DESIGN AND FABRICATE ROLLOVER WARNING DEVICE WITH IOT MONITORING SYSTEM FOR HEAVY VEHICLES

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BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (AUTOMOTIVE TECHNOLOGY) WITH HONOURS

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A thesis submitted in fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering Technology (Automotive Technology) with Honours

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I thus attest that I have carefully reviewed this thesis and believe it to be of sufficient quality and scope to be awarded the degree of Bachelor of Mechanical Engineering Technology (Automotive Technology) with Honors.

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DEDICATION

First and foremost, I'd like to thank Allah for giving me the courage to finish my research and see my thesis realised. This study and research are dedicated to my beloved parents, Rosli bin Rashid as well as Nor Azhariah Binti Zakaria, who have always supported and encouraged me in completing my study. Not forget to mention my siblings, supervisor Ir.Ts.Dr. Mohamad Hafiz bin Harun, and my friends who have supported me throughout my education journey. Thank you for all your assistance, which I will always appreciate and will never forget.

ABSTRACT

Among all the types of car accidents, overturned big truck accidents are some of the deadliest. Several things can lead to injuries or deaths among guests. This thesis looks at how rollover warning devices (RWDs) can be made for cars on the road, especially ones with a higher center of gravity and a higher height-to-track-width ratio. The dynamics of a road car are mostly studied by RWD, along with an estimate of how stable the vehicle is when turning instantly. The dynamic winding stability conditions, especially the load transfer ratio (LTR), are used by the RWD to figure out the turnover index number. Digital models were used to build the project, and real data was used to test it.Also, the device is passive and the driver has to do something for it to work. This means that it can only help with slowly building up dangerous moves, like those that happen during ramp manoeuvres. The block model values of the transition index algorithm can be changed and improved with MatLab software. At the same time, the given transition trend warning system was looked at with TruckSim software. This transition index method is based on what other researchers have said about the fastest response time. The MATLAB/Simulink program is used to simulate step steering moves at different speeds in order to find the rollover index. Based on what was found, it can be said that Odenthal's rollover index algorithm creates the fastest rollover index using the car unit's early warning indicator. Finally, as an option to acceleration along the side, In the rollover index method, the modified Odenthal rollover index technique is used along with inputs from the driver for steering and vehicle speed. We showed what the improved Odenthal rollover index algorithm can do by simulating step turning maneuvers at different speeds and loads using the Hardware-in-the-Loop (HIL) simulation in the TruckSim driving simulator and the MATLAB/Simulink software.

ABSTRAK

Di antara semua jenis kemalangan kereta, kemalangan trak besar terbalik adalah antara yang paling mematikan. Beberapa perkara boleh menyebabkan kecederaan atau kematian di kalangan tetamu. Tesis ini melihat cara peranti amaran pusing ganti (RWD) boleh dibuat untuk kereta di jalan raya, terutamanya yang mempunyai pusat graviti yang lebih tinggi dan nisbah ketinggian-ke-trek-lebar yang lebih tinggi. Dinamik kereta jalan kebanyakannya dikaji oleh RWD, bersama-sama dengan anggaran sejauh mana kenderaan itu stabil apabila membelok serta-merta. Keadaan kestabilan belitan dinamik, terutamanya nisbah pemindahan beban (LTR), digunakan oleh RWD untuk mengetahui nombor indeks pusing ganti. Model digital digunakan untuk membina projek, dan data sebenar digunakan untuk mengujinya. Selain itu, peranti ini adalah pasif dan pemandu perlu melakukan sesuatu agar ia berfungsi. Ini bermakna ia hanya boleh membantu dengan perlahan-lahan membina pergerakan berbahaya, seperti yang berlaku semasa manuver tanjakan. Nilai model blok algoritma indeks peralihan boleh diubah dan diperbaiki dengan perisian MatLab. Pada masa yang sama, sistem amaran arah aliran peralihan yang diberikan telah dilihat dengan perisian TruckSim. Kaedah indeks peralihan ini adalah berdasarkan apa yang penyelidik lain katakan tentang masa tindak balas terpantas. Program MATLAB/Simulink digunakan untuk mensimulasikan pergerakan stereng langkah pada kelajuan yang berbeza untuk mencari indeks peralihan. Berdasarkan apa yang ditemui, boleh dikatakan algoritma indeks pusing ganti Odenthal mencipta indeks pusing ganti terpantas menggunakan penunjuk amaran awal unit kereta. Akhir sekali, sebagai pilihan untuk pecutan di sepanjang sisi, Dalam kaedah indeks pusing ganti, teknik indeks pusing ganti Odenthal yang diubah suai digunakan bersama input daripada pemandu untuk stereng dan kelajuan kenderaan. Kami menunjukkan perkara yang boleh dilakukan oleh algoritma indeks peralihan Odenthal yang dipertingkatkan dengan mensimulasikan manuver pusing langkah pada kelajuan dan beban yang berbeza menggunakan simulasi Hardware-in-the-Loop (HIL) dalam simulator pemanduan TruckSim dan perisian MATLAB/Simulink.

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Finally, yet importantly, to my beloved father, I would like to thank Rosli Bin Rashid, for his support and for being a rock for me in all of my undertakings. Also receiving my eternal affection is my mother, Nor Azhariah Binti Zakaria, for her tolerance and comprehension. Additionally, I want to express my gratitude to my dear friends for their unwavering love, prayers, and support. Finally, yet importantly, I want to express my gratitude to everyone who helped me, encouraged me, and inspired me to start my education.

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LIST OF SYMBOLS AND ABBREVIATIONS

K_a	-	to regulate the impact of the body lateral acceleration reaction
K_r	-	to controlling the impact of the body roll angle response
kg	-	Unit for weight
TTW	-	Time to warn
TTR	-	Time to response
COG	-	Center of gravity
PSO	-	Particle Swarm Optimization
SSF	-	Static Rollover Index
ACO	-	Ant Colony Optimization
SIL	-	Software in the Loop
HIL	-	Hardware in the Loop
LTR	-	Load Transfer Ratio
RI	-	Rollover Index
MIROS	-	Malaysia Institute of Road Safety Research
MORI	-	Modified Odenthal Rollover Index
RSC	-	Roll Stability Control
RSF	-	Roll Safety Factor
RWD	-	Rollover Warning Device
SSF	-	Static Stability Factor
SUV	-	Sport Utility Vehicle
WHO	-	World Health Organization
YSC	-	Yaw Stability Control
ABS	-	Anti-Brake Locking System
ECU	-	Electronic Control Unit
GSA	-	Gravitational Search Algorithm
DHIL	-	Driver Hardware-in-the-Loop
RMP	-	Royal Malaysian Police
GPS	-	Global Positioning System
ESP	-	Electronic Stability Program

AI	-	Artificial Intelligence
HIV	-	Human Immunodeficiency Virus
AIDS	-	Acquired Immune Deficiency Syndrome
GDP	-	Gross Domestic Product
RMP	-	Royal Malaysia Police

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CHAPTER 1

INTRODUCTION

1.1 Background

The incidence of road accidents is on the rise in contemporary times, despite advancements in vehicle safety technology. It is a common occurrence for accidents to transpire on frequently utilized highways. The World Health Organization (WHO) reports that Malaysia and other low- and middle-income nations with populations of 100,000 or fewer have a road fatality rate of 10.3 per 100,000, which is higher than high-income nations like the United States. Despite having only 40% of the world's registered vehicles, low and middle-income countries are the ones who cause nearly 90% of all traffic deaths. Over the past four to five decades, the death rates of a sizable number of high-income nations have decreased. Road accidents constitute the leading cause of fatalities, physical harm, and incapacitation. Approximately 50% of all traffic fatalities are attributed to individuals who are pedestrians, cyclists, or operators of motorized two-wheel vehicles. The term "vulnerable road users" is used to describe these individuals. They are increasingly common in economies that are less developed across the globe. Annually, car accidents result in the loss of more than 1.17 million lives and cause injuries to an additional 20-50 million individuals.

Moreover, the age group of individuals involved in the accident is primarily young people ranging from 5 to 29 years old, rendering it a more equal representation. Annually, traffic accidents result in the deaths of 1.17 million individuals, which makes up 70% of all fatalities. Based on estimations, the majority of fatalities in traffic accidents are attributed to pedestrians, comprising 65% of the total. Among those killed, children make up 35% of the pedestrian fatalities. Additionally, it is estimated that the number of individuals who lose their lives in traffic accidents globally ranges from 23 to 34 million. The current quantity is nearly double the amount that was originally approximated. According to estimates, more than 200 individuals hailing from the United States fall victim to fatalities associated with traffic incidents that take place in other nations on a yearly basis.

Additionally, it is worth noting that in Europe, the number of fatalities resulting from traffic accidents exceeds 50,000, while over 150,000 individuals sustain injuries. During the period spanning from 1990 to 2011, there was a significant increase of 70% in the total fatalities resulting from accidents in Malaysia as compared to the previous year. According to the estimation made by the Chief of Traffic Police in Bukit Aman, the number of fatalities resulting from motor vehicle accidents on Malaysian roads is approximately 19 individuals per day. This estimate appears to be relatively high in light of Malaysia's overall population of 28 million individuals. The imperative to undertake this task arises from the observation that the nation is encountering challenges in its pursuit of attaining developed country status as the year 2020 approaches. In developing nations, two-wheeled vehicles, including motorcycles, have become common on roadways. Motorcyclists who sustain injuries in a collision with another vehicle are particularly vulnerable to harm, particularly those that impact the head. As per the findings of a national RTA statistic compiled by the Royal Malaysian Police, it has been observed that a significant number of fatal accidents in Malaysia can be attributed to the actions of motorcyclists (Khairul Amri Kamarudin et al., 2018).

The fatality rate of non-commercial drivers is higher than that of commercial drivers in the majority of accidents involving heavy vehicles. Merely 4.40% of the total driving registries in Malaysia related to heavy transportation, while heavy transportation and buses accounted for 4.20% and 0.20%, respectively. According to the Road Safety Department of

Malaysia, the fatality rate of passengers in large vehicles, which is approximately four percent, is relatively low when compared to the total number of fatalities resulting from traffic accidents. Nonetheless, there exists an absence of information regarding the incidence of fatalities and accidents associated with large automobiles. In 2014, there were 57,430 road accidents that involved heavy vehicles, buses, and taxis. Annually, accidents involving heavy vehicles result in the loss of 1,000 lives. The majority of fatalities, specifically 80%, are attributed to individuals traveling in other automobiles. In comparison to other road categories, motorways have a higher likelihood of experiencing accidents involving large vehicles, as well as accidents involving heavy vehicles in general, which may result in fatalities.

Numerous nations are also apprehensive about vehicular collisions on roads that involve weighty automobiles. In the United States, it is observed that although heavy vehicles constitute merely 3 percent of the total registered vehicles, their share in the total vehicles driven per mile is only 7 percent. Conversely, it can be observed that a significant proportion of fatal collisions, approximately eleven percent, involve vehicles of considerable size. According to Manap et al. (2021), despite constituting a mere 3% of the total registered vehicles in Australia, heavy vehicles are accountable for a significant 80% of severe or fatal accidents. There are various factors that contribute to road accidents, such as distracted driving, driving under the influence, failure to signal when changing lanes, speeding, disregarding traffic signals, and overturning while turning corners. Rollover is a significant contributing factor to road accidents among the various factors involved.

Linstromberg and Scherf (n.d.) reported that rollover accidents resulted in the fatalities of more than 10,000 individuals and caused injuries to approximately 229,000 individuals solely in the United States in 2003. In light of the available data, researchers are increasingly demonstrating interest in investigating the behavior of vehicle components, as well as passive and active restraint systems, under rollover loads. This is being done with the aim of enhancing occupant protection. Four new test configurations have been developed based on accident analyses to ensure a realistic reconfiguration of vehicle behavior during development tests. Familiarity with the boundary between roll and no roll is a prerequisite for the advancement of restraint mechanisms. The utilization of test and simulation tools facilitates a comprehensive development process, which in turn enables the adaptation and enhancement of rollover protection systems.

1.2 Statement of the Problem

According to Figure 1-1, a rollover transpires when a vehicle rotates over a genuine longitudinal or lateral axis of 90 degrees or greater. A rollover event occurs when a motor vehicle experiences a loss of control over two of its wheels, resulting in a lateral slide towards one side. All types of vehicles are susceptible to the phenomenon, however, those with a greater vertical dimension, such as buses, SUVs, and heavy trucks, are at a substantially elevated threat. Several variables, such as unexpected steering, sudden alterations in direction, or swift turns executed at high velocities, can result in the displacement of the center of gravity of a vehicle, causing it to tilt to one side and subsequently overturn. Furthermore, larger vehicles, such as tractor-trailers, that are overloaded with excessive weight, are at a heightened risk of experiencing rollover incidents.

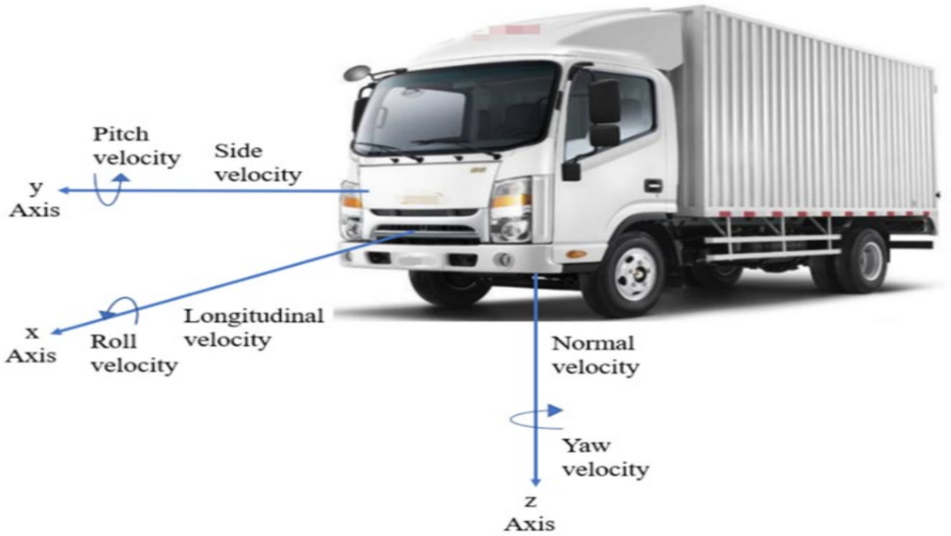

Figure 1-1 SAE coordinate system

Based on the data obtained from Ministry of Transport 2019, there were 832,673 vehicles involved in road accidents. Motorcar has the highest involvement followed by Four Wheel Drive vehicles and in third place is Heavy Goods Vehicle which has the total amount of 37,874 road accidents. It made up to 4.15% of all vehicles on Malaysian highways in 2019 and was involved in 4.55% of all accidents, 3% of accidents resulted in the deaths of Malaysian HGV drivers and uncountable secondary crash deaths involving HGV accidents. These accidents result in a significant impact on logistic costs and the death of the road users. As per the findings of MIROS, a significant proportion of bus accidents in 2012 were attributed to mechanical failures, which led to harm to passengers. Specifically, 21.4% of such incidents were caused by this factor. Malfunctioning brakes contribute to 2.15% of all recorded causes of vehicular accidents, whereas faulty tires account for 28.6% of all recorded causes of vehicular accidents.

One of the accidents that can occur is rollover. Rollover can take place only if the driver error or driver behavior which needs certain conditions to meet. According to Figure 1-2, human factor is the main reason for 93% of accidents (Islam et al,. 2019).

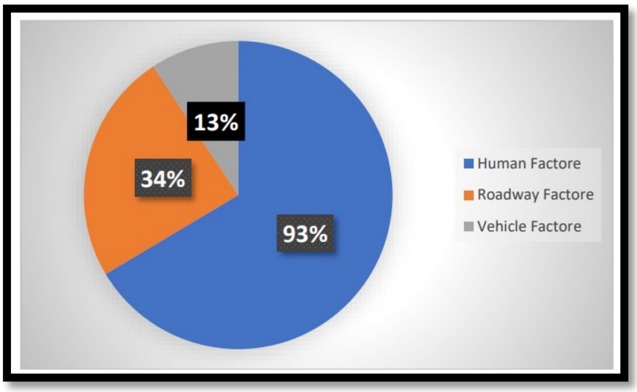

Figure 1-2 The contribution of accidents factors in percentage 2008

(Islam et al., 2019)

According to Figure 1-3, AASHTO, 2010, these are the crash contributing factors when it is break down.

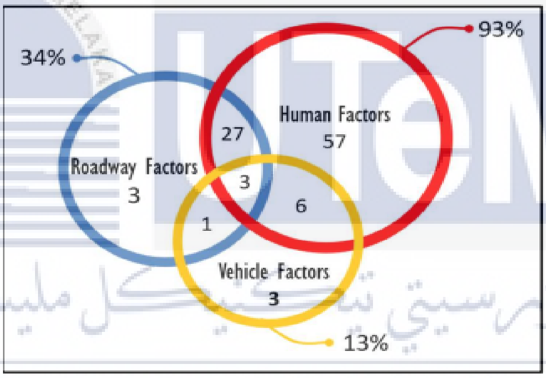

Figure 1-3

The results of statistical analysis suggest the implementation of vehicle assistance devices, such as a rollover warning system, to reduce the impact of human error in causing vehicle shifts. The purpose of the rollover warning system is to offer the driver with a prompt head-up warning, enabling them to expeditiously rectify the maneuver. Consequently, it will assist in minimizing vehicular collisions. The occurrence of a heavy-duty vehicle rollover is a matter of considerable concern with regards to road safety on a global scale. Although rollovers are infrequent, they can be extremely fatal when they do happen. The implementation of effective mechanisms to alert drivers of potential rollover hazards is of utmost importance in the development of a dependable active safety warning system that can be integrated into heavy-duty commercial vehicles.

1.3 Research Objective

The objective is to design and evaluate a rollover warning system suitable for installation in heavy-duty vehicles. The subsequent enumeration presents a more comprehensive catalogue of the intended aims:

a) To design and fabricate rollover warning devices for heavy vehicles.

b) To embed the IoT system in Rollover Warning Device for monitoring purposes.

1.4 Scope of Research

- The modified rollover index is combined in the microcontroller.
- The rollover warning device is develop using Matlab/Simulink.
- The IoT system is design and develop as a monitoring system that receives, stores and analyzes data transmitted by the microcontroller.
- To set up wireless communication technologies to facilitate the transmission of the gathered sensor data to a centralizes monitoring system.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The modern world has witnessed a new kind of mobility helped by the use of motor vehicles, leading to an upsurge in traffic. With the global increase in the number of motor vehicles, highway distances, and vehicle travel distances, there is a growing likelihood of individuals being exposed to road accidents. With the passing of time, there has been a noticeable increase in the number of factories established to cater to the needs of the community, as compared to the past. Consequently, many different kinds of vehicles are required to convey the essential materials to the manufacturing facility. The incidence of vehicular accidents, including those involving rollovers, has been observed to rise in line with the increasing number of vehicles on the road.

2.2 Indication of Early Warning

Ensuring safety is of utmost importance for both the automobile and its passengers. It is imperative for individuals to exercise caution with respect to human error factors, including but not limited to reckless driving, driving while experiencing fatigue, and exhibiting ignorance towards environmental concerns. These errors have the potential to result in the vehicle to rollover.

According to (Mohd Nor & Dol Baharin, 2014), The most dangerous type of heavy vehicle accident is a rollover. The mean number of individuals harmed per incident is 25. If the side and roof structures of a vehicle fail to support the passenger safety compartment, it can lead to grave and lethal injuries to those who are confined within. A wide range of rollover avoidance mechanisms have been developed by researchers and engineers to tackle this problem. On the contrary, during the onset of the impending rollover phase, there may be inadequate time for actuators to react suitably, particularly in instances that cause major damage. In order to reduce the occurrence of heavy vehicle rollover incidents, it is possible to predict the probability of rollover and subsequently determine a suitable lead time. Rollover early warning indicators are deemed crucial in notifying the driver in advance of the occurrence of a rollover, wherein either of the vehicle's tires lifts up.

2.3 Indication of Rollover

A rollover event refers to an unintended incident whereby a motor vehicle overturns onto its roof or either of its sides. The term applies to any mode of transportation that undergoes a complete revolution along a genuine longitudinal or lateral axis measuring 90 degrees or greater. The fatality rate associated with rollover incidents appears to be higher compared to other categories of vehicular accidents. The built features of sizable automobiles have been identified as a significant factor in their not optimal roll stability and susceptibility to rollover incidents. Traffic accidents have emerged as a significant concern that affects transportation security due to their potential to cause fatalities and property damage.

2.3.1 Types of vehicle rollover

The National Highway and Traffic Safety Administration (NHTSA) puts rollovers into groups based on what caused them. (Amirul Affiz, 2014) Some classes use terms like turn-over, flip-over, climb-over, end-over-end, and bounce-over. Figure 2-1 shows how a car rolls when it makes sharp turns and the centrifugal forces caused by the turns meet the normal surface friction.

Figure 2-1 Centrifugal Force Countered by Normal Surface Friction Causes the Vehicle to Turn Over (Young et al., 2007)

When a car hits an object with a slope, like the back of a river or a broken guardrail, it turns around its longitudinal axis. Figure 2-2 shows cars that have flipped over.

Figure 2-2 Vehicle Flip Over (Young et al., 2007)

As shown in Figure 2-3, the climbs over factor happens when a car goes over a large fixed obstacle, like a fence or barrier, that is big enough and tall enough to lift the car off the ground.

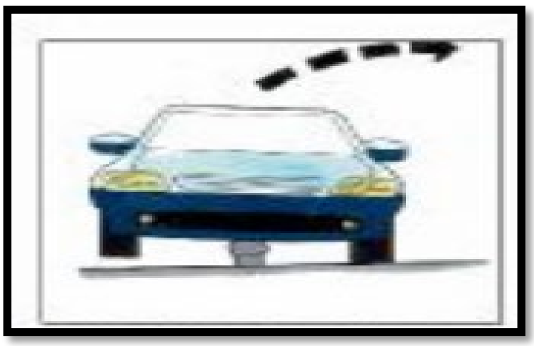

Figure 2-3 Vehicle Climbs Over a Fixed Object

(Linstromberg & Scherf, n.d.)

The phenomenon of end over end factor is observed when a vehicle experiences roll along its lateral axis. This phenomenon may occur when a vehicle abruptly halts, causing the weight distribution to shift towards the front. The illustration presented in Figure 2-4 portrays the rotational motion of the vehicle around its central axis.

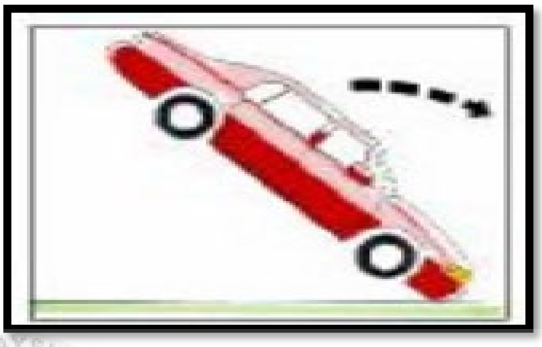

Figure 2-4 Vehicle Rolls on its Lateral Axis or End over end (Linstromberg & Scherf, n.d.)

The bounce over factor refers to the phenomenon wherein a vehicle overturns subsequent to colliding with an immovable object and rebounding. The rollover maneuver is required to take place in close proximity to the stationary obstacle, as depicted in Figure 2-5.

Figure 2-5 Vehicle motion during typical roll Bounce Over initiated rollover (Young et al., 2007)

2.3.2 Rollover Index types

Kazemian et al. (2017) have classified vehicle rollovers into two categories, namely tripped (as depicted in Figure 2-6) and untripped (as illustrated in Figure 2-7). Tripped rollovers are a type of vehicles accident that results from the contact between a vehicle's tyre and an object, leading to the end of the vehicle's lateral motion and resulting rolling of the vehicle around the obstacle. Common tripping hazards include curbs, rocks, soil, and ramps. On the other hand, untripped rollover occur by a combination of steering input, velocity, and ground friction. This collision was influenced by high-risk steering moves such as J-hooks, sudden turns, and sudden lane changes. A rollover event is differentiated from a typical trip occurrence due to the absence of a trip item, and is marked by a sudden displacement in the position of the center of gravity. In contrast, existing rollover indices are formulated to identify rollovers that have not been triggered, and encounter difficulties in detecting rollovers that have been triggered. The statement indicates that the present rollover index is based on lateral acceleration observations and can solely detect untripped rollovers that result from high lateral acceleration during a sudden turn. The study conducted by Kazemian et al. (2017) indicates that the existing rollover indices utilized in automobiles are capable of identifying solely untripped rollovers due to the presence of high lateral acceleration. The effectiveness of these indices in detecting rollovers is restricted. According to the statement, the existing rollover indices utilized in the transportation sector solely acknowledge untripped rollovers that occur due to excessive lateral acceleration. These indices are not capable of detecting a rollover that has been triggered by extended vertical external forces.

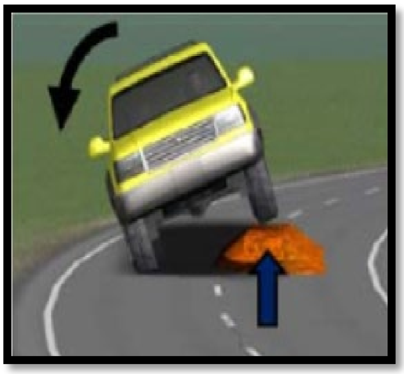

Figure 2-6 Tripped Rollover (Kazemian et al., 2017)

Figure 2-7 Untripped Rollover (Kazemian et al., 2017)

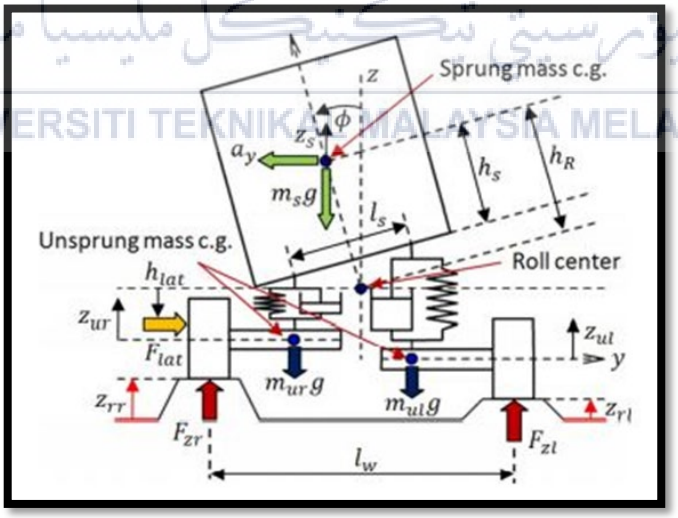

Figure 2-8 Untripped and Tripped Rollover Model (Kazemian et al., 2017)

Several factors contribute to the rollover of these vehicles, such as the diversity of maneuvers, driving conditions, road conditions, vehicle geometry, and car performance. In order to identify the occurrence of rollover, it is essential to establish a metric or gauge that measures the stability of the automobile. According to Peters (2006), the index empowers the controller to make use of control in determining the likelihood of a rollover and giving the suitable instructions. The computation of each index involves the utilization of sensor data in combination with the dynamic state of the vehicle. In order to determine rollover thresholds, it is necessary to measure the value against predetermined programmed values. The static stability factor is a fundamental metric that indicates a vehicle's inherent inclination to overturn and is commonly derived from static testing scenarios.

After choosing one of the rollover indices, you can use different control methods to make the vehicle's behavior stable. Many studies showed different ways to stop a vehicle from rolling over, such as different suspension systems (Cech, 2000), different braking systems, and steering control mechanisms that could be triggered in different ways. (Kazemian et al., 2017) says that active steering control, which is based on discrete-time systems, can be used to study how a car rolls.

Rollover index of the vehicle is a live variable that can be used to detect wheel lift-off conditions. The following is the essential definition of the term rollover R:

$$\mathrm{R} = \frac{F_{zr} - F_{zl}}{F_{zr} + F_{zl}}, -1 \leq \mathrm{R} \leq 1 \tag{2.1}$$

Where F_{zr} and F_{zl} represent the vertical forces of the right and left tyres, respectively. When the vehicle gets closer to the rollover threshold, the index value goes either above or below one. It is essential to note that when the car moves in a straight line down the road, the Fzr and Fzl values are both zero, and the rollover value is also zero. As $F_{zl} = 0$, R=1 and the vehicle will be on the correct tyre on the surface. Because the forces are immeasurable, relation 1 cannot be implemented. Numerous efforts by researchers have been made to obtain the indices. A lateral acceleration and an untripped rollover index were the results of many of the attempts. An R rollover index formula based on ϕ and a_y.

$$R_1 = \frac{2m_s a_y h_R}{mgL_w} + \frac{2m_s h_R \tan(\phi)}{mL_w} \tag{2.2}$$

Where $m = m_s + m_u$, h_R represents the height of the centre of gravity, m_u represents the unsprung mass, m_s represents the sprung mass, a_y represents the lateral acceleration, and ϕ is the rotation angle. This rollover index is only helpful for determining whether or not a rollover has already been tripped. Because it can be challenging to determine the roll angle, some studies defined the rollover index based solely on the lateral acceleration. The stability control system equipped with this index can potentially restrict the lateral movement of the vehicle. Still, it cannot detect rollovers brought on by vertical forces and road inputs (Kazemian et al., 2017).

$$R_2 = \frac{2m_s a_y h_R}{mgL_w} \tag{2.3}$$

The commercial version of the index includes an additional independent evaluation of the acceleration of the sprung mass (Phanomchoeng & Rajamani, 2013).

$$R_3 = \frac{2m_s a_y h_R}{mgL_w} + \frac{2m_s h_R \tan(\phi)}{mL_w} + \frac{m_u(\ddot{z}_{ur} - \ddot{z}_{ul})}{mg} \tag{2.4}$$

Where $(\ddot{z}_{ur} - \ddot{z}_{ul})$ denotes the difference in unsprung mass acceleration.

2.3.3 Instability in static roll

The experiments yielded the other suggested static RIs, such as Side Pull Ratio and The conducted experiments have resulted in the identification of additional static refractive indices, namely the Side Pull Ratio and Tilt Table Ratio, which exhibit a high degree of proximity to the SSF. In order to enhance the precision of rollover indicators in dynamic scenarios, a number of dynamic RIs that consider the state of the vehicle have been suggested by Ataei et al. (2019).

The roll over score technique has been improved by combining insights from the manoeuvrability assessment, specifically the Fish hook move by the National Highway Traffic Safety Administration, to help consumers in understanding the roll over resilience of automobiles. The factor of static stability (SSF) is determined by dividing the height of the centre of gravity (C.G.) by half of the width of the track. Three different methodologies have been developed by researchers to prevent an untripped rollover. The initial category utilises suspension activation, anti-roll bar activation, and stabiliser activation to directly regulate the roll motion of the vehicle. According to Chen et al. (2011), the implementation of higher thresholds has the potential to reduce rollover incidents.

2.3.4 Instability in dynamic roll

Multiple sources have suggested the addition of suspension effects in the static refractive index. The research suggests additional static resistance indices, such as side pull and tilt table ratios, that exhibit a level of comparability to the SSF. Several dynamic rollover indicators (RIs) have been suggested to enhance the precision of rollover indicators for dynamic settings by considering the vehicle's condition. The indicators frequently make assumptions regarding a genuine vehicle state during a rollover event, such as the vehicle's roll angle, lateral acceleration, or roll rate. This serves as an early indicator of a potential rollover event. The lateral load transfer ratio (LTR), as described by Ataei et al. (2019), is a commonly utilised resistance index in dynamic scenarios.

As per the findings of Doumiati et al. (2009), it has been established that the index for lateral load transference is influenced by the forces that exist between the road and the wheel. The assessment of the score is conducted through a comparative analysis of the lateral forces generated by the left and right wheels, with the controller being triggered when the discrepancy surpasses a predetermined threshold. The roll angle experienced during cornering can be attributed to the roll stiffness of the axle and the position of the roll centre. The determination of the roll centre of a suspension system can be achieved by utilising the rotational motion of the tyre as it encounters a mark in a lateral direction.

The roll centre is the location where the mass of the sprung suspension experiences lateral forces without rolling.

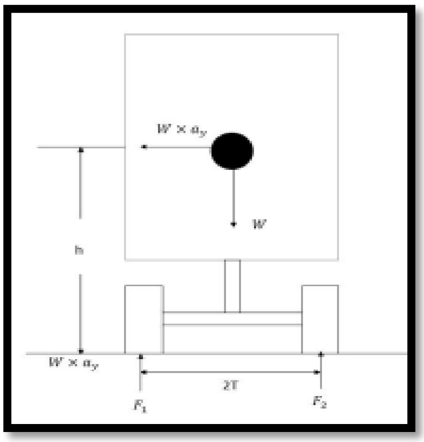

Figure 2-9 Rigid Vehicle Model (Ataei et al., 2019)

2.4 Implementation and Testing

To carry out the implementation and testing phases, two distinct simulations were emplyed, namely Software in the Loop (SIL) and Hardware in the Loop (HIL). These two loop solutions enable the testing of self-generated solutions through simulations of real-world scenarios. The utilisation of these tools expedites the process of product development and enhances the efficacy of quality management, thereby reducing the dependency on tangible prototypes and assessments.

2.4.1 Software In the Loop (SIL)

The Software In the Loop (SIL) unit analysis is conducted on the code intended for the identification and correction of system-level errors, that includes code generation validation. Users have the option to incorporate a software component into an environment simulation through the utilisation of the Software In the Loop (SIL) methodology. Moreover, the adaptability of this methodology enables rapid experimentation of diverse scenarios and control algorithms. The authors of the study conducted by Ben Ayed et al. (2017) claim that they have established a Software-in-the-Loop (SIL) setting to facilitate the formulation of control methods for hybrid automobiles. This setting facilitates the assessment of diverse vehicular dynamic characteristics concerning supplementary mass and the centre of gravity's placement. In addition, this methodology enables the representation, simplification, and separation of the complicated and non-linear six degrees of freedom kinematics of the automobile. In their study, Ben Ayed et al. (2017) introduced a cost-effective simulation approach for SIL assessment. The simulation was designed to evaluate the control law of a quadricopter, utilising MATLAB/Simulink for control law and Xplane for vehicle dynamics and flight environment.

2.4.2 Hardware In the Loop (HIL)

The Hardware in the Loop (HIL) Simulation is a testing methodology that involves connecting the physical subsystem to a simulated environment, where the remaining system is simulated. This particular methodology proves to be particularly advantageous in cases where it is not practical to model the subsystem under consideration. This form of testing eliminates the risks linked with physical experimentation, thereby enabling the secure evaluation of the system's reaction to rigors procedures. The utilisation of Hardware-in-the-Loop (HIL) testing is progressively gaining popularity in both industrial and research settings for the purpose of developing and refining novel technology, as stated by S. J. Rao in 2013.

In order to fulfil the requirement for more research and intensified experimentation, the Transportation Research Centre (TRC) and The Ohio State University, contracted by the National Highway Traffic Safety Administration, developed and constructed a Hardware-in-the-Loop (HIL) configuration for tractor and trailer systems that can accommodate up to five axles, as shown in Figure 2-10. The HIL (Hardware-in-the-Loop) device consists of ten brake chambers, with each of the five axles being allocated one. According to the research conducted by S. J. Rao in 2013, the determination of brake chambers and hose lengths was based on empirical data obtained from a 2006 Volvo 6x4 VNL 64T630 tractor and a 53-foot Fruehauf Box trailer.

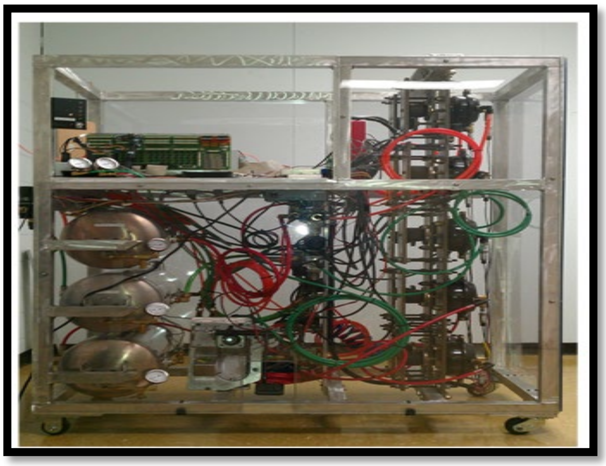

Figure 2-10 Hardware In the Loop System (S. J. Rao, 2013)

2.4.3 Vehicle testing implementation

According to the NHTSA, there is an important priority placed on improving the safety of heavy trucks for both their occupants and other individuals utilising the roadways. The NHTSA conducts comprehensive evaluations on heavy trucks to determine their safety and establish enforceable standards for manufacturers to enhance overall safety. In addition, by subjecting tractor-trailer combinations to rigors testing on the track is a process that is both costly and time-consuming. Furthermore, it is accompanied by the potential for driver harm and test surface damage, which ultimately restricts the ability to conduct high-speed testing. The limitations of physical experimentation call for the exploration of alternative approaches for assessing high-level manoeuvres, among which Hardware in the Loop Simulation (HIL) represents a viable alternative. The Hardware in the Loop (HIL) Simulation is a testing methodology that involves the connection of the physical subsystem to a simulated environment, where the remaining components of the system are simulated. This particular methodology proves to be particularly advantageous in situations where it is not possible to model the subsystem under consideration. This form of testing reduces the risks related in physical testing, enabling the secure evaluation of the system's reaction to extreme operations. The employment of Hardware-in-the-Loop (HIL) testing has gained momentum in both industrial and academic settings for the purpose of refining and advancing novel technological innovations (Rao & Member, 2013).

The Simulink algorithm operates on a similar logic as the ABS, as it tracks the wheel slip ratios and angular acceleration of all wheels. The data obtained from the Hardware-in-the-Loop (HIL) simulation was carefully analysed to determine the different thresholds of angular acceleration that trigger the Anti-lock Braking System (ABS), and subsequently integrated into the Simulink model. The ESC model's thresholds for lateral acceleration and yaw rate were established through a comprehensive analysis of experimental data provided by HTM. This data encompassed various dynamic steering manoeuvres, including the J-turn, double lane change, follow cone path, and high dynamic steer. Subsequently, the TruckSim vehicular model was integrated with the Simulink model utilising an S-function. Braking manoeuvres of comparable nature were executed under road conditions to validate the algorithm's effectiveness. The outcomes were subsequently compared with the HIL and experimental results obtained from HTM. The metrics employed to compare SIL and HIL simulations with experimental data were stopping time, ABS modulation time, and average brake chamber pressure, as reported by S. Y. Rao and Member in 2013.

2.5 Internet of Things (IoT)

The Internet of Things (IoT) refers to a set of devices and apparatuses that possess the capability to transmit and receive data autonomously over a Wi-Fi network, without requiring any human intervention. This refers to a software component that facilitates the integration of physical items and common devices with the World Wide Web. Computers that are enabled with IoT technology have the capability to establish connections with each other via the internet and can be programmed to perform a diverse range of tasks. The implementation of the Internet of Things (IoT) is expected to facilitate the delivery of secure and effective transportation services. The reason for this is that Internet of Things (IoT) systems are operated by event-driven programmes that receive inputs in the form of sensed data, user feedback, or other external stimuli. The previously mentioned data is acquired through a multitude of internal sensors, which are complex devices designed to detect and react to various electrical and other types of signals.

2.5.1 Smartphones

The utilisation of cellphones for automatic collision tracking has been elaborated upon by Varma Sri Krishna Chaitanya in a scholarly work published in 2013. Automated collision warning systems have been integrated by BMW and General Motors. The accident occurrence is analysed through the utilisation of sensors, including accelerometers and airbag deployment displays, which are integrated into the vehicles. The data is subsequently transmitted to a response centre via the built-in cellular radios. Regrettably, the majority of automobiles lack an automated system for alerting drivers of potential accidents. Consequently, the utilisation of smartphones has replaced the previously mentioned gadget, as it has the capability to identify injuries and promptly notify the appropriate authorities without human intervention. The utilisation of cellphones in instead of automated crash warning systems presents various benefits, such as the capacity for fast transportation and the provision of accident alert notifications in diverse modes of transportation, including but not limited to bicycles and motorbikes. Moreover, due to the fact that each mobile device is associated with its respective owner, the process of identifying the offender is uncomplicated. In the case of an incident, the sensors of a smartphone determine the GPS location, altitude, and auditory footprint of the vehicle and transmit this data to a centralised server via an integrated cellular connection, which subsequently relays it to the emergency department.

2.5.2 GSM and GPS

In (V Praveena, 2014), the utilisation of GSM and GPS technologies is elaborated upon in the context of accident detection and automated message transmission. Global Positioning System (GPS) satellites are employed to accurately determine the precise location, elevation, distance, and position of the crash. A conventional device for detecting and communicating road accidents using a microcontroller utilises an infrared sensor for object identification. In case of an incident, the device utilises the GPS module to calculate the geographical coordinates of the accident site. Subsequently, the system transmits a distress signal to the medical facility, providing the precise geographical coordinates of the automobile.

2.5.3 Vehicular As-Hoc Network (VANET)

In the study conducted by Bruno Fernandes in 2015, VANET was utilised as a technology for accident warning. This was achieved through the incorporation of two sensors, namely a collision sensor and an airbag device. Upon detection of an injury, the aforementioned sensors transmit the collected data to a device that is based on a microcontroller. The crash location is determined through the utilisation of GPS technology, and subsequently, the device relays the location data to a designated recipient via GSM communication. The transmission of communication to the rescue crew is facilitated through the utilisation of Vehicular Ad Hoc Networks (VANETs), which are dynamic networks that link mobile vehicles. The transmission of information is directed through the Vehicular Ad Hoc Network (VANET) to the team responsible for providing assistance. Initially, a cautionary communication is sent out from a source node to all vehicles along the route.

2.5.4 Technology for mobile devices

As per Tvrzský's (2011) eCall architecture, it can be inferred that the eCall framework facilitates communication between the incident vehicle and the Public Service Answering Point (PSAP) through the utilisation of the GSM cellular network. The forthcoming eCall service will utilise the E112 unified pan-European emergency call number to facilitate comprehensive roaming capabilities across Europe. Figure 2a illustrates the components of the eCall architecture as defined by the eCall Driving Group, which include the vehicle, network, and PSAP. Additionally, the diagram shows the transmission of voice and data calls between the vehicle and the PSAP in the event of an emergency.

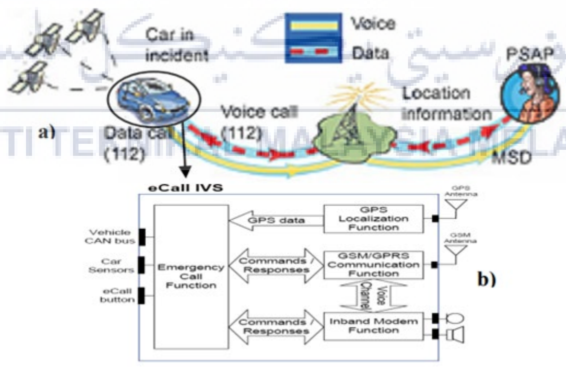

Figure 2-11 Architecture of the eCall service and eCall IVS

Standardization efforts for the technology used to apply the design in Fig. 2a focus on two main areas: the transport protocol used to send the Minimum Set of Data (MSD) to the PSAP through the cellular network, and the content and format of the MSD. eCall support guidelines are made by the European Telecommunications guidelines Institute (ETSI). CEN/TC 278 WG15 (eSafety) is in charge of defining the MSD at the moment. ETSI-MSG and 3GPP are in charge of defining the MSD communication. The MSD message (Road transport, 2008) is limited to 140 bytes and includes the time and location of the accident, an indication of whether the eCall was activated manually or automatically, the type and identification number (VIN) of the vehicle, the number of passengers, and other optional data.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Broadly speaking, a rollover event takes place when a motor vehicle experiences a collision that results in it overturning onto its side or roof. A vehicle that rotates along an axis of 90 degrees or greater in either a longitudinal or lateral direction can be classified as such. In instances of severe damage, the actuators may not have adequate time to respond appropriately once the rollover phase has commenced. In order to mitigate the issue of rollover incidents involving heavy vehicles, it is essential to possess the capability to assess the likelihood of such an occurrence and subsequently determine an optimal lead time for intervention.

Consequently, a device intended to mitigate the occurrence of rollover accidents has been developed and produced. The objective of this mechanism is to provide the driver with a prompt alert prior to the occurrence of a vehicle rollover. The system has been constructed utilizing MATLAB Simulink in order to anticipate the outcome resulting from the application of an external input.

3.2 Project Flowchart Process

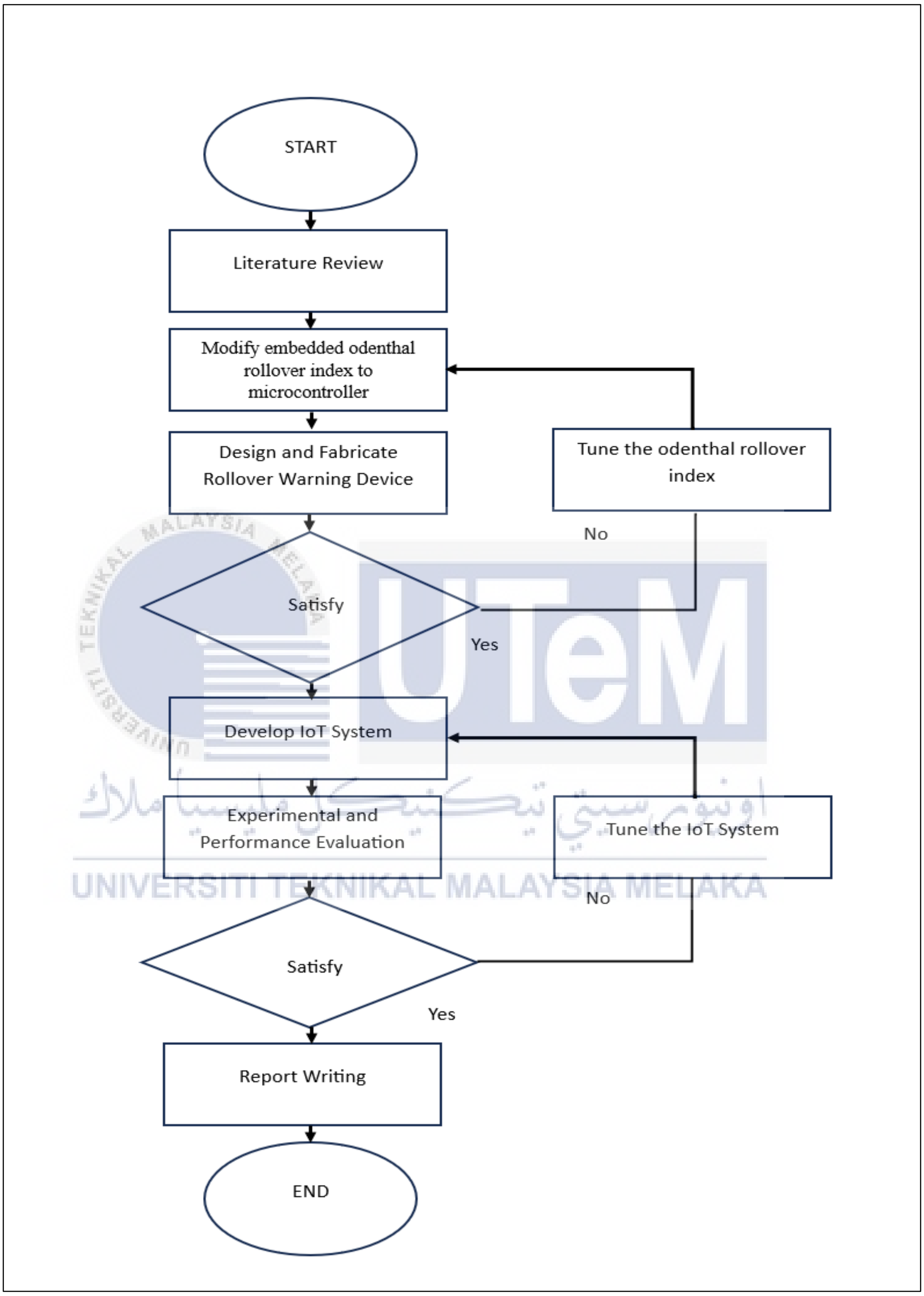

Figure 3-1 Project Flowchart Process

3.3 Gantt Chart

Table 3-1 Gantt Chart

SEMESTER 2 2022/2023 (PSM 1)																
		WEEKS OF STUDY														
NO	TASK DESCRIPTION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	REPORT WRITING															Proposal report submission
2	INTRODUCTION															
	1.1 Background															
	1.2 Problem Statement															
	1.3 Research Objective															
	1.4 Scope of Research															
3	LITERATURE REVIEW															
	2.1 Introduction															
	2.2 Early warning indication															
	2.3 Rollover Index															
	2.4 Implementation and testing															
	2.5 Internet of Things (IoT)															
4	METHODOLOGY															
	3.1 Introduction															
	3.2 Project Process Flowchart															
	3.3 Gantt Chart															

	3.4 Software in the Loop															
	3.5 Hardware in the Loop															
	3.6 Odenthal Rollover Index Algorithm															
	3.7 Modified Rollover Index Algorithm for Commercial Vehicle															
	3.8 Particle Swarm Optimization (PSO)															
	3.9 Simulation Setting															
	3.10 Test of a Modified Odenthal Rollover Index for Commercial Vehicle															
	3.11 Parameter															
	3.12 Equipment															
	3.13 Limitation															
SEMESTER 1 2023/2024 (PSM 2)																
		WEEKS OF STUDY														
5	4.0 Result and discussion															
	4.1 Introduction															
	4.2 The operation of the modified ordenthal rollover index algorithm															
	4.3 Conclusion of the result															

6	5.0 Conclusion and recommendation															
	5.1 Conclusion															
	5.2 Recommendation															
7	Reference															

3.4 Software In the Loop (SIL)

The TruckSim driving simulator is utilized to apply algorithm input to software in the loop, as shown in Figure 3-4. The TruckSim driving simulator software requires the input of data related to vehicle categories, velocity, and steering angle. Subsequently, the TruckSim driving simulator will generate the steering input and vehicle velocity, denoted as v. The two aforementioned parameters will serve as input for the rollover index algorithm at the second block. The algorithm for computing the rollover index will be implemented within the Matlab/Simulink software platform. This metric can be utilized to determine the tendency of the automobile to rollover incidents. When a vehicle approaches the point of rolling over, the index rate reaches a value of one or higher. In instances where the rate exceeds one, the speaker will initiate playback and the LED array will become illuminated.

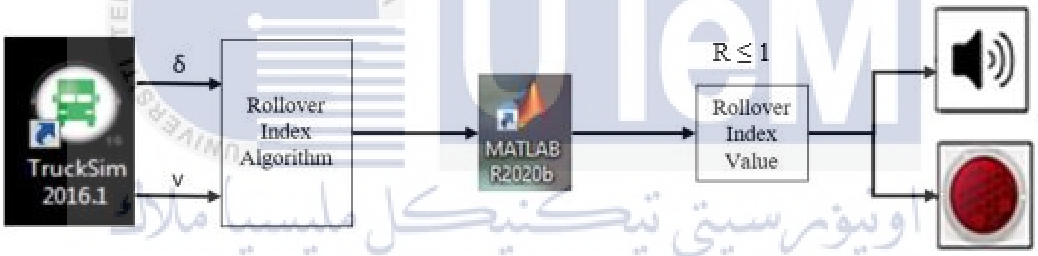

Figure 3-2 Input from Algorithms at Software in the Loop

3.5 Hardware In the Loop (HIL)

TruckSim simulation software can be used to evaluate rollover prediction. TruckSim Software is used to obtain a real vehicle simulation as well as an output graph to compare with the output graph of the MATLAB Simulink software. Before applying the Arduino DUE board, a set of block models is created for the rollover index parameter.

3.6 Odenthal Rollover Index Algorithm

The vehicle rollover model was used to generate the rollover index algorithm. The vertical tyre force is essentially represented by $\boldsymbol{F_{Z,L}}$ and $\boldsymbol{F_{z,R}}$. Calculating the rollover index RI requires balancing the vertical load and roll movements. Consequently, RI is displayed as

$$RI = \frac{F_{Z,L} - F_{Z,R}}{F_{Z,L} + F_{Z,R}} \tag{3.1}$$

Where $F_{Z,L}$ represents the tyre force on the left side and $F_{z,R}$ represents the tyre force on the right side. Therefore,

$$RI = RI_{Odenthal} = \frac{2m_2}{mT}\left[(h_R + h\ cos\phi)\frac{a_{y,2}}{g} + h\ sin\phi\right] \tag{3.2}$$

Equation (3.2) is used to analyze the capability of the rollover index based on Odenthal's fastest warning reaction time. According to (Odenthal et al., 1999), by conclude

$$h_R + h\cos\phi = h_{cg2} \tag{3.3}$$

The equation (3.2) can therefore be adjusted as follows

$$RI_{Odenthal} = \frac{2m_2(h_{cg2})a_{y,2}}{mgT} + \frac{2m_2 h\, sin\phi}{mT} \tag{3.4}$$

3.7 Modified Rollover Index Algorithm for Heavy vehicles

The body lateral acceleration, $a_{y,2}$ and the body roll angle, ϕ , contribute to the RI capability, as shown in equation (3.4). The gains, K_a and K_r, are applied to a previous Odenthal rollover index with the goal of increasing sensitivity and optimise capability. As a result, the MORI algorithm is described as follows

$$RI_{Modified\ Odenthal} = K_a\left[\frac{2m_2(h_{cg2})}{mgT}\right]a_{y,2} + K_r\left[\frac{2m_2 h}{mT}\right]sin\phi \tag{3.5}$$

As shown in equation, the body roll angle response is handled by the gain of K_a, whereas the body lateral acceleration reaction is handled by the gain of K_r (3.5). A sensitivity analysis method is used to determine the K_a and K_r values in order to enhance the functionality of the modified Odental rollover index. The rollover index value, which passes one and then goes back to normal, is used to determine the K_a and K_r values. A simulation was done utilising a heavy vehicle model with step-steering manoeuvre motions at a speed of 100 km/h in order to ascertain the values of K_a and K_r.

Figure 3-5 depicts the relationship between the heavy vehicle rollover index and the time to warn (TTW). For an effective early warning reaction, the rollover safety factor (RSF) is set to 0.75. Figure 3-5 demonstrates that K_a must be increased from 0.97 to 1.10 in order for a heavy vehicle to return to its original position. When K_a is 0.97, the left tyre of the heavy vehicle axle begins to decelerate at 2.15 seconds and returns to its original position at 2.42 seconds. Currently, the greatest RI is 1.0046. When K_a is 0.98, the left tyre of the heavy vehicle axle begins to lift-off at 2.05 seconds and returns to its previous position at 2.51 seconds, with a RI of 1.0150 at this stage. In addition, when K_a reaches its maximum value of 1.10, the left tyre of the heavy vehicle axle begins to separate after 1.74 seconds and returns to normal after 8.91 seconds. This value of K_a yields a maximum RI of 1.1392 As a result, it is accurate to remark that as the K_a value increases, the time for the left tyre of the heavy truck axle to begin lifting off decreases, but the time required to return to its normal state increases. In the interim, the maximum RI value is increasing. Figure 3-5 depicts that when the K_a value reaches 1.11, the RI value remains greater than 1, as indicated by the dashed line. It shows that one side of the big vehicle tyre is still lift-off and that heavy vehicle tends to flip over. Furthermore, the rollover index results reveal that the large vehicle settling time is consistent at 4.30 s for K_a values ranging from 0.97 to 1.10. It also demonstrates that the heavy vehicle is steady after 4.30 s if the K_a value is within 0.97 and 1.10.

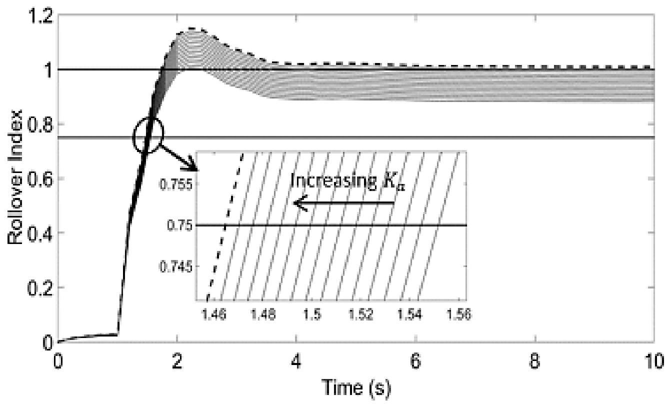

Figure 3-3 Heavy vehicle Rollover Index Affected by Ka

Moreover, the graphical representation in Figure 3-6 illustrates the impact of Ka on the TTW. It is evident that an increase in the value of Ka leads to a corresponding acceleration in the TTW. The data demonstrates that the lateral acceleration of the heavy vehicle's body is significantly influenced by Ka. The reason for this phenomenon is that the application of steering input results in a notably elevated lateral acceleration on the high friction surface during said maneuver. Experimental proof suggests that alterations in the TTW can be attributed to variations in the Ka value. Moreover, as illustrated in Figure 3-6, the test has yielded an optimal Ka value of 1.10. In the event that the value of Ka exceeds 1.10, it can be observed that one of the sides of the tire of the heavy vehicle experiences lift-off, ultimately leading to the rolling over of the vehicle. The previously mentioned attitude ultimately renders the driver incapable of improving the maneuver, resulting in the overturning of the large vehicle.

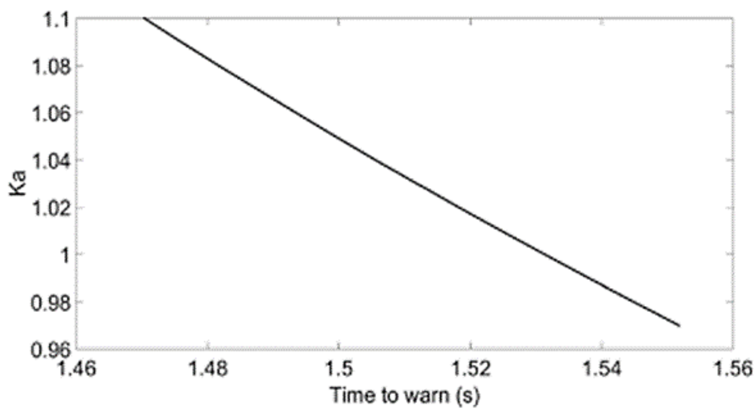

Figure 3-4 Effect of Ka to TTW

The method of investigating frequency response is still utilized in order to figure out the most accurate value for Kr. The determination of the optimal Kr value follows a similar approach to that of Ka, whereby it is reliant on the attainment of a RI value of 1, followed by a return to the default value. The previously described approximations are employed in TruckSim for executing step-steering maneuvers with heavy vehicles traveling at a speed of 100 km/h. The depiction of the RI reaction based on the Kr effect is presented in Figure 3-7. The value of Kr is maintained at 4.5 within the range of 11.0, thereby facilitating the heavy vehicle's restoration to its original state. At Kr value of 4.5, the left axle of the heavy vehicle experiences a deceleration at 2.04 seconds, followed by a return to normal state at 2.40 seconds. Currently, the maximum Rollover Index (RI) recorded is 1.0064. At a Kr value of 5.0, the left tyre of the heavy vehicle's axle experiences a deceleration at 1.97 seconds, followed by a recovery to normal conditions at 2.48 seconds. Subsequently, the tyre achieves a maximum RI of 1.0170 within 2.48 seconds. Moreover, at the point where Kr attains its maximum value of 11.0, the left tyre of the axle of the heavy vehicle undergoes separation after a duration of 1.57 seconds and subsequently reverts to its original state within a period of 8.81 seconds. At its highest point, the Kr value exhibits a refractive index of 1.1546. The increase in Kr is observed to have a negative correlation with the time taken for the left tyre of the heavy vehicle axle to initiate lifting off, while a positive correlation is observed with the time taken for it to return to its original state. Simultaneously, the highest RI value is on the rise.

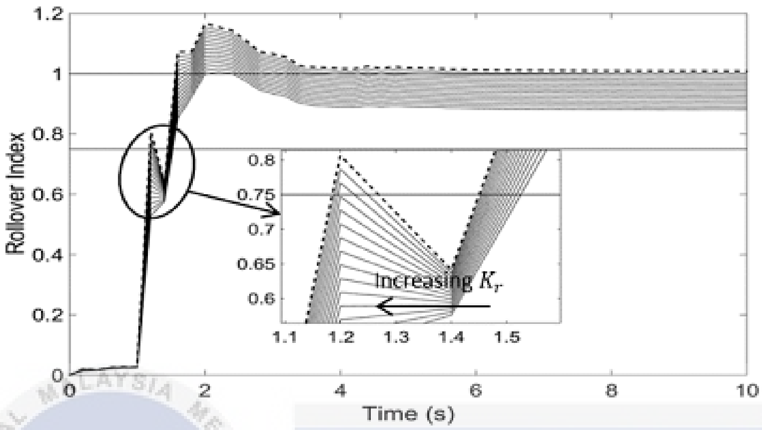

Figure 3-5 Heavy vehicle Rollover Index Influenced by Kr

The graph in Figure 3-8 illustrates that the RI value maintains a value above 1 when the Kr value approaches 11.5, as indicated by the dashed line. The observation suggests that a side of the heavy automobile tire remains elevated from the surface and displays a tendency to overturn. The findings of the rollover index demonstrate that the settling time of heavy vehicles remains consistent at 4.30 seconds across Kr values spanning from 4.5 to 11.0. Furthermore, it is indicated that a heavy vehicle exhibits stability at or beyond 4.30 seconds provided that the Kr value falls within the range of 4.5 to 11.0. The graphical representation in Figure 3-8 illustrates the impact of Kr on the TTW, while disregarding Kr's influence on the TTW. It is evident that an increase in the value of Kr leads to a corresponding acceleration of the TTW. Moreover, it can be observed from Figure 3-8 that the TTW experiences a significant decrease, reaching 1.19 seconds. The test results have revealed that the ideal Kr value is 11.0. The findings illustrate that the element Kr exerts a significant influence on the roll impact of a large automobile. However, it can be observed from equation (4.4) that the lateral acceleration of the vehicle, denoted as $a_{y,2}$, and the roll angle of the vehicle, represented by the symbol ϕ, are the primary factors that impact the driver's TTW through their effects on the roll movement of the vehicle. As a result, the operator is afforded a reduced amount of time to execute adjustments to the maneuvers. This study evaluates the steering and vehicle velocity inputs as a means of enhancing the TTW.

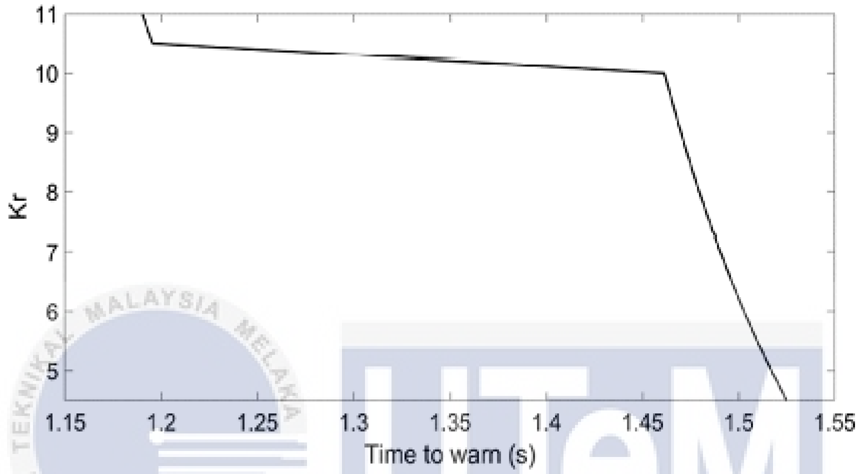

Figure 3-6 Impact of Kr to TTW

The present study utilizes the MORI algorithm to integrate the steering and vehicle velocity inputs. The equation employed in this study to represent the inputs of steering and vehicle velocity was formulated by Gillespie et al. (1992). During the process of cornering, the steering angle caused by the driver and the vehicle's motion variables, such as lateral acceleration, can be considered as inputs and outputs, respectively. Furthermore, the large vehicle sustains a consistent speed and follows a path with a fixed curvature. Consequently, the steering and vehicle velocity inputs formula is as follows:

$$a_y = \left[\frac{\frac{v^2}{57.3Lg}}{1 + \frac{Kv^2}{57.3Lg}} \right] \delta \tag{3.6}$$

As v is the vehicle's speed, L is its wheelbase, K is its steering gradient, and δ is the front-wheel steering angle. Nevertheless, roll angle estimation is taken into account when calculating the roll angle reaction. Using an observer and a dynamic model of the vehicle's roll dynamics, the roll angle is calculated. Roll angle estimate is distinct as

$$\ddot{\phi} = \frac{m a_y h_R cos\phi + mgh_R sin\phi - \frac{1}{2} kT^2 sin\phi - \frac{1}{2} cT^2 cos\phi(\dot{\phi})}{I_{xx} + m{h_R}^2} \tag{3.7}$$

Where I_{xx} is the roll inertia.

3.8 Thingspeak

ThingSpeak is an Internet of Things (IoT) platform that functions as a robust and adaptable tool for gathering, displaying, and examining live data from different sensors and devices. ThingSpeak, created by MathWorks, facilitates the seamless connection of IoT devices to the platform, allowing users to input data. This data can then be watched and controlled via configurable charts, graphs, and widgets. ThingSpeak enables us to connect to Matlab to extract valuable insights from rollover warning to send the data and display them in Thingspeak. It will be used for monitoring rollover index of heavy vehicles.

3.9 MIT App Inventor

MIT App Inventor is a user-friendly and intuitive visual programming environment that enables us to connect the Thingspeak data to the platform. MIT App Inventor allows us to create and construct applications using a user-friendly interface that involves dragging and dropping elements, thus reducing the requirement for intricate coding terminology. The main purpose of MIT App Inventor is to publish data from Thingspeak and connects it to the AI Companian of the application can be download on a smartphone. It will enable us to track Rollover Index data from the phone app directly without needing to use Thingspeak.

3.10 Simulation Setting

The present study employs Particle Swarm Optimization (PSO) technique to modify the values of Ka and Kr parameters, as suggested by Harun et al. (2020), in order to enhance the performance of the heavy vehicle model under 131 different load scenarios. Table 3.3 presents the optimized Ka and Kr parameters for different loads. These were employed for investigations carried out under diverse heavy vehicle weight circumstances.

Table 3-2 Optimize Parameter values of Ka and Kr for each load conditions

Load Condition	K_a	K_r
Unladen	1.2083	4.0049
Half-Laden	1.4934	4.2213
Laden	1.8775	4.2327

3.11 The Test of a Modified Odenthal Rollover Index for Heavy vehicle

This section outlines the methodology employed to evaluate the MORI's capability through the utilization of the testal approach. The present study employs the TruckSim driving simulator as a test methodology, utilizing a heavy vehicle model in the form of a truck, and integrates the MORI algorithm with the buzzer limit to generate an ultimate rollover warning system. The evaluation of the efficacy of the heavy vehicle rollover index is conducted through the utilization of a driver-hardware-in-the-loop (DHIL) real-time simulation phase within the TruckSim driving simulator.

Figure 3-10 shows how the test process is set up. The input variables of the test include the angle and speed of the steering wheel, which were produced by the TruckSim driving simulator. The present investigation evaluates the performance of the MORI in carrying out steering maneuvers consisting of 60 steps, while operating within the speed range of 60 to 100 km/h. The TruckSim driving simulator and Matlab/Simulink are utilized for this purpose. Prior to the tire reaching lift-off and the RI value surpassing one, the velocities are established based on the SAE-932949 velocity classifications for low, medium, and high velocities. The examination vehicle is subjected to three distinct loading conditions, namely full loading (12,600 kg), half loading (11,300 kg), and no loading (10,000 kg). The present study has established an RSF threshold of 0.75 as indicative of an early warning signal. Figure 3-10 illustrates the truck model utilized in step-steering drills conducted on the TruckSim driving simulator. Table 3 displays the attributes pertaining to large automobiles. The Heun solver is used to simulate the truck model and MORI algorithm, with a step size of 0.01s (Harun et al., 2020)

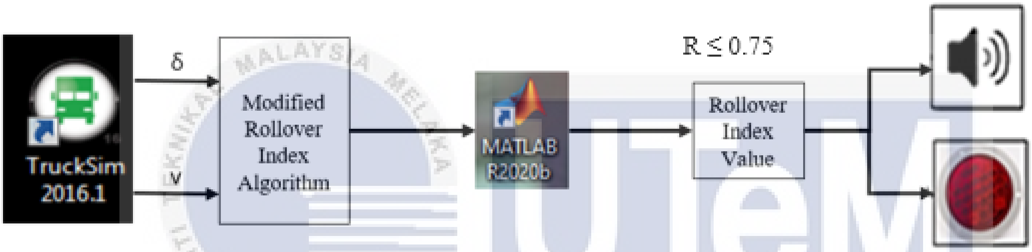

Figure 3-7 Heavy vehicle in TruckSim Driving Simulator with Rollover Index Algorithm in Matlab/Simulink

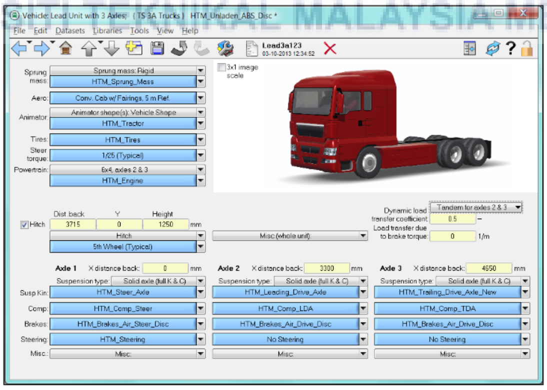

Figure 3-8 Heavy vehicle in TruckSim for Step Steering Manouevers Test

3.12 Parameters

The parameter for this thesis is used from the Scania specification.

Table 3-3 Scania Parameter

Parameter	Value
Sprung mass, M_s	6,360 kg
Unsprung mass, M_u	530 kg
Tire stiffness, K_t	900,000 N/m
Front spring stiffness, K_{sf}	250,000 N/m
Rear spring stiffness, K_{sr}	1,083,004 N/m
Front damper coefficient, C_{sf}	15,000 N/m
Rear damper coefficient, C_{sr}	26,000 N/m
Track width, t	2.6 m
length, l	7.9 m
a	3.012 m
b	4.9 m
Height, h	2920 m
I_{xx}	7,695.6 kg.m^2
I_{yy}	30,782.4 kg.m^2

3.13 Equipment

Throughout this task, a diverse range of instruments are employed. The TruckSim Software served as a crucial instrument in obtaining an actual vehicle simulation and output graph, which was then compared to the output graph generated by the MATLAB Simulink software. Furthermore, the cordless drill, files, and screwdriver are indispensable tools required for the construction of the rollover warning device.

3.14 Limitation of Proposed Methodology

The prime mover was widely utilized as the preferred means of transportation for industrial purposes, particularly in Malaysia. This research paper centers on heavy vehicles, given their extensive utilization as a means of transportation, with the aim of minimizing rollover occurrences. This study was carried out as a laboratory session and in a limited environmental setting.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

According to Harun et al. (2020), Odenthal's rollover index algorithm outperformed other algorithms in terms of driver response time, requiring only 0.51 seconds for the driver to notice an imminent rollover. The duration may be deemed late for class, as the ideal driver reaction time for a suitable response is approximately 0.70 to 0.75 seconds. Consequently, an improved algorithm is necessary to offer timely notification and a suitable Time-to-Rollover (TTR) for implementing corrective measures in the event of an impending rollover. Section 4.3 outlines and introduces the proposed technique, known as the modified Odenthal rollover index (MORI), in order to address this problem. The proposed methodology is derived from the preceding Odenthal rollover index technique, as indicated by its name.

4.2 Operation of modified Odenthal rollover index algorithm

The study assesses the effectiveness of the MORI response in relation to the original Odenthal rollover index. This study considers the response requirements for the TTW (Time to Wait) and TTR (Time to Respond) rollover index. The TTW refers to the duration required for the rollover index (RI) to notify the driver as a result of the vehicle's unstable motion. After addressing the TTW, the driver can effectively handle the maneuver scenario during TTR by taking actions such as decreasing the vehicle's speed or making adjustments to the steering input. Based on this study, TTR provides the driver with sufficient time to counteract their maneuvers, but TTW is observed to elicit the driver's quickest response.

The study assessed the MORI's efficiency by conducting tests utilizing the Matlab/Simulink software and the TruckSim driving simulator. A step-steering maneuver is used to navigate at a speed ranging from sixty to one hundred kilometers per hour. The heavy truck is being tested in three distinct conditions: completely loaded, with a weight of 12,600 kg, half-loaded, with a weight of 11,300 kg, and unladen, with a weight of 10,000 kg. In order to assess the MORI's capacity, these parameters are implemented on the large-scale vehicle. The early warning indicator sets the rollover safety factor (RSF) to 0.75. Figure 4-1 compares the efficacy of MORI reactions and the Odenthal rollover index. The massive vehicle is currently moving at a velocity of 60 km/h while executing 60 steering maneuvers. At 11.35 seconds, when a rapid steering input is made, the MORI and Odenthal rollover indices indicate a maximum rollover index of 0.57. At a velocity of 60 km/h, neither of the rollover indices surpasses the RSF threshold. However, in terms of the Odenthal rollover index, the MORI line yields a quicker (TTW).

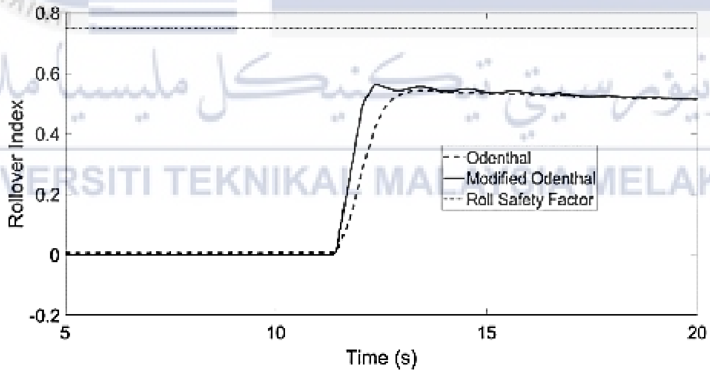

Figure 4-1 Unladen State with a Velocity of 60km/h

However, even when the speed of the large vehicle is increased to 80 km/h, the MORI and Odenthal rollover index lines do not intersect with the RSF line in Figure 4-2. Nevertheless, when the velocity increases from 60 km/h to 80 km/h, both the MORI and the Odenthal rollover indicators exhibit an increase, reaching a value of 0.72. Although the velocity has increased in this scenario, it remains below the RSF limit of 0.75. Therefore, the rollover warning system does not alert the driver.

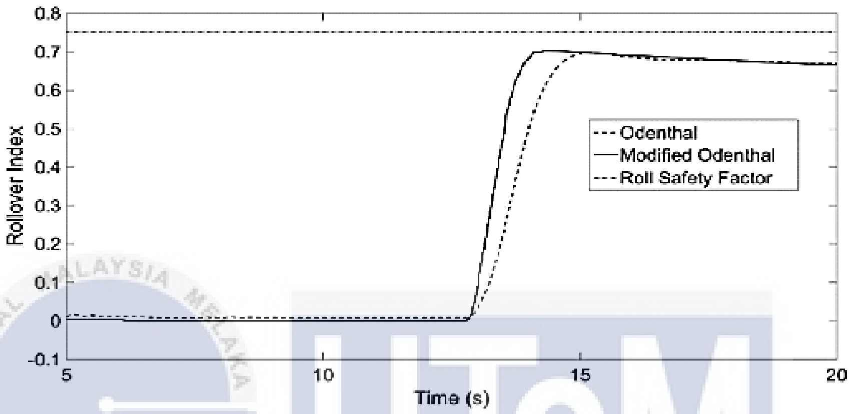

Figure 4-2 Unladen State with a Velocity of 80km/h

When the velocity is raised from 80 to 100 km/h, both the MORI and Odenthal rollover index lines intersect the RSF line at the same time. The large vehicle is capable of reaching a velocity of 100 km/h under conditions of being unladen or without any cargo. Figure 4-3 indicates that the Odenthal produces a rollover index of 1.26 and intersects the RSF line in 7.28 seconds after the steering input is delivered. Simultaneously, the maximum rollover index of MORI, which intersects the RSF line at 6.38 seconds, is 1.48. TTW was designed by MORI with a 12.36% quicker speed compared to Odenthal. When the big vehicle accelerated to high speeds, the MORI's reactivity underwent a noticeable alteration in the TTW. The rollover index for the MORI is higher than that of the Odenthal. When the rollover index line intersects with the RSF line, the early warning indicator produces an audible buzzer sound and a visual warning indication. Due to the MORI's enhanced responsiveness, the driver has sufficient time to adjust the maneuver by either decreasing velocity or altering steering input.

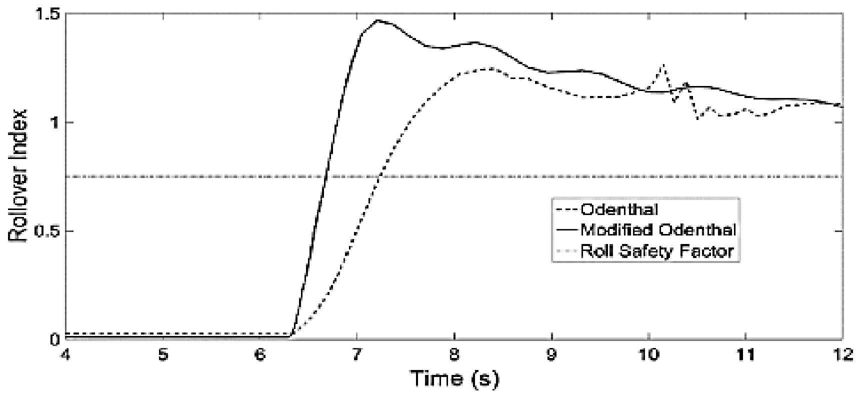

Figure 4-3 Unladen State with 100kmh of Velocity

Subsequently, the carrying capability of the MORI is assessed by subjecting the heavy vehicle to a weight of 11,300 kg, which is equivalent to half of its maximum load capacity. The heavy vehicle's maximum rollover index, determined by MORI and Odenthal, is 0.61 when it is traveling at a speed of 60 km/h and executes a rapid steering maneuver within a time frame of 10.4 seconds. Figure 4-4 demonstrates this point. The rollover index value exhibits a 0.04 rise in comparison to the unloaded condition. Furthermore, this leads to an augmentation in the weight, thereby amplifying the centrifugal force produced by the heavy vehicle when turning. It is evident that when the load escalates, the centrifugal force proportionally intensifies. Since the generated rollover index is below 0.75, the heavy vehicle is considered stable and will not trigger a rollover alert from the rollover warning system.

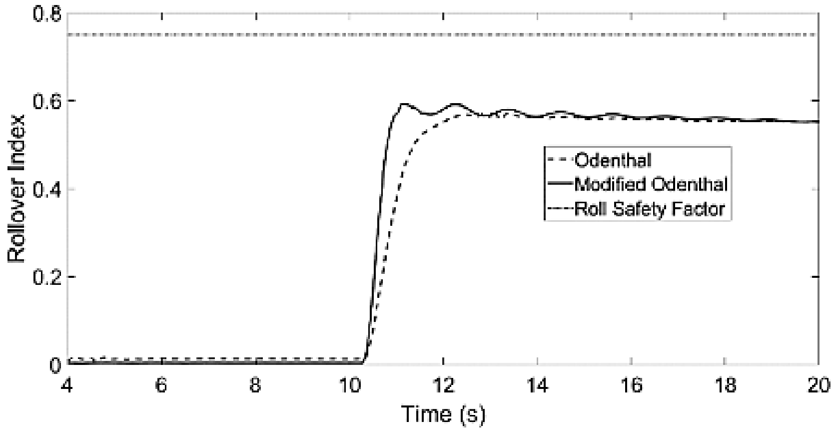

Figure 4-4 Half-Laden State with a Velocity of 60km/h

Figure 4–5 illustrates the rollover index values when the velocity of heavy transportation increases from sixty to eighty km per hour with a 50 percent load. The heavy vehicle rollover index increases when an immediate steering input is made within a time frame of 13.8 seconds. The Odenthal rollover index reaches its peak value of 0.82 at 15.03 seconds and intersects with the RSF line. The MORI produced a maximum rollover index of 0.83 and crossed the RSF line 0.84 seconds earlier than the Odenthal. The heavy vehicle is deemed to be unstable at specific rollover index values, and the rollover warning system alerts the driver. As a result, the rollover warning has a Time-to-Turn Warning (TTW) that is 5.59 percent higher than the Odenthal rollover index. This is important for the driver to effectively handle the maneuvering situation.

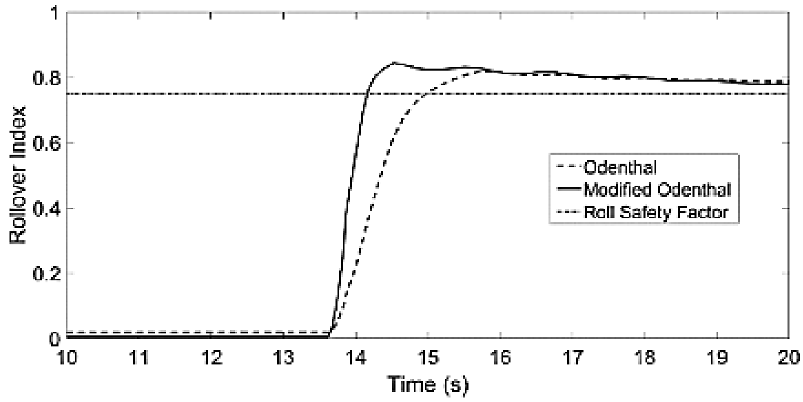

Figure 4-5 Half-Laden State with a Velocity of 80km/h

Figure 4-6 illustrates the MORI and Odenthal rollover index values for a partially loaded heavy truck when the velocity increases to 100 km/h. The speed limit of 100 kilometers per hour was established after conducting an initial investigation using the TruckSim driving simulator, which indicated that the heavy vehicle would experience a rollover at speeds exceeding this threshold. As evidenced, the MORI estimation of the rollover index exhibits a shorter (TTW) compared to the Odenthal estimation. This will lead to a significant rise in (TTW) when compared to Odenthal. Odenthal's rollover index value reached its highest point at 1.11 while the vehicle was traveling at a speed of 100 km/h and the steering input was made within 6.43 seconds. The point when the rollover index value intersected the RSF line occurred at 7.19 seconds. MORI recorded a peak rollover index of 1.16, surpassing the RSF line 0.65 seconds or 9.04% ahead of Odenthal. The greatest rollover index values suggest that there is a separation on one side of the heavy vehicle tire, which poses an imminent threat to the driver and other drivers on the road. Hence, the MORI reaction time, which exhibits a 9.04% improvement compared to Odenthal's, allows the driver to execute a maneuver before any of the tires start to experience a loss of grip.

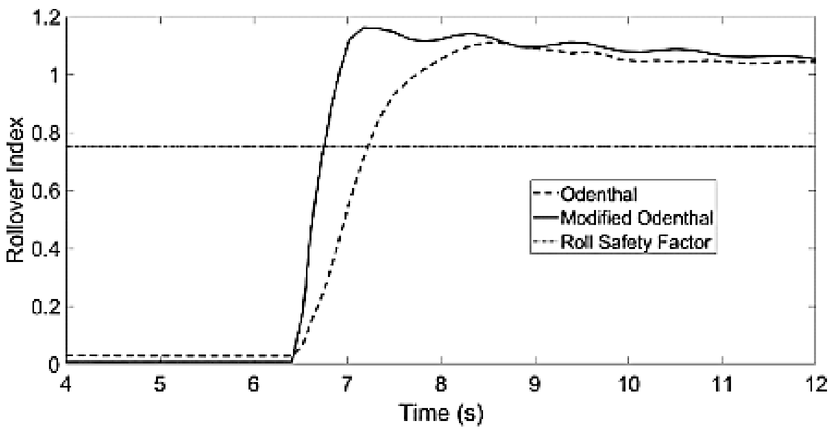

Figure 4-6 Half-laden State with 100km/h of Velocity

In addition, the MORI's capacity is assessed based on whether it is fully loaded or laden with 12,600 kg (Liu, 1999). According to Figure 4-7, when the heavy vehicle is carrying its maximum weight, it travels at a speed of 60 km/h and makes a sudden steering adjustment of 60 degrees starting at 9.2 seconds. The MORI and Odenthal rollover indices started to increase at 9.2 seconds in this situation. Given that the highest value produced by both indexes is 0.57, it may be concluded that neither the RI line nor the RSF line intersect. Furthermore, it has been found that the MORI exhibits a more rapid (TTW) response compared to the Odenthal. The rollover warning system fails to notify the driver in this instance. As shown in Figure 4-7, the large vehicle is able to maintain its speed even while it is carrying a load and receives a sudden steering command. Therefore, it may be asserted that the heavy vehicle exhibits stability when traveling at moderate speeds.

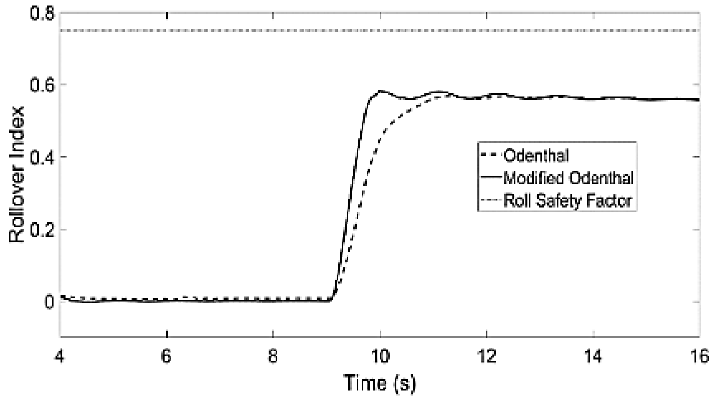

Figure 4-7 Laden State with 60km/h of Velocity

In Figure 4-8, it can be observed that the two rollover index lines start to ascend at 6.57 seconds when the vehicle's velocity is raised to 80 km/h while carrying a load, and a sudden 60-degree turn is executed. The Odenthal line intersected the RSF line after 7.7 seconds, leading to a rollover index of 0.91. Furthermore, the MORI meet RSF line exhibits a TTW that is 0.49 seconds faster than the Odenthal line, while also having a rollover index of 0.94. This circumstance results in an asymmetrical distribution of force on either side of the vehicle. As a result, the rollover warning system will provide information to the driver.

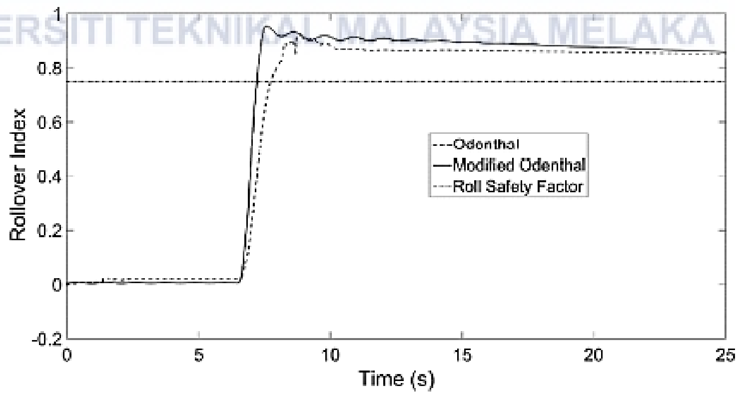

Figure 4-8 Laden State with 90km/h of Velocity

Additionally, the MORI's performance is evaluated under the condition of being heavily loaded and traveling at a high speed of 90 km/h. The maximum velocity of 90 km/h is selected for this loaded condition based on an evaluation from a driving simulator, which indicates that the bus will experience a hazardous rollover if the velocity exceeds 90 km/h. When the vehicle was traveling at a speed of 90 km/h and the steering wheel was turned by 60 degrees, Figure 4-9 shows that the MORI and Odenthal lines increased after 7.82 seconds. At 8.50 seconds, the Odenthal crosses the RSF line and gradually reaches a maximum rollover index of 1.09. MORI is surpassing the RSF line at a time of 7.95 seconds, which is 0.55 seconds quicker than Odenthal TTW. The MORI consistently achieves the highest rollover index value of 1.19 for this specific maneuver. Figure 4-9 demonstrates that the MORI reaction exhibits a 6.47 percent higher rate than the Odenthal response. The rollover index yielded a value greater than one, indicating a complete separation of the tires on one side of the car. If one of the vehicle's tires is lifted off the ground, the car may either roll over or return to its original position, depending on its following condition. Consequently, it is necessary to send a warning signal to the driver in advance of tire separation. This advance notification allows the driver a chance to rectify their maneuvering by decreasing the speed of the vehicle or adjusting the steering input.

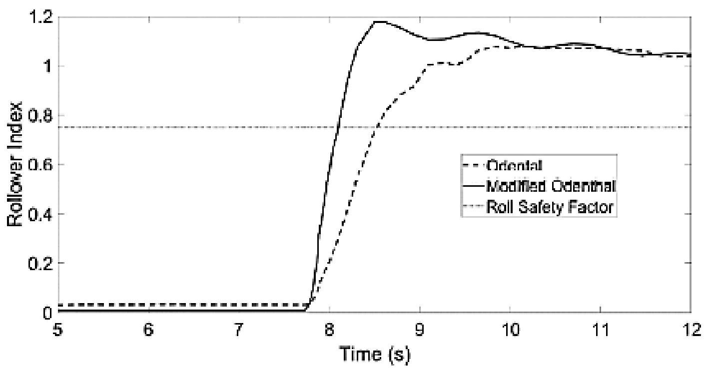

Figure 4-9 Laden State with 120km/h of Velocity

Table 4-1 Modified Odenthal and Odenthal Rollover Index Time Reactions

		RSF Lines			
Load type	Velocity(km/h)	Modified Odenthal(s)	Odenthal(s)	Time differences(s)	Percentages(%)
Unladen	60	-	-	-	-
	80	-	-	-	-
	100	6.38	7.28	0.9	12.36
Half-Laden	60	-	-	-	-
	80	14.19	15.03	0.84	5.59
	100	6.54	7.19	0.65	9.04
Laden	60	-	-	-	-
	80	7.21	7.7	0.49	6.36
	90	7.95	8.50	0.55	6.47

The response times for the MORI and Odenthal rollover indices are shown in Table 4-1 for a variety of load conditions. More speed always means more RI was demonstrated in every scenario. According to the data in Table 2 and Figures 4-1 through 4-9, MORI can make a RI prediction much faster than Odenthal.

4.3 Conclusion of the result

Based on the findings mentioned above, this study may assert that varying results can be achieved depending on factors such as road conditions, steering angle, and truck load. In the case of an unladen truck, the likelihood of rollover is mostly associated with high speeds, since the reduced weight compared to half-laden and fully loaded trucks might result in imbalanced load distribution and a shift in the center of gravity. The significance of this matter becomes particularly evident when one is operating a motor vehicle that is transporting a load that is not properly secured. The implementation of the Rollover Warning Device serves the purpose of notifying the driver in situations where the truck is at risk of rolling over, hence reducing the potential loss of life for innocent individuals on the road.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

A novel approach has been developed for heavy vehicles, which integrates the MORI algorithm with driver steering and vehicle velocity input, instead of relying on lateral acceleration to assess the risk of rollover. The capabilities of MORI were assessed using a TruckSim driving simulator and Matlab/Simulink software. The MORI's capacity was assessed by step-steering maneuvers conducted at different velocities and weights. The test results demonstrate that the MORI reaction exhibits a 12.36% higher speed compared to the Odenthal response. In addition, the MORI demonstrated exceptional effectiveness at high velocities. Consequently, the MORI has the capability to produce a faster TTW and offer the driver with adequate TTR for corrective measures. Hence, it is feasible to avert a rollover incident or collision.

The MORI algorithm enhances the driver's TTW by utilizing the heavy vehicle's velocity and steering input. The MORI analysis yielded the fastest Time To Warn of 0.9 seconds, surpassing the previous researcher's documented time of 0.95 seconds. This allows the driver plenty of time to make necessary adjustments. The rollover warning system's ability to promptly react can aid the driver in responding to the rollover alert. Therefore, when the MORI algorithm is used together with vehicle speed and steering commands, it produces the most efficient early warning system and has a notable ability to avert rollover accidents.

5.2 Recommendation

An assessment was conducted on the effectiveness of the Modified Odenthal Rollover algorithm using a DHIL TruckSim driving simulator and MATLAB/Simulink. The evaluation focused on the impact of vehicle speed and driver steering inputs. The driving simulator DHIL TruckSim was employed to accurately reproduce real heavy vehicle combinations. The effectiveness of the Modified Odenthal Rollover technique was assessed through the utilization of the DHIL TruckSim simulator and MATLAB/Simulink. The Modified Odenthal Rollover algorithm can also be tested on an actual heavy vehicle. Conversely, conducting a test that involves aggressive driving on a large, heavy vehicle requires a facility that is both extremely efficient and secure. This measure is implemented to ensure the safety of driving and mitigate potential harm to properties.

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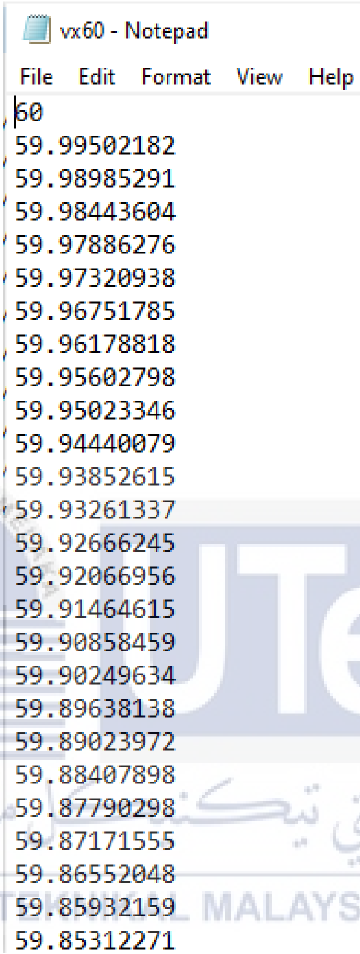
APPENDIX

Appendix A Vehicle Velocity for 60km/h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File Edit Format View Help

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Appendix B Vehicle Velocity for 80km/h

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File Edit Format View Help

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Appendix C Vehicle Velocity for 90km/h

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File Edit Format View Help

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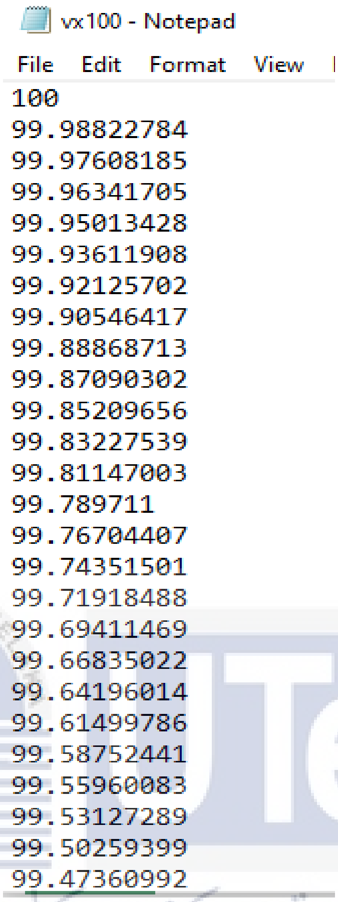
Appendix D Vehicle Velocity for 100km/h



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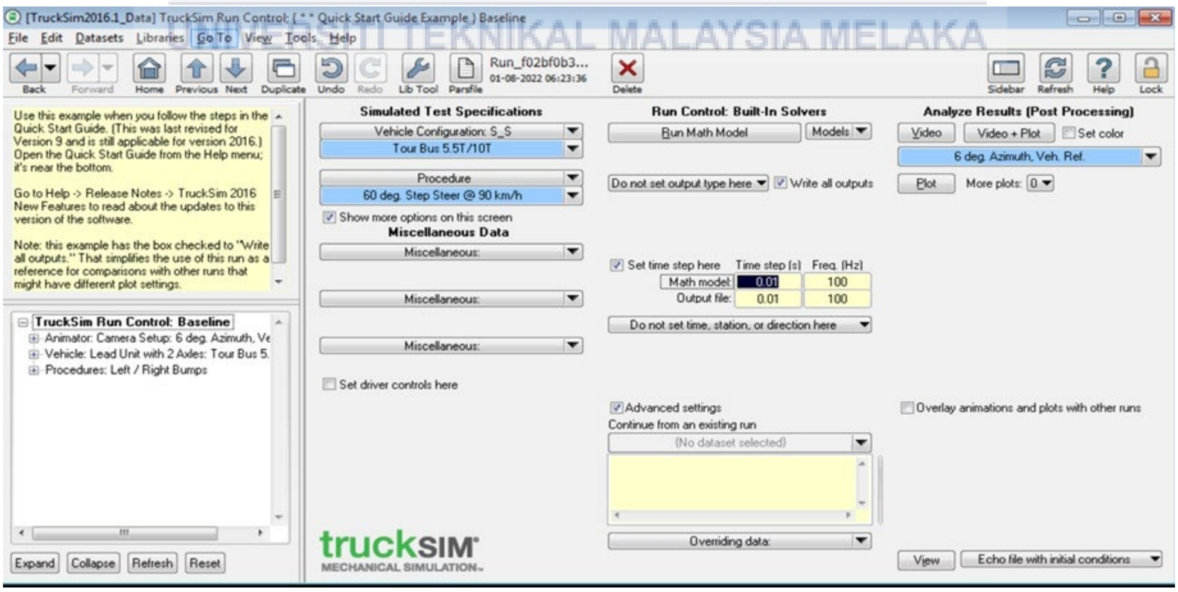
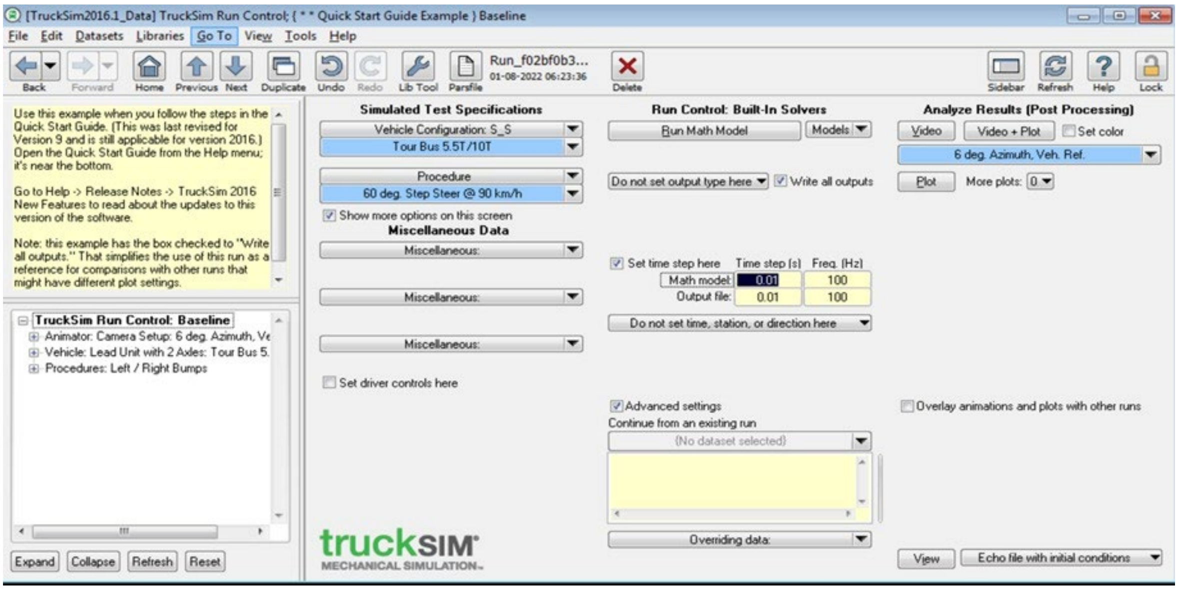
Appendix E TruckSim Home Apperance Setting



Appendix F Vehicle Apperance Setting



Appendix G User Interface