TTC submitted by the OEM

One of the above options was selected to ensure a safe testing environment was at the discretion of the laboratories. If the experiment ended because the vehicle has failed to interfere (sufficiently) or if the GVT has abandoned it, it was suggested that the VUT and/or GVT be steered away from the impact either manually or by reactivating the steering control of the driving robot or GVT. The resulting lateral velocity was raised by 0.1 m/s for the next sample.

3.1.11 Test Planning with Implementation of Test Facility

For this part, the planned LDW and LKA test protocol will be implemented with the on-road test facility. The test facility that is rain simulator is used to simulate the test during rainy conditions. All of the procedures will be the same as the dry test, except there will be a lorry which will aid the test. The test track setup for both dry and wet test is as follows. The test will be held near to Universiti Teknikal Malaysia Melaka (UTeM) Main Campus, which is between Kolej Yayasan Saad and Dewan Citra Kasih. The track will be about 2.5 km long. Figure 3.15 shows the planned test track for the test.

Figure 3.15: Planned test track (www.google.com/maps, 2019)

As from the 2.5 km track, the only section that will be used is only around 300 m long. This is because the 300 m track area is ideal for the test as it is a straight path form. The road will be closed to smoothen the test. Figure 3.16 shows the traffic management plan for closing the road.

From Figure 3.16 below, the red side of the road will be the track. The track is divided into 5 checkpoints for the driver. The first checkpoint will be the start of the test. The second checkpoint is where the car is at the required speed of LKA and LDW to activate the driving assistance which is around 72 km/h. The third checkpoint, the rain will be simulating for about 300 m for the wet test and does not applicable to the dry test. This part is aided by a lorry that carries a large tank of water and a rain simulator. After passing through the fourth checkpoint, the car will be slowing down before approaching the fifth checkpoint. Figure 3.17 shows the planned test track setup

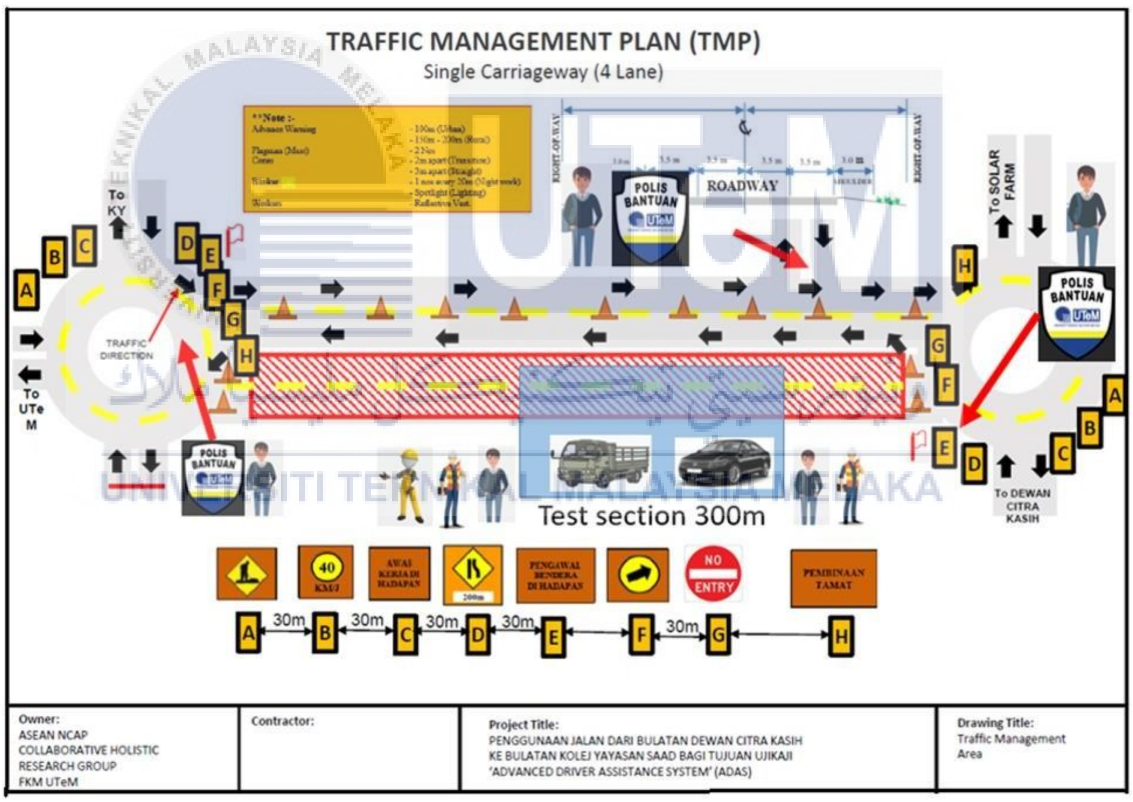


Figure 3.16: Traffic management plan

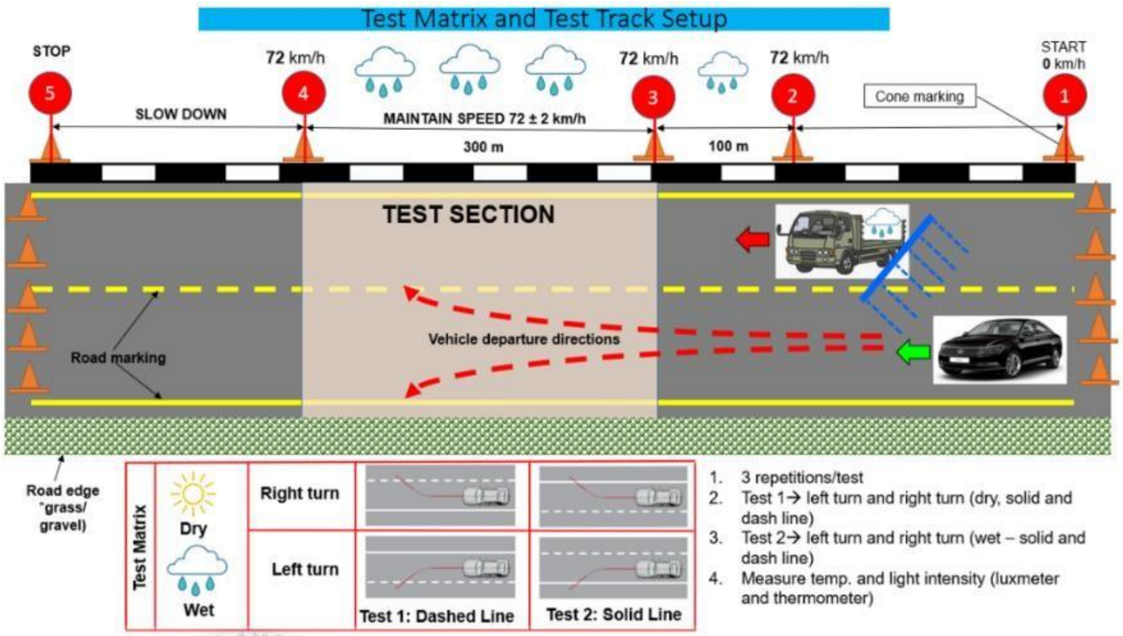


Figure 3.17: Planned test track setup

3.2 Development of Rain Simulator

For this part, it focuses solely on the development of an on-road test facility, which is Rain Simulator. The market analysis was being studied first followed by the benchmark of the product. These can provide a clear idea of how to develop the rain simulator. Then, the product specification will be developed that follows the customer requirements. After that, several conceptual designs are being gathered and final design selection will be selected. The selection of the final design is being selected based on characterization that fits best for the test protocol during rainy weather. The detailed design of the final design has been done in three steps. Firstly, the selection of the material is conducted. The material selection should be user-friendly which is easy to use and follows the budget given. Secondly, the three-dimensional computer-aided design (3D CAD) model of rain simulator is being developed. The development of the model is being done from a software called CATIA. This development is important for the third step, which is the analysis of the rain simulator. CATIA can analyse the structure and sizing of the system and data can be gathered easily. After all the stages above have been done, fabrication of the system will be conducted before the date of the test protocol. To ensure the effectiveness of the system, prototype testing will be run. Figure 3.18 shows the flowchart of the development of rain simulator.

3.2.1 Market Analysis

Many rain simulators can be got from the market. The rain simulator is mostly focusing on agricultural field. The rain simulator can make human making less effort in watering the plants. Figure 3.19 shows the rain simulator that have been used in watering crops.

Figure 3.19: Rain simulator in watering crops (www.youtube.com, 2017)

The water that spurt out from the nozzles are in the mist form which is technically the same as the way rain falls which is in drizzle form. Unfortunately, this type of rain simulator is not suitable enough to be used, as it is not capable of simulating the rain as heavy rain, which is one of the most common rain in South East Asia. The rate of the rainfall should be as close as South East Asian's rainfall so that it can fulfil the requirement during on-road test protocol.

The country that have been set as a benchmark is at Malaysia as Malaysia are one of the countries situated at South-East Asia. The characteristics of the Malaysian climate are that is has a uniform temperature, high humidity and abundant rainfall. The wind is generally weak. Malaysia is also located in the equatorial region that are extremely rare to have clear sky even during severe drought.

Based from Figure 2.9 and Figure 2.10 from Chapter 2, Malaysia have 2 monsoon seasons which are Northeast Monsoon and Southeast Monsoon. From November to January, it normally having a heavy rainfall due to Northeast Monsoon while from June to July, it normally having severe drought due to the Southeast Monsoon. As for the test, it will be held at Melaka. Based from Figure 3.25 above, Melaka's annual mean monthly rainfall is from 1500 mm to 2500 mm. This shows that Melaka's rain precipitation is average, which are likely the same as other South-East Asia countries.

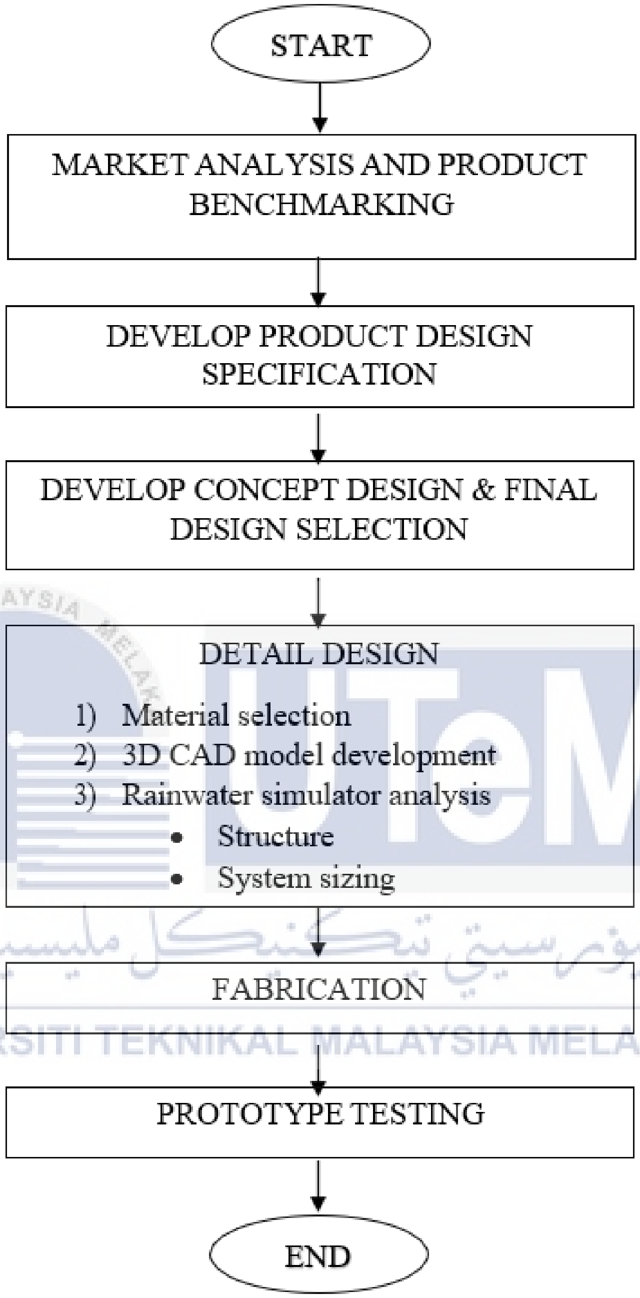


Figure 3.18: Flowchart of the development of rain simulator

3.2.2 Product Benchmarking

There are many concepts of rain simulator available in the market such as cage, tower, gun, and fan concept. However, these concepts are not suitable with the planned test protocol as it may have difficulties to spurt water wholly on the windshield of car. Thus, the intensity of the simulating rain cannot get the same as Malaysia’s rainfall intensities, which are light, moderate and heavy rainfall. Figure 3.20 below shows the concepts of rain simulator available in the market, which are (a) cage, (b) tower, (c) gun, (d) fan concepts.

(a) (b) (c) (d)

Figure 3.20: Concepts of rain simulator, which are (a) cage, (b) tower, (c) gun, and (d) fan concepts

3.2.3 Product Design Specifications

In the development process of rain simulator, the result of the design planning process that governs the engineering design tasks are compiled in the form of a set of Preliminary Product Design Specification (PDS). PDS is the basic control and reference document for the design of the rain simulator. PDS is important as it describes the product and the market it is intended to satisfy.

Product Design Specification: Rain Simulator

Product Identification

- Function: To simulate rainy weather towards the car
- Good spread of water towards the car's windshield
- Able to spray for long distance
- Easy to connect
- Easy to carry

Key Performance Target

- The rain simulator should be portable
- The rain simulator should be able to withstand high pressure water
- Durability of the rain simulator should be last at least 4 years

Market Identification

- Initial Production: 1 unit
- Competing product: Other products offers the same function, but unable spray the water at high pressure

Physical Description

- Rain simulator has approximately 955 mm of length, 500 mm of width and less than 20 mm of height
- Material used is Polyvinyl Chloride (PVC) pipes with joints
- Brass nozzle
- Weight target: Lightweight

Financial Requirement

- Target cost for fabricating the rain simulator is RM100

Life Cycle Target

- Useful life of 4 years
- Reliability (mean time to failure): 10 years
- End of life strategy: Recycle the rain simulator

3.3 Develop Conceptual Design & Final Design Selection

3.3.1 First Concept

For the first concept, it will use multiple nozzles to spurt out the water for a larger area. The system will be connected to a pipe which is mainly produced a high-pressure water with the help of a motor generator. This system is suitable to be place at the back of lorry. Figure 3.21 shows the first concept of rain simulator.

This system is suitable to be place at the back of lorry. The water will be spurted to the windshield of the car, which will be moving close to the lorry. The bigger the area of spurting water can assure the water can be distributing evenly to the windshield. Other than that, it offers lightweight as it uses PVC pipes. The PVC pipes is common use for water flowing and the PVC material can be cut easily. Furthermore, it is easy to apply with the water valve, which has been prepared by the lorry itself.

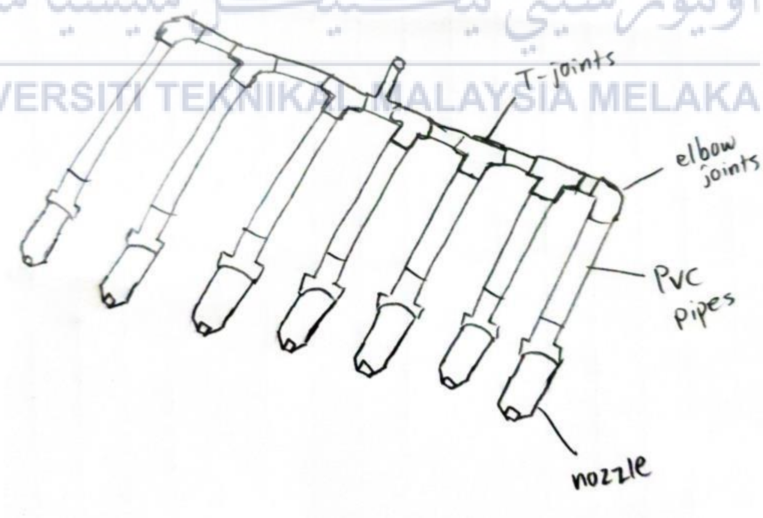


Figure 3.21: First concept

3.3.2 Second Concept

For the second concept, it will use an industrial fan. The fan itself can provide a high-speed wind, which can make the water can be spurted at longer distance. The water is stored in the tank, which is situated at the stand of the fan. Figure 3.22 shows the second concept of rain simulator.

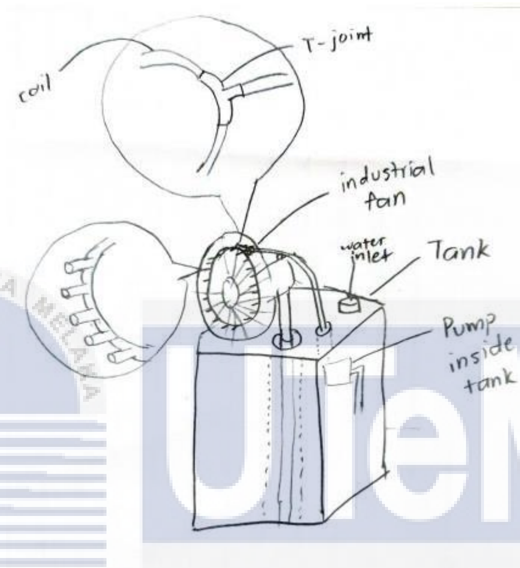


Figure 3.22: Second concept

At the tank, there will be a pump and it will help to pump out the water so that the water will be flowing inside a small pipe, which will be connected at the coil. The coil will have a T-connector and a number of small nozzles to spurt out the water from the coil. The smaller the size of nozzle at the coil can produce a good water flow rate. This can make the water to spurt at longer distance as the wind from the fan supports the water movement towards the windshield of the car. The rain simulator can be place at the back of the car or lorry.

3.3.3 Third Concept

For the third concept, it will use a number of showerheads. The showerheads can ensure the water will cover almost all the area of the car’s windshield. The water pipe valve will aid the flow of water. The rubber sucker can assure the easy connection on the roof of the car. Figure 3.23 shows the third concept.

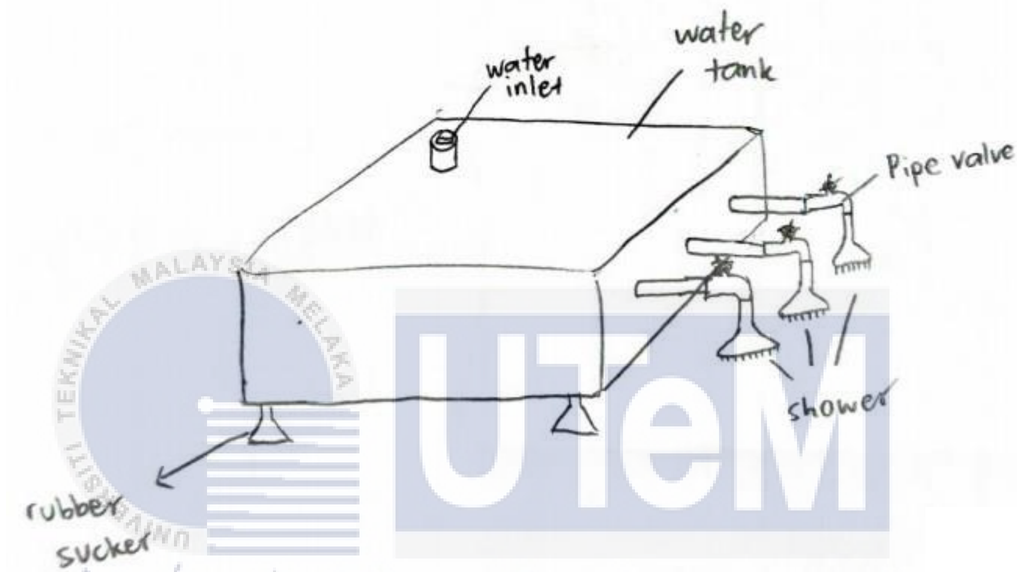


Figure 3.23: Third concept

The system uses a tank to store the water. This can make the system becomes heavy. The weight targeted for the system is around 200 kg, which is one of the requirements at the test protocol in terms of carrying load. The tank can be place at the top of the car. To ensure the tank is not moving, the rubber sucker will be applied below of the tank so that the tank will stick at the top of the car.

3.3.4 Final Design Selection

For the final design selection, the method that has been used is Pugh Decision Matrix Method. The chosen concept design is the first concept. Table 3.2 below shows the Pugh Decision Matrix method.

From the table, the first concept was chosen as the datum as it is one of the best solutions among other concepts. The first concept design scores the most '+' compare to others. This is because of the first design has a better spray distance compare to other concepts. The spread of water towards the windshield of the car is better than the second concept. It also can withstand high-pressure water compared to the third concept, which cannot withstand high-pressure water. The first concept also offers an easy connection compared to the second design. The first concept is guaranteed easy to be carried compared to other concepts.

3.4 Detailed Design

CATIA V5 software is used to design, simulate, analyze and manufacture products. The rain simulator concept design is first design in CATIA software. Then, the finish actual rain simulator concept design is been given some modification in the length of the rain simulator. The reason for the modification from the first rain simulator concept is to make sure that the length of the rain simulator is compatible for the back of the selected lorry. Figure 3.24 below shows the rain simulator drawing that has been done and Figure 3.25 below shows the exploded view of the rain simulator.

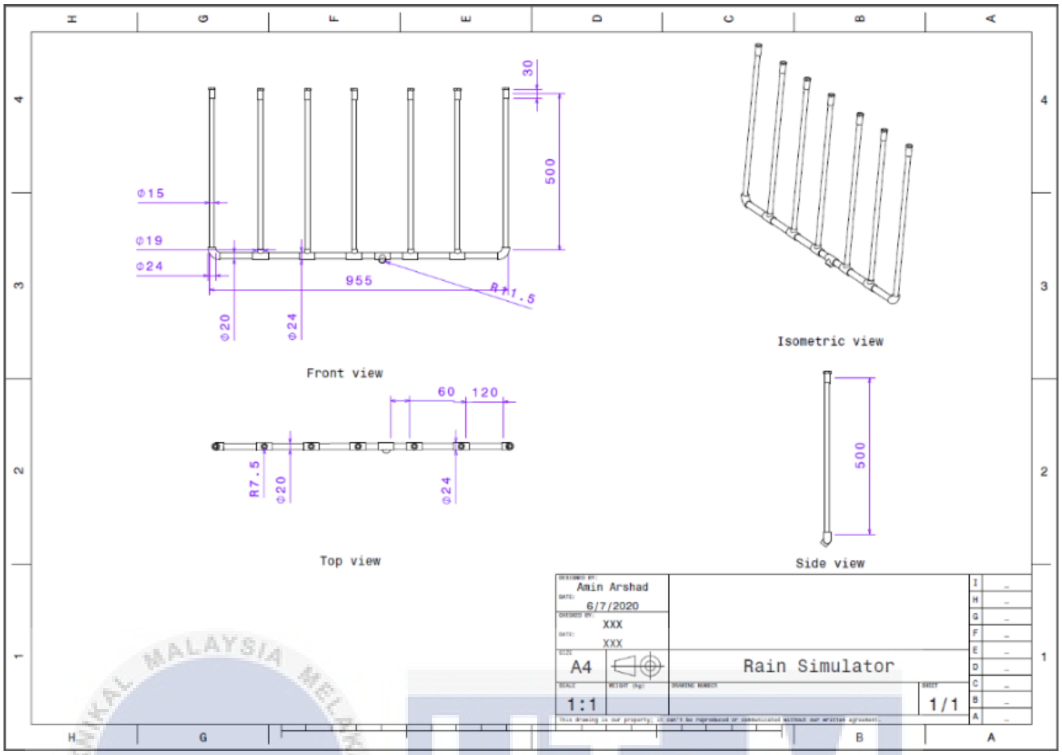


Figure 3.24: Rain Simulator Drawing

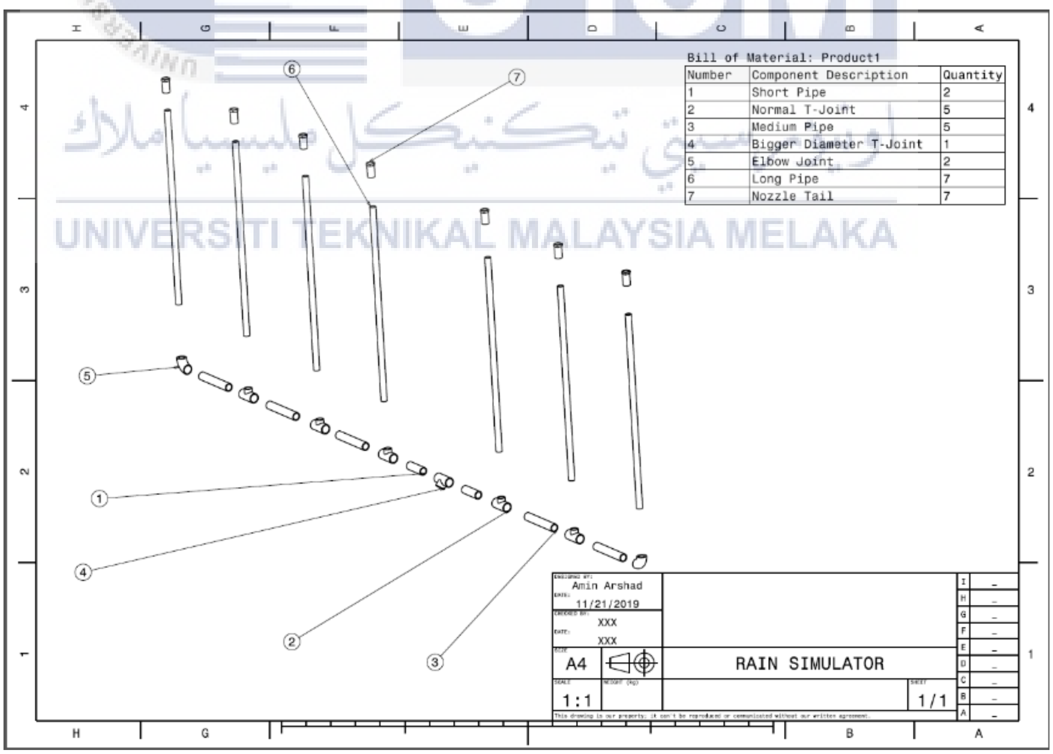


Figure 3.25: Exploded View of Rain Simulator

Table 3.2: Pugh Decision Matrix Method

Design Selection Criteria	Datum	Solutions		
		1st Concept Design	**2nd Concept Design**	**3rd Concept Design**
Able to spray for a long distance	**0**	+	**0**	**-**
Good spread of water towards the windshield of the car	**0**	++	**-**	+
Can withstand high pressure water	**0**	++	+	**-**
Easy to be connect	**0**	++	**0**	+
Easy to carry	**0**	+	-	**0**
	Total +	7	**1**	**2**
	Total 0	**0**	**2**	**1**
	Total -	**0**	**2**	**2**
	Nett Score	**7**	**-1**	**0**

Legend:

1) + illustrates that it is better than datum
2) 0 illustrates that it is equal to datum
3) – illustrates that it is worse than datum

3.5 Predicted Performance of Rain Simulator

To get the water spurting out from the rain simulator, the rain simulator needed a motor to get the aid in pump out the water from the water tank. The motor that will be used is 5-Horsepower Robin EY 20-3 Motor. This motor can generate a high pressure of water at the nozzle. Figure 3.26 shows the 5-Horsepower Robin EY 20-3 Motor.

Figure 3.26: 5-Horsepower Robin EY 20-3 Motor

To verify whether the performance of motor is suitable for the test, the specifications of the motor has been analyzed. The goal is to get a suitable speed of water to spurt out to the car in the test in m/s as it is easier to estimate the distance of the moving car and the lorry. Figure 3.27 shows the rain simulator and Table 3.3 shows the specifications of 5-Horsepower Robin EY 20-3 Motor.

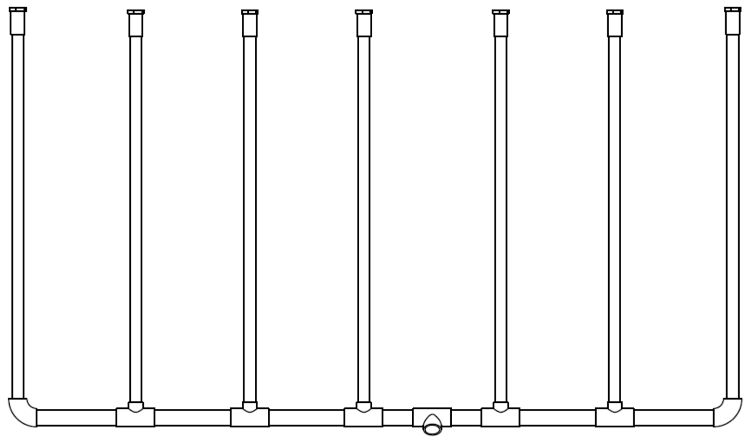


Figure 3.27: Rain Simulator

Table 3.3: Specifications of 5-Horsepower Robin EY 20-3 Motor (www.lazada.com, 2019)

Features:
Heavy-duty gasoline engine centrifugal pump.
High water delivery volume with 500 Litres/minute.
Supported by low fuel consumption Subaru Robin engine.
Specification:
Inlet / Outlet Diameter: 50mm (2")
Total Head: 32 m
Suction Head: 8 m
Max. Pumping capacity: 600 Litre / min
Self-Priming Time (at 5m): 110 sec.
Dry Weight: 25 kg

Based from Figure 3.27 above, the rain simulator has 1 inlet and 7 outlets of piping system. Total flowrate in inlet is always the same as total flowrate in outlet. Therefore, there are 2 assumptions that can be made from this system.

The first assumption that can be made is the piping system does not have any major and minor losses acted in the system. The equal flowrate from inlet and outlet can be shown as:

$$\Sigma Q_{in} = \Sigma Q_{out} \tag{3.1}$$

$$Q_{in} = Q_1 + Q_2 + Q_3 + Q_4 + Q_5 + Q_6 + Q_7 \tag{3.2}$$

Where:

i. Q_{in} is the flowrate of water at inlet of the piping system

ii. Q_{out} is the flowrate of water at outlet of the piping system

The flowrate of water, Q can be expanding as:

$$Q = AV \tag{3.3}$$

$$A_{in}V_{in} = A_1V_1 + A_2V_2 + A_3V_3 + A_4V_4 + A_5V_5 + A_6V_6 + A_7V_7 \tag{3.4}$$

Where:

i. A_{in} is the area of the inlet pipe

ii. V_{in} is the speed of water at the inlet pipe

Given flowrate of water from the 5-Horsepower Robin EY 20-3 Motor is 500 L/min. Convert 500 L/min to m^3/s. 500 L/min is equivalent to 0.00833 m^3/s.

To determine the speed of water flow, it can be got from the flowrate of water. Flowrate of water at inlet can be calculated as:

$$Q_{in} = A_{in}V_{in} \tag{3.5}$$

$$A_{in} = \pi/4 \text{ x } 0.0038^4 \tag{3.6}$$

$$A_{in} = 1.638 \text{ x } 10^{-6} \text{ m}^2 \tag{3.7}$$

$$0.00833 \text{ m}^3\text{/s} = (1.638 \text{ x } 10^{-6} \text{ m}^2)\ V_{in} \tag{3.8}$$

$$V_{in} = 5086.52 \text{ m/s} \tag{3.9}$$

At every outlet, it has a similar diameter of pipes, thus the area of the pipe can be calculated as:

$$A_{out} = \pi/4 \text{ x } 0.0015^4 \tag{3.10}$$

$$A_{out} = 3.976 \text{ x } 10^{-8} \text{ m}^2 \tag{3.11}$$

$$A_{out} = A_1 = A_2 = A_3 = A_4 = A_5 = A_6 = A_7$$

Where:

i. A_{out} is the area of the outlet pipe

Substitute Eq. (3.7), Eq. (3.9) and Eq. (3.11) into Eq. (3.4):

$$(1.638 \text{ x } 10^{-6} \text{ m}^2)\ (5086.52 \text{ m/s}) = (3.976 \text{ x } 10^{-8} \text{ m}^2)\ (V_1 + V_2 + V_3 + V_4 + V_5 + V_6 + V_7)$$

Assume $V_1 + V_2 + V_3 + V_4 + V_5 + V_6 + V_7 = 7V_{out}$

$$[(1.638 \text{ x } 10^{-6} \text{ m}^2)\ (5086.52 \text{ m/s})] / (3.976 \text{ x } 10^{-8} \text{ m}^2) = 7V_{out}$$

$$209440.30 \text{ m/s} = 7V_{out}$$

$$V_{out} = (209440.30 \text{ m/s})/7$$

$$V_{out} = 29935.76 \text{ m/s per nozzle} \tag{3.12}$$

Speed of water at the outlet pipe, V_{out} is higher than speed of water at the inlet pipe, V_{in} due to diameter of outlet pipes are smaller than inlet pipe. The smaller the diameter of pipe, the higher the speed of water. The speed of water is suitable to be spurt from long distance. To determine the flowrate of water at outlet, it can be calculated as:

$$Q_{out} = A_{out}V_{out} \tag{3.13}$$

Where:

i. A_{out} is the area of the outlet pipe

ii. V_{out} is the speed of water at the outlet pipe

Substitute Eq. (3.11) and Eq. (3.12) into Eq. (3.13):

$$Q_{out} = (3.976 \text{ x } 10^{-8} \text{ m}^2) (29935.76 \text{ m/s})$$

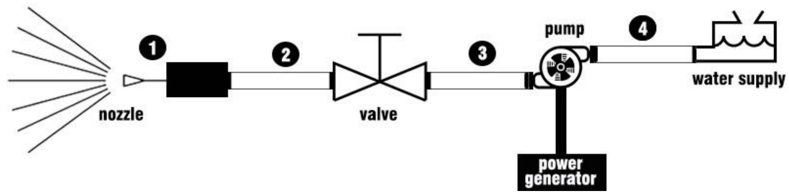
$$Q_{out} = 0.00119 \text{ m}^3\text{/s}$$

The flowrate of water at every outlet of the system is 0.00119 m^3/s. 0.00119 m^3/s is being converted to L/min to become 71.4 L/min. At every nozzle at outlet, the flowrate of water is 71.4 L/min.

The second assumption is assumed that major and minor loss is considered into the system. The flowrate of water at every outlet nozzle should be less than 71.4 L/min due to the loss of energy accounted during the flow of water. Thus, from both assumptions it can be concluded that the performance of motor is suitable for the test.

3.6 Fabrication

Figure 3.28 illustrates the interaction between rain simulator parts analysis. From the analysis, the brass nozzle connects with the 15 mm-PVC pipes that have been connected with elbow and T-joints. The joints then connected with 20 mm-PVC pipes. The pipes are also connected with a 20mm water valve, which has been connect with the 5-Horsepower motor. To give a strong and stable physical structure, the 15mm-PVC pipes have been tightened with a long PVC pipe in order to give a consistent angle and distance between the pipes during dispersion of water process.



1) 15 m diameter PVC pipes (7pieces)

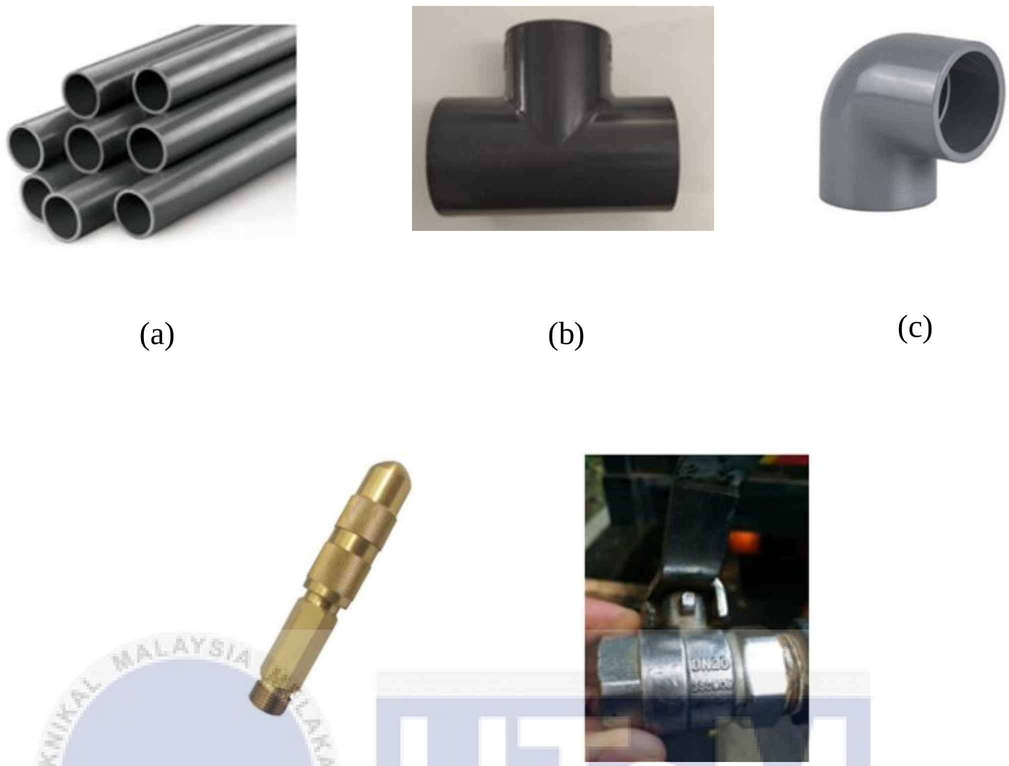
2) 20 mm diameter PVC pipes

3) 30 mm diameter plastic hose

4) 30 m diameter plastic hose

Figure 3.28: Illustrations of the interactions of parts

The rain simulator will be installed at the back of the lorry that carries a tank of water. In order to make a perfect dispersion of water towards the car, the number of nozzles has been used. To make it lightweight, the number of PVC pipes has been used. The Rainmaking Machine consist of several parts such as PVC pipes, T joints, elbow joints and brass nozzles. It then connected to a 20 mm-water valve that is suitable to produce a high pressure of water. The valve is connected to a 5-Horsepower Robin EY 20-3 motor which is used to pump the water out of the tank. Figure 3.29 below shows the (a)15 mm and 20 mm diameter PVC pipes, (b) T-Joints, (c) elbow joints, (d) brass nozzles, and € water valve.



(a) (b) (c)

(d) (e)

Figure 3.29: Components of rain simulator which are; (a)15 mm and 20 mm diameter PVC pipes, (b) T-Joints, (c) elbow joints, (d) brass nozzles, and (e) water valve

3.7 Prototype Testing

After the parts have been connected, it then undergoes initial testing before proceeding it as a test facility. This is to ensure the performance of the rain simulator and to decide whether the rain simulator is good enough to use during the test protocol. This type of testing should be almost the same as the test protocol that has been planned. Figure 3.30 shows the rain simulator connected at the back of lorry.

Figure 3.30: Connected rain simulator at the lorry

At the back of the lorry, there is a large tank that carries tonnes of water. The rain simulator has been connected to a valve that is connected to a pipe. To make the water spurt in high pressure, the pipe is connected to 5-Horsepower Robin EY 20-3 motor. To test the projection of spurting water, the rain simulator then has been tested towards the static car. Figure 3.31 shows the rain simulator spurting out the water towards the static car and Figure 3.32 shows the view from inside of the static car.

Figure 3.31: Rain simulator spurting out water towards static car

Figure 3.32: View from inside of the static car

From this test, the distance of moving water can be seen clearly. The high number of nozzles connected helps the water to spread at all area of the windshield of car. The safety distance between a moving car and a moving lorry during the test protocol can be concluded. This also can verify that the rain simulator is safe to use during the test protocol.

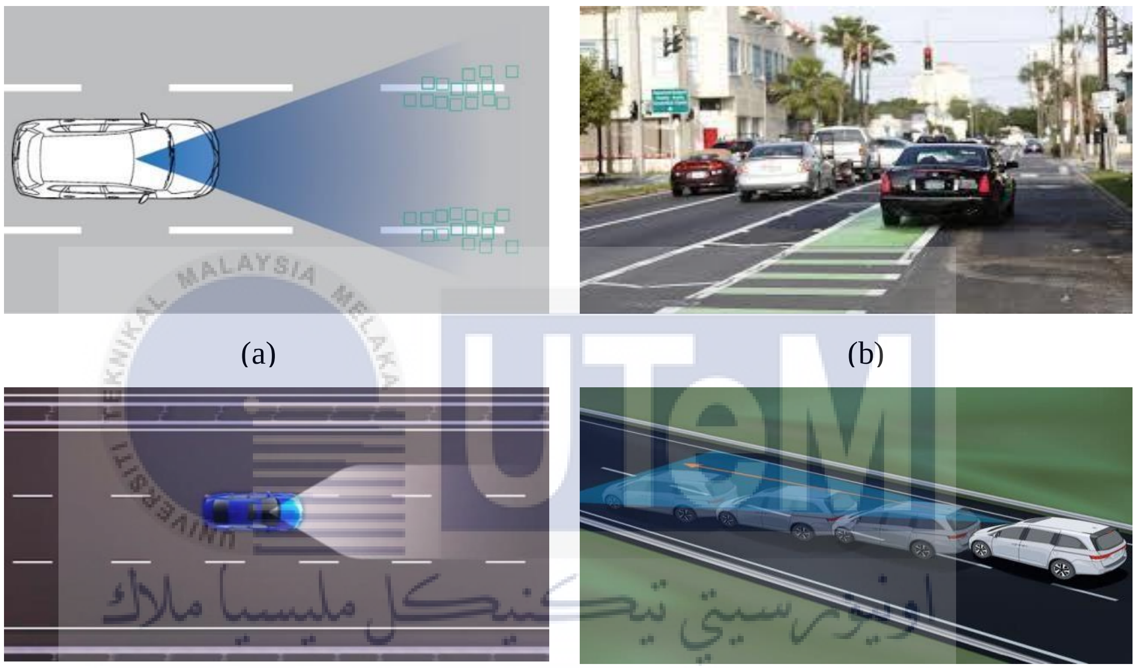
3.8 Data Collection Plan

After several benchmarking from other NCAP test protocols, the standard data collection plan has been gathered which has been adapted from Euro NCAP standard data collection plan. All of the conditions required by Euro NCAP are needed to be fulfil in order to get an accurate data. Table 3.4 shows the plan of data collection that is suitable for the test protocol.

Table 3.4: Plan of data collection

	Left Departure				Right Departure			
Test Number								
Road Line (Dash/Solid)								
Weather Condition (Dry/wet)								
Test Time (i.e. 0800)								
Ambient Temperature (ºC)								
Light Intensity (Lux)								
Test Speed (km/h)								
Steering Angle (<1º/s)								
Departure Rate (0.2–0.5 m/s)								
LDW Active (Yes/No)								
LKA Active (Yes/No)								
Remarks: i.e. car (1) stay within lane, (2) went over line, (3) touch line, and (4) system disengage								

From Table 3.4, the test will be conducted for left departure and right departure. From the departures, several remarks need to be considered during the test such as the car stay within the lane, the car went over the line, the car touches the line and the car's system disengaged. Figure 3.33 shows the examples of; (a) the car stays within lane, (b) the car went over lane, (c) the car touches the line and (d) the car's system disengaged.



(a) (b)

(c) (d)

Figure 3.33: The examples of; (a) the car stays within lane, (b) the car went over lane, (c) the car touches the line and (d) the car's system disengaged.

3.9 Preparation of Test

Before the test is conducted, the test track was set up accordingly based from Figure 3.16. The cones and temporary signboards have been set up exactly based from the planned test track with the aid of Auxiliary Police of UTeM. This can ensure that the two main roads are safe enough to drive for the test and also for other drivers that driving near the test track area. Figure 3.34 shows the situation before the test conducted and Figure 3.35 shows the situation after the cones and signboards have been set up.

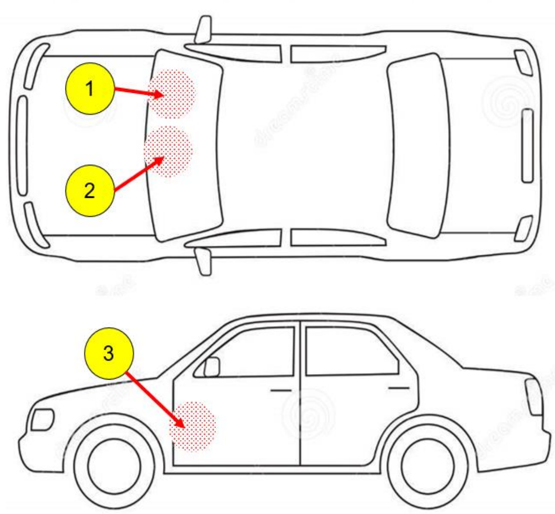
Figure 3.34: The situation before the test conducted

Figure 3.35: The situation after the cones and signboards have been set up

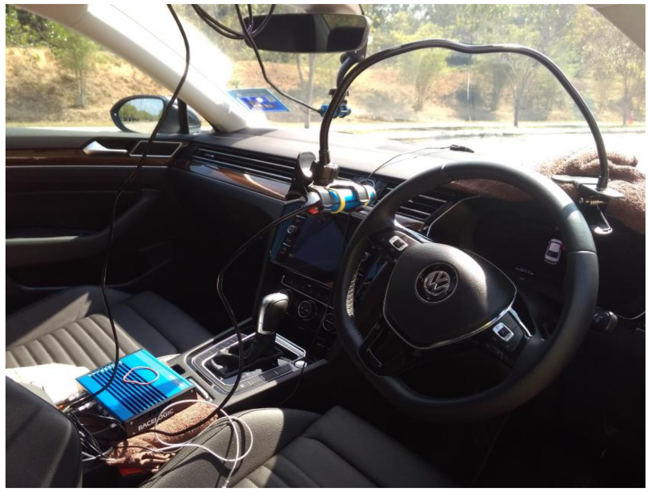
The car that has been used for the test is 2019 Volkswagen Passat 2.0 TSI. This is because the car has already been equipped with LKA and LDW systems. Figure 3.36 shows the 2019 Volkswagen Passat 2.0 TSI.

Figure 3.36: 2019 Volkswagen Passat 2.0 TSI

Before the car will be undergoing the test, the car should be installed several equipment that needed for the test documentations. 3 cameras have been set up at the car, with 2 cameras inside the car and 1 GoPro camera at the side of the car. It also has been mounted with VBOX video to record the lateral acceleration of the car. Figure 3.37 shows the illustration of (a) camera set up positions, (b) inside-car cameras, (c) side-car camera.



(a)



(b)

(c)

Figure 3.37: Illustration of (a) camera set up positions, (b) inside-car cameras, (c) side-car camera

Based from the Figure 3.37 (a) above, it shows the positions of the camera at the car. From the inside, one camera is pointed at the dashboard gauge, and one camera is pointed at the front windscreen of the car which has been shown in Figure 3.36 (b) above. This can record the front scenario of the car when the LKA and LDW are activated at certain speed of car. Figure 3.38 shows the camera pointing at dashboard gauge.

Figure 3.38: Camera pointing at dashboard gauge

From outside which are shown in Figure 3.37 (c), it is pointed towards the solid and dashed road lines. This can record the side scenario of the car whether the car passed through the road line or not when the LKA and LDW are activated at certain speed of car.

After the test facilities has been set up, a lux meter is needed to record the light intensity during the test. Direct sunlight, rainy weather, and other conditions must be taken into consideration as there may be disturbing reflections. It is because, the mixture of the two of lighting and precipitation greatly affected the availability of LDW and LKA. Figure 3.39 shows the lux meter.

Figure 3.39: Lux meter

In order to get an accurate result, every test needs a test conduction time to verify the time of the test recorded on the camera. Before every trial started, record the time from the digital watch at the side camera mounted at the car. This method can ensure that the recorded data does not redundant with other data. Figure 3.40 shows a digital watch that have been used during test.

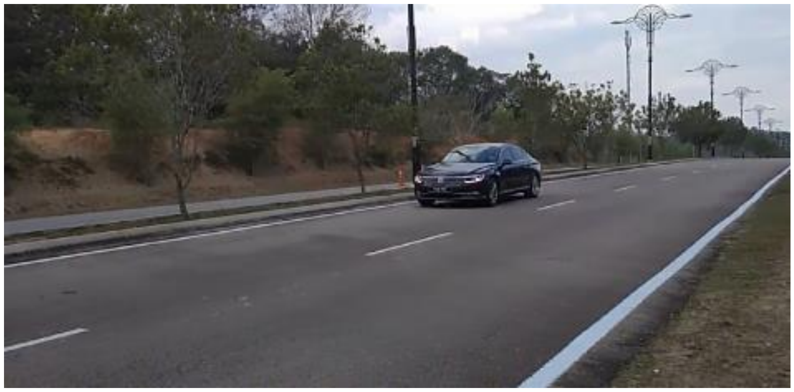
Figure 3.40: Digital watch that have been used during test

3.10 Conduction of Test

After the test facilities has been set up, the car can undergo the test. Before start the test, the driver needs to do inspections towards the mounted cameras whether it has been on the position perfectly. Other than that, the time and the light intensity of the track are recorded for each trial. Figure 3.41 shows the situation when the test is about to start.

The test track is divided into 5 checkpoints accordingly based from the planned test track. The car will start moving at the first checkpoint and will need to get a speed of more than 60 km/h to activate the driving assistance once the car starts approaching the second checkpoint. After the system activates and in cruising mode, the car will be steering gently towards the road markings for 5 times in every trial for 300 m once the car approaching the third checkpoint. As for wet test which is during simulated rainy weather, at the third checkpoint the lorry will start simulate the rain towards the car and the car will be follow closely at the back of lorry. This part also takes a 300 m distance. After passing through the fourth checkpoint, the car will be slowing down before approaching the last checkpoint. Figure 3.42 shows the situation during dry test when the car (a) approaching solid road line and (b) approaching dashed road lines and Figure 3.43 shows the situation during wet test when the car (a) approaching solid road line and (b) approaching dashed road lines.

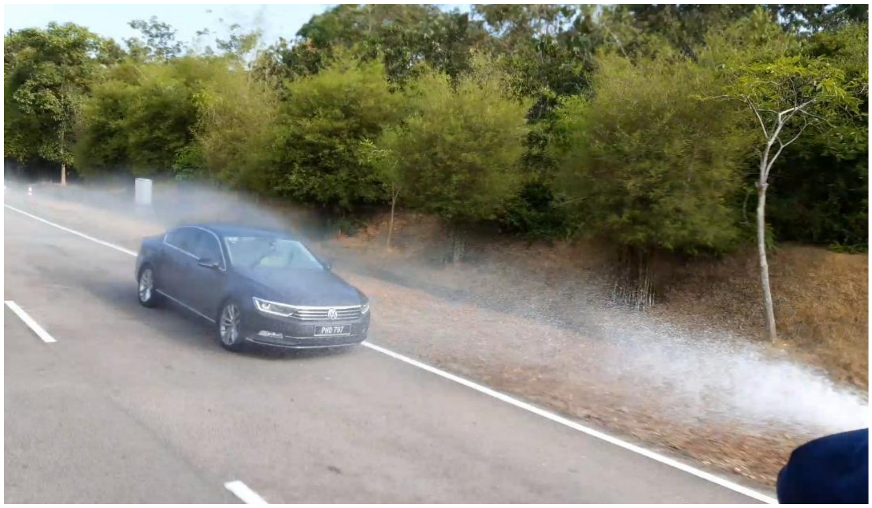
Figure 3.41: The situation when the test is about to start



(a)

(b)

Figure 3.42: The situation during dry test when the car (a) approaching solid road line and (b) approaching dashed road lines



(a)

(b)

Figure 3.43: The situation during wet test when the car (a) approaching solid road line and (b) approaching dashed road lines

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results of the Test

The test during clear and simulated rainy weather has been performed in duration of 2 days. Each type of weather has been carried out 2 types of tests which are left departure and right departure. In each test, it has 2 criteria of road lines needed to be done which are solid and dashed lines. Table 4.1 shows the overall results for LDW and LKA test.

The test has been carried out 5 times of trials for each type of road lines in every one departure direction. This method can save time as it does not need to repeat in every test just for a simple left or right departure. This also can save fuel consumption of the car. As for the light intensity, it plays a huge role in evaluating the performance of LDW and LKA systems. This is due to the LDW and LKA systems are from camera-based system, and it needs a good intensity of light to detect the road markings. According to Gordon et. al. (2010), the system is only available when the data capture from the camera is successful and hence the system's likelihood depends on the quality and continuity of the lane markings, any contamination of the road surface and also the lighting conditions.

Table 4.1: Overall results for LDW and LKA test

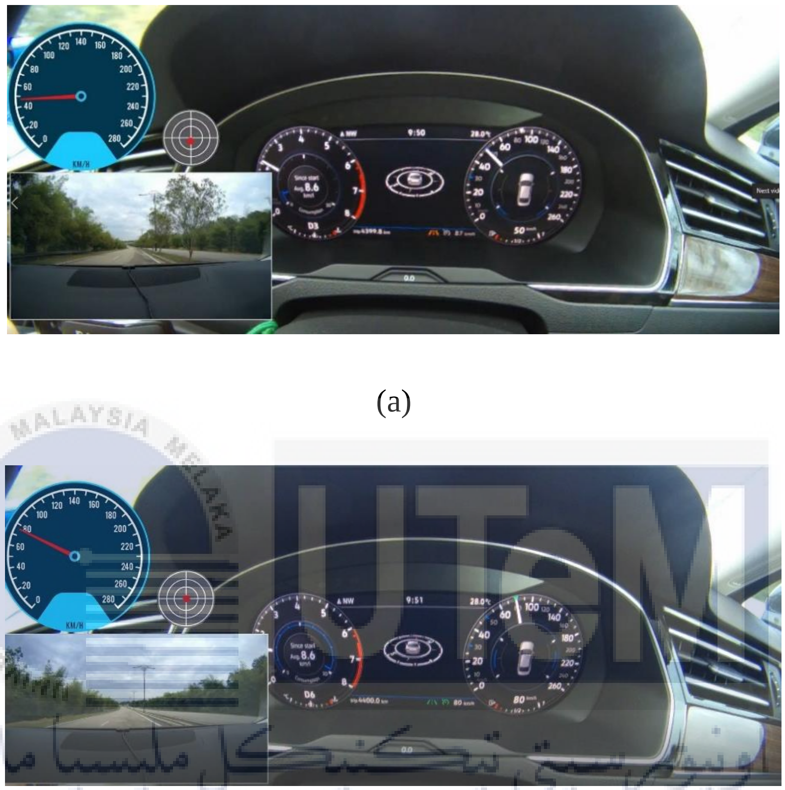
	Left Departure				Right Departure			
Test Number	-	-	-	-	-	-	-	-
Road Line (Dash/Solid)	Solid	Dash	Solid	Dash	Solid	Dash	Solid	Dash
Weather Condition (Dry/wet)	Dry	Dry	Wet	Wet	Dry	Dry	Wet	Wet
Test Time (i.e. 0800)	0934	0957	1635	1403	1124	1059	1547	1612
Ambient Temperature (ºC)	31.8	31.8	36.8	38.1	38.8	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 (<1º/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: i.e. car (1) stay within lane, (2) went over line, (3) touch line, and (4) system disengage	1	1	1	1	1	1	1	1

Based from Table 4.1, the test conditions required is suitable to describe the unresponsive driver who is about to make an unintended lane changing. For the test speed gathered in the data, in every test it shows that the car has an uneven speed pattern. The desired speed of the car is 75 km/h, which is 15 km/h more than the minimum speed required to activate the system. The desired speed should be higher than the minimum speed required because of the system needs a time to process and adapt with the front situation of the car after the speed has approached more than 60 km/h. This is known as stabilization time. The system also only works when the car is moving in cruising speed. However, the car struggles to get the desired speed in every test due to the condition of the test track used. The test track used has an uneven road pattern, such as bumpy and curvy road which will affect the speed of the car.

During departure of lane attempt, the driver should steer the steering to one direction for less than 1º/s of steering angle with a range of 0.2 m/s to 0.5 m/s of departure rate and then remove his hands from the steering. To get the perfect steering angle and departure rate, the driver should be determining the maximum angle to steer as it prevents the car from oversteer.

4.1.2 Clear Weather Test Results

For the clear weather test which is known as dry test from the Table 4.1, it shows that LDW and LKA systems have given a great feedback for both solid and dash road lines tests. For LDW system, the system has given a warning to the driver that the car was about to make an unintended lane changing, while for LKA system, the car is still within the lane for every types of road lines test, which indicates that the system has gently steered back into the lane. This shows that both of the systems are working perfectly during clear weather. Figure 4.1 shows the illustration of the car's dashboard and front scenario when (a) the system is inactive and (b) the system is active.



(a)

(b)

Figure 4.1: The illustration of the car's dashboard and front scenario when

(a) the system is inactive and (b) the system is active

4.1.3 Rainy Weather Test Results

For the rainy weather test known as wet test from the Table 4.1, the rain simulator that has been designed from the previous chapter has been changed to another rain simulator. This is because of during the first trial of the test, the rain simulator has not simulated the same as the desired raining pattern. The previous rain simulator has shown a good raining pattern when simulating on the static car, which it shows that the water is fully spurt on every area of the car's windshield. However, during moving phase, the rain simulator cannot fully spurt on the windshield of the car, due to the influence of surrounding disturbance such as the existence of air flow of moving car and also the surrounding winds towards the spurt water. This can make the water splitting and cannot be spread wholly on the car's windshield.

As for the new rain simulator, which has a single nozzle with a diameter of 38 mm, it shows that the flow rate of water is good enough to simulating a desired raining pattern which is heavy rain. The water is spread nicely on every area of the car's windshield even when the car is in motion. The result is both of the systems are working well even in heavy rain as both systems provided a great feedback for testing on solid and dash road lines. In terms of LDW system, the system gave the driver a warning that the car was about to make an unwanted lane change, while for the LKA system, the car is still in the lane for every types of road lines test, suggesting that the system has gently steered back into the lane. From the heavy rain test, it can confirm that both of the systems can still perform well during light rain. Figure 4.2 shows the illustration of (a) car's dashboard with front scenario and (b) side scenario when the system is inactive and Figure 4.3 shows the illustration of (a) car's dashboard with front scenario and (b) side scenario when the system is active.

However, this test protocol can only approve by making the evaluation from the captured video. The assessment method performed only by visual data. The limitations of this method are the cameras are not synchronized to each camera which may not be accurate in terms of the time of the test held. Thus, this result is accurate but not 100 percent reliable due to the limitations of the test facilities given.

(a)

(b)

Figure 4.2: The illustration of (a) car’s dashboard with front scenario and side scenario when the system is inactive

(a)

(b)

Figure 4.3: The illustration of (a) car's dashboard with front scenario and

(b) side scenario when the system is active

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, the new test protocol for LDW and LKA systems based on selected environment and road conditions parameters has been developed. The test protocol is adapted from Euro NCAP's test protocol, with several changes that suitable with South-East Asia's weather condition. The test protocol comes with a test track layout, traffic management plan and a rain simulator to simulate rainy weather towards the car. However, the test facility given especially for the test track have constrains that will affect the data such as a bumpy and curvy road. Other than that, there is no correlation between the number of cameras used for the test, which might not be precise as to the actual time of the test. The method of assessment carried out only by visual data. For the rain simulator, the fabricated rain simulator was replaced with other rain simulator. This is due to the fabricated rain simulator does not spread the water on every area of car's windshield to simulate heavy rain due to the surrounding disturbance.

Finally, a car that equipped with LDW and LKA systems has been tested under Malaysian road environment which is under South-East Asia region. The car used for the test is Volkswagen Passat 2.0 TSI. Both systems perform well under conditions of clear and heavy rain. The tests showed that the car was staying inside the lane with the aid of the LKA system, which it gently steered the car back into the center of the lane. However, the data collected is accurate but not 100 percent reliable due to the limitations of the provided test facilities.

5.2 Recommendations for Future Works

There are several recommendations that can be improves for future works study. One of the recommendations is to perform on-road test at secured test track. This project also can use dedicated data acquisition system or interrelated camera system and synchronized time. Other than that, the test track design can implement the stabilization time for the lane support system. Furthermore, auxiliary verification system can be used to verify when the LDW and LKA systems has become active. Next, to get an accurate steering and throttle input, a steering robot can be developed. Finally, a remote activation system for rain simulator can be developed. This type of development can decrease a number of human powers needed to simulating the rain towards the moving car

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APPENDICES

Appendix 1

Activity	Timeline (weeks)													
	SEMESTER 1													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Title review														
Develop test protocol														
Concept generation														
Concept selection														
Design evaluation														
Develop on-road test facility														
Report submission														
PSM presentation														

Appendix 2

Activity	Timeline (weeks)													
	SEMESTER 2													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Perform on-road test	■	■	■											
Data collection and analysis	■	■	■	■	■	■	■	■	■	■	■	■	■	
Report submission													■	■
PSM presentation													■	■