UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DESIGN AND FABRICATE ROLLOVER WARNING DEVICE WITH IOT MONITORING SYSTEM FOR COMMERCIAL VEHICLE

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A thesis submitted
in fulfillment of the requirements for the Degree of
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APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Mechanical Engineering Technology (Automotive Technology) with Honours.

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DEDICATION

I would like to thank Allah for the Almighty, my creator, my pillar of strength, and my source of inspiration, knowledge, and understanding. He gives me strength throughout this program and on His wings only I have soared.

I would also like to dedicate this to my family, especially to my parents who encouraged me all the way, instilled in me a desire to learn, prayed a lot for my success, and made sacrifices so I could have a successful future.

Also, to dedicate to my supervisor Ir. Ts. Dr. Mohamad Hafiz bin Harun, and his colleagues who have assisted me during the academic path. May the blessing of Allah be with them now and always "Aamiin Ya Robbal Alamin".

ABSTRACT

Instances of commercial vehicle accidents, namely rollovers of lightweight trucks, are often recorded. Rollover events have a higher death rate compared to other types of crashes, impacting both the drivers and passengers. Several variables contribute to the incidence of rollovers, leading to both physical injuries and deaths. The objective of this project is to create a Rollover Warning Device (RWD) that is specially tailored for commercial vehicles, with a specific emphasis on those that have a greater center of gravity height-to-track width ratio. The Roadway Departure Warning (RWD) system gathers information about the movement of a road vehicle and evaluates its current capacity to stay upright using the rollover index algorithm. The rollover index algorithm used in a rear-wheel drive (RWD) system determines the rollover index value by using the load transfer ratio (LTR). The block model parameters of the rollover index methods are optimized with MATLAB. The rollover index in MATLAB/Simulink will be determined by analyzing the step steering motions performed at different velocities. The use of the improved Odenthal rollover index approach is shown in the TruckSim driving simulator and MATLAB/Simulink software. This is accomplished by modeling step steering maneuvers at different speeds and loads using the Hardware-in-the-Loop (HIL) simulation approach. The test results indicate that the modified Odenthal rollover index algorithm provides a 12.3% enhancement in Time-to-Warn (TTW) for the driver, as compared to the Odenthal index. Furthermore, it enables a suitable Time-To-Respond (TTR) for the driver to efficiently carry out remedial actions. The utilization of the upgraded Odenthal rollover index algorithm successfully reduces rollover events by enhancing the early warning system.

ABSTRAK

Kejadian kemalangan kenderaan komersial, iaitu terbalik trak ringan, sering direkodkan. Peristiwa berguling mempunyai kadar kematian yang lebih tinggi berbanding dengan jenis kemalangan lain, yang memberi kesan kepada pemandu dan penumpang. Beberapa pembolehubah menyumbang kepada kejadian terbalik, yang membawa kepada kedua-dua kecederaan fizikal dan kematian. Objektif projek ini adalah untuk mencipta Peranti Amaran Rollover (RWD) yang disesuaikan khas untuk kenderaan komersial, dengan penekanan khusus pada kenderaan yang mempunyai nisbah lebar pusat graviti tinggi-ke-trek yang lebih besar. Sistem Amaran Berlepas Laluan Jalan Raya (RWD) mengumpulkan maklumat tentang pergerakan kenderaan jalan raya dan menilai kapasiti semasanya untuk kekal tegak menggunakan algoritma indeks pusing ganti. Algoritma indeks pusing ganti yang digunakan dalam sistem pacuan roda belakang (RWD) menentukan nilai indeks pusing ganti dengan menggunakan nisbah pemindahan beban (LTR). Parameter model blok kaedah indeks peralihan dioptimumkan dengan MATLAB. Penggunaan pendekatan indeks peralihan Odenthal yang dipertingkatkan ditunjukkan dalam simulator pemanduan TruckSim dan perisian MATLAB/Simulink. Ini dicapai dengan memodelkan manuver stereng langkah pada kelajuan dan beban yang berbeza menggunakan pendekatan simulasi Hardware-in-the-Loop (HIL). Keputusan ujian menunjukkan bahawa algoritma indeks peralihan Odenthal yang diubah suai memberikan peningkatan 12.3% dalam Masa-untuk-Amaran (TTW) untuk pemandu, berbanding dengan indeks Odenthal. Tambahan pula, ia membolehkan Masa-Untuk-Tindak Balas (TTR) yang sesuai untuk pemandu melakukan tindakan pembetulan dengan cekap.

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The text begins with an invocation to Allah, the Most Forgiving and Most Merciful of all.

Initially, I express my gratitude and admiration to Allah the Supreme Being, who is responsible for my existence and sustenance, for all the blessings bestowed upon me throughout my lifetime. The purpose of this message is to express gratitude towards Universiti Teknikal Malaysia, Melaka (UTeM) for furnishing the research platform. Gratitude is expressed towards the Malaysian Ministry of Higher Education (MOHE) for providing financial aid.

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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

Despite the emergence of advanced technology aimed at enhancing vehicle safety globally, they are unable to mitigate the escalating accident rate. Highway accidents are unavoidable since they occur daily, irrespective of the time. The National Centre for Injury Prevention and Control, part of the Centers for Disease Control and Prevention, has revealed that accidents resulted in the deaths of 1.35 million individuals globally. Worldwide, the number of fatalities resulting from accidents involving vehicles, buses, motorbikes, lorries, or pedestrians is estimated to be as high as 3700. 50% of the deaths are attributed to pedestrians, motorcyclists, and cyclists. Accidents resulting in injuries are projected to rank as the ninth most common cause of mortality globally across all age groups and as the primary cause of death among children and adolescents. Currently, fatalities resulting from accidents surpass those caused by HIV/AIDS. The projected expenditure for both fatal and non-fatal accident injuries is anticipated to amount to $1.8 trillion during the time frame of 2015 to 2030, measured in 2010 USD. This is a proportion of 0.12% of the yearly tax levied on the global gross domestic product (GDP). The accidental mortality rates in low-income nations are thrice greater than those in high-income ones. Between 2013 and 2016, there was no decrease in the fatality rate of accidents in any low-income nation. Low- and middle-income countries (LMICs) comprise just 60% of the total number of registered automobiles globally, although they experience more than 90% of collision-related fatalities. LMIC is facing significant financial restrictions as a result of injuries caused by collisions. From 2015 to 2030, it is projected that low- and middle-income countries (LMIC) would face an economic burden of $834 billion (in terms of 2010 USD value) due to the consequences of both fatal and non-fatal injuries resulting from automobile crashes. Over 200,000 individuals perish annually due to vehicle deaths occurring in other countries. Europe had approximately 50,000 fatalities and 150,000 injuries as a result of vehicle accidents. The Transport Minister, Datuk Seri Dr. Wee Ka Siong, said that Malaysia documented 255,532 road accident instances from January to September 2021. According to the figures provided by the Royal Malaysian Police (RMP), there were a total of 3302 fatalities.(Mohan K Ramanujam, 2022)

In Malaysia, over 34,747 traffic accident incidents involving trucks were reported. A comprehensive examination of road accident cases conducted by the Malaysian Institute of Road Safety Research (MIROS) revealed that head-on accidents and rear-end collisions are prevalent, accounting for about 32.8% and 28.4% of the total accident rate, respectively. Regarding the rollover incident, about 3.5 percent of cases include the rear end of automobiles. Among these cases, there is an estimated average pattern where 51 percent occur during daylight and 49 percent occur at night. Approximately 55.1 percent of incidents take place at nighttime in places without sufficient lighting, resulting in decreased visibility for drivers.

Various forms of road accidents occur, including head-on collisions, rear-end collisions, side-impact or T-Bone crashes, sideswipe incidents, rollovers, single-vehicle collisions, and multiple-vehicle collisions.

Based on the road accident statistics from the Royal Malaysian Police (RMP), it can be seen that in Malaysia The overall number of traffic accidents rose from 24,581 in 1974 to 328,264 in 2017, representing a more than 135 percent rise for 30 years. Therefore, while examining fatal accident instances involving big trucks, it was found that one of the contributing factors was the occurrence of rollover incidents. While the number of incidents may be limited, they have the potential to result in accidents, including those that pose a risk of fatality (Mohamad Alsharif et al, nd). The data indicates that heavy trucks are involved in around 3.5 percent of all collision incidents.

Lateral vehicle rollover crashes account for the bulk of incidents, with roofing intrusion, projection, and total and partial ejection being the most common injury mechanisms. These devices pose a risk to the safety of drivers and passengers in the event of rollovers since rollover collisions are highly hazardous situations that often lead to increased deaths. While safety measures have made significant progress in recent years, rollovers continue to be one of the most lethal forms of severe accidents. The severity of a rollover collision incidence may be assessed using two criteria: the number of fatalities and the specific conditions surrounding the rollover.

1.2 Problem Statement

Car rollover occurs when a vehicle loses control, veers onto its side or front, and continues to roll. The number of times a vehicle rolls before stopping is determined by the magnitude of the collision. It happens when a vehicle undergoes a rotation of at least 90 degrees along its longitudinal axis, causing the wheels to rise off the ground. Tall and narrow heavy vehicles, such as commercial trucks, buses, and SUVs, have a higher susceptibility to rollovers. These vehicles have decreased roll stability as a result of their elevated center of gravity.

Automobile rollovers are intricate occurrences. The safety of road users and the likelihood of a crash are influenced by three primary factors and their interactions: the driver's state (such as fatigue or drowsiness), the driving environment (including weather, road conditions, and time of day), and the condition of the vehicle (such as inadequate maintenance or failure to conduct pre-trip inspections).

As to the National Highway Traffic Safety Administration (NHTSA) and Federal Motor Carrier Safety Administration (FMCSA), over 56 percent of commercial truck rollover accidents occur on straight roadways, as opposed to ramps or curves. It occurs diurnally rather than nocturnally.

Commercial vehicle rollover accidents mostly occur on dry surfaces, accounting for around 93 percent of such incidents, surpassing other contributing variables. Approximately 28 percent of commercial vehicle accidents may be attributed to speeding. Furthermore, studies indicate that 66 percent of commercial truck rollover events occur with drivers who have around ten years of driving experience. Rosenfeld, J. (2016, December 13)

Rollovers mostly occur due to human mistake or neglect. High velocity on curved roadways, miscalculating the degree of a bend, and abrupt manoeuvres can need the driver to swiftly manoeuvre their car in order to avoid accidents, resulting in a rollover. 85 percent of rollover deaths are caused by single-vehicle events. Nevertheless, the remaining 15 percent of accidents that involve two or more cars are very severe, resulting in significant injuries or fatalities for the victims. Additional factors contributing to rollovers include the dimensions, form, and elevation of the vehicle. Furthermore, vehicles such as commercial tractor-trailers, commercial box vans, pickup trucks, passenger vans, and SUVs are particularly vulnerable due to their smaller and higher structure.

Furthermore, they possess a disproportionate weight distribution towards the upper part, resulting in an elevated centre of gravity that diminishes their equilibrium and steadiness. Another aspect that contributes to mishaps is those that are connected to speed. Around 40 percent of deadly rollover collisions result from excessive speeding. Based on the statistics, it can be seen that roads with high posted speed limits are associated with a higher occurrence of rollover accidents. The major mistakes made by divers include exceeding the speed limit when operating cars, particularly on curved roads, engaging in distracted driving (such as chatting on the phone, eating, drinking, texting, etc.), miscalculating the severity of a bend, and several more.

Due to previous evidence, it is recommended to use vehicle assistance technology, such as the rollover warning system, in order to mitigate human error that leads to rollovers. The rollover warning systems will notify the driver, allowing them to reposition themselves and prevent a traffic accident. Advanced rollover safety systems use intelligent algorithms to evaluate the likelihood of a vehicle rollover and provide timely warnings when deemed appropriate.

Once a possible rollover is detected, the information is communicated via the use of a flashing sign and lights. Motorists who may be at risk of experiencing a car rollover will see active warning indicators. Contemporary advanced rollover systems consider several criteria, including velocity, mass, partially loaded, unloaded, vehicle stature, and vehicle configuration, to determine the threshold for rollover.

By incorporating supplementary vehicle data into the rollover determination threshold, the precision and utility of the rollover warning system may be significantly enhanced. Once a vehicle is set in motion, it will continue to move until its momentum gradually diminishes. A real-time algorithm is used to forecast the probability of a commercial vehicle experiencing a rollover. Consequently, their study will provide a groundbreaking approach centered on manipulating steering input and the vehicle's response to speed limits. The reference is from Baker et al's work in 2001.

1.3 Research Objective

The main goal of this research is to design and build a rollover warning system for commercial vehicles. The following are the specific objectives:

a) To design and fabricate rollover warning devices for commercial vehicles.
b) To embedded the IoT system in Rollover Warning Device for monitoring purposes.

1.4 Scope of Research

The scope of this research are as follows:

- The modified rollover index is combined in the microcontroller.
- The rollover warning device is developed using Matlab/Simulink.

- The IoT system is designed and developed as a monitoring system that receives, stores, and analyzes data that transmitted by microcontroller.
- Implement suitable wireless communication technologies for transmitting the collected sensor data to a central monitoring system.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In today's modern society, travel by motor vehicle provides an unparalleled level of mobility, resulting in a constant increase in traffic. As the number of motor vehicles, the distance of highways, and the distance traveled by a vehicle increase worldwide, people are more and more likely to be exposed to road accidents. As time changes, many factories are opened to supply products to the community at this time than before. Therefore, many vehicles are needed to transport the necessary materials to the factory. As the number of vehicles increases every day, the reported accident cases also increase including rollover vehicle incidents.

2.2 Early Warning Device

Researchers and engineers have created various rollover prevention technologies to overcome this problem. Once the next transition phase starts, there is not enough time for the activator to react effectively, especially in serious damage situations. To avoid rollover concerns, it is important to be able to assess the possibility of a rollover and determine sufficient time earlier than usual. Hence, early warning indications for rollovers are crucial in alerting the driver before the tires lose traction on the road, so preventing the vehicle from rolling over. Safety is important for both vehicles and passengers.

However, they must be careful with human errors such as driver fatigue, drowsiness, not paying attention while driving, and many more. These errors will cause the vehicle to roll and cause death.

2.3 Rollover Index

A rollover occurrence occurs when a vehicle has a loss of control and veers onto its side or front, subsequently undergoing a rolling motion. It signifies that a vehicle has a loss of control and has the potential to roll over, either once or several times, depending on the magnitude of the sideways acceleration, which is equal to or exceeds 90 degrees. Rollovers have a greater death rate in comparison to other forms of vehicular incidents. While all vehicles may experience rollovers, commercial trucks are particularly vulnerable owing to their top-heavy loads and greater center of gravity, which compromises their balance and stability. Rollovers are among the most dangerous categories of traffic collisions. When an occurrence takes place, it results in severe harm or perhaps death. If the victim sustains severe injuries, they may have incapacity as a consequence of their injury. Such occurrences might result in financial setbacks for the person, their family, and the whole country. Rollover crashes have an impact on the country's economic gross domestic product (GDP). However, this study will only concentrate on two specific factors: the steering angle and its impact on longitudinal speed. The rollover index (RI) is a metric used to predict an imminent rollover event by estimating the roll angle or roll rate of the vehicle body based on lateral acceleration and the time it takes for the wheels to rise off the ground. The suggested Rollover Index (RI) is a metric that quantifies the likelihood of rollovers occurring and implementing it may effectively mitigate the risk of rollovers.

2.3.1 Types of Rollover Accidents

Two types of vehicle rollovers exist: lateral and rotation. Vehicles roll longitudinally during lateral rollover. Many of them occur, accounting for 98% of traffic accidents. When a vehicle spins perpendicular to its vertical longitudinal central plane, it rolls over. This sort of rollover causes 1–2% of accidents. 2014 (El-Menyar et al.).

‘**Turn over**’ occurs when the vehicle is stopped suddenly and causes it to be overturned.

Figure 2-1 Vehicle illustration when trip-over (Parenteau et al., 2003)

The phenomenon known as 'fall over' occurs when the terrain on which the vehicle is moving slopes downhill towards the vehicle's center of gravity (COG), causing the COG to extend beyond the wheels.

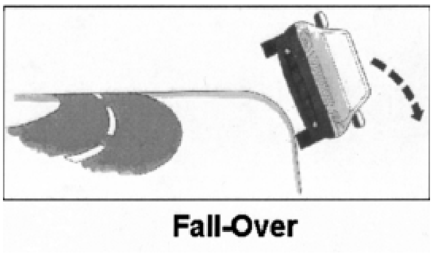


Figure 2-2 Vehicle illustration when fall-over (Parenteau et al., 2003)

A **'flip over'** accident occurs when the vehicle rotates about its longitudinal axis due to the presence of ramp-like features, such as a twisted ground rail.

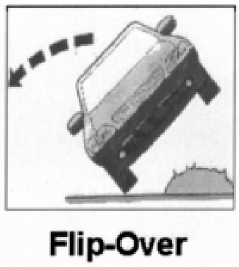


Figure 2-3Vehicle illustration when flip-over (Parenteau et al., 2003)

A **'Bounce over'** scenario arises when the vehicle rebounds off a stationary object and flips over.

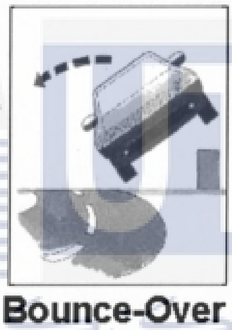


Figure 2-4 Vehicle illustration when bounce-over (Parenteau et al., 2003)

The **'turn-over'** occurrence arises when the centrifugal force resulting from a quick turn or rotation of the vehicle is counteracted by a flat surface.

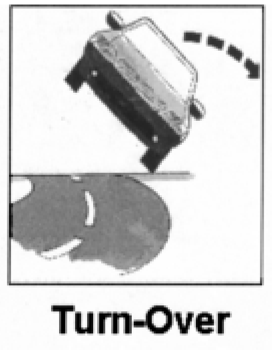


Figure 2-5 Vehicle illustration when turn-over (Parenteau et al., 2003)

'The impact with another vehicle' refers to an incident when an accident happens as a result of coming into contact with another vehicle, leading to an overturning of the car.

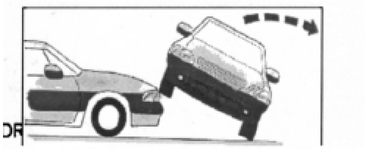


Figure 2-6 Vehicle illustration when collision with another vehicle is occured (Parenteau et al., 2003)

An **'ascend over'** event refers to a situation when a vehicle ascends and surpasses an object, such as a guard rail or barrier, that is sufficiently elevated to raise the vehicle off the ground.

Figure 2-7 Vehicle illustration when climb-over (Parenteau et al., 2003)

The **'end-over-end'** phenomenon refers to the vehicle rolling mostly around its lateral axis after a collision with a concrete barrier.

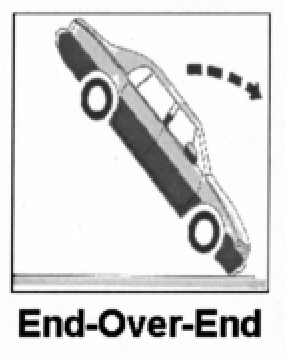


Figure 2-8 Vehicle illustration when end-over-end (Parenteau et al., 2003)

Among all of the rollover types, the turnover type will be the emphasis of this research.

2.3.2 Types of Rollover Index

According to (Phanomhoeng & Rajamani, 2013), vehicle rollover is divided into two categories such as tripped (as in figure 2-6) and un-tripped (as in figure 2-7). Tripping is one of the most common reasons vehicles to overturned. It occurs when a vehicle tire hits some external forces such as a curb or ditch that shift the vehicle's weight to one side, causing it to roll over before it can regain balance. Tripped rollovers can also occur in off-road situations on a slope that is too steep to keep the vehicle upright. Potholes, guard rails, soft soil, curbs, and surface discontinuities, snowbanks, or other objects can cause tripping. This situation can happen when a vehicle is traveling forward, especially at a high speed.

Non-tripped rollovers are less frequent than tripped rollovers and mostly happen in vehicles with a high center of gravity. In an "un-tripped" rollover, the vehicle overturns without being influenced by external factors, such as tire forces, inertial effects, and gravity, which might cause the vehicle to become unstable. Consequently, the driver's ability to manipulate the vehicle may be compromised, perhaps leading to the car overturning.

Conventional rollover indices are limited to detecting rollovers that have not been triggered, namely those caused by the significant lateral acceleration of the vehicle. These indicators are unable to identify the rollover caused by vertical external pressures acting in the longitudinal direction.

According to (Kazeman et al, 2017), the existing indices used in vehicles can only detect un-tripped rollovers resulting from high acceleration but are unable to detect tripped rollovers produced by long-range vertical external forces.

Vehicle rollovers may be influenced by several variables, including driving style, road conditions, vehicle attributes, and vehicle capabilities. To identify a rollover, it is necessary to construct an index that quantifies the stability of a vehicle. The index enables the controller to determine the likelihood of rollovers and provide suitable signals, accordingly, as stated by Peters et al. (2006). The calculation of each indicator is based on sensor data and the current situation of the vehicle's dynamics.

The value has to be determined by comparing it to a certain pre-programmed number that acts as the threshold for rollover. Static roll instability and dynamic roll instability are two measures used to assess the likelihood of a vehicle rolling over. The vehicle rollover index is a metric that may be used to detect when a wheel becomes airborne in real-time. The rollover index is as stated below:

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

The vertical forces exerted by the left and right sides of the tires are denoted as Fzl and Fzr, respectively. When the vehicle is on the verge of tipping over, the index value is equal to or higher than 1. When the vehicle is moving in a straight line and there is no rollover, the Fzr and Fzl values are similar. This assumes that Fzl is equal to zero, R is equal to one, and the right tyres of the vehicle are in contact with the surface.

Due to the absence of force measurements, index (201) is not applicable. Researchers have made many efforts to retrieve the indices associated with lateral acceleration and un-tipped rollover. The rollover index, R, is calculated using a formula that relies on the values of 0 and ay.

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

The variables in question are as follows: m represents the center of gravity height, mu represents the un-emerged mass, ms represents the emerged mass, ay represents the lateral acceleration, and represents the rotation angle. The rollover index may be used to identify rollovers that have not been triggered. Due to the challenging nature of measuring roll angles, Odenthal et al. (2015) conducted many tests that focused only on determining the rollover index based on lateral acceleration. The index stability control may restrict the vehicle's lateral movement and is incapable of detecting rollovers caused by vertical forces and road inputs.

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

The acceleration of the emerging mass is assessed separately in this particular kind of commercial index (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 $(\ddot{z}_{ur} - \ddot{z}_{ul})$ represent the disparity in the velocities of un-emerged mass.

2.3.3 Static Roll Instability

Various rollover indices have been suggested to enhance the identification of rollovers. As per the study conducted by Harun et al. in 2020, the measurements of rollover were first acquired using static or steady-state rollover transition models. The Static Stability Factor (SSF), commonly referred to as the Static Rollover Index (SRI), is a measurement that compares the half-track of a vehicle to the height of its Centre of Gravity (COG) (Lapapong, 2010). This metric is defined concerning any geometric characteristic of the vehicle. Czechowicz and Mavros (2014) suggested that the static RI should be revised to include suspension effects. Additional fixed resistance indices, as suggested by Lapapong (2010), such as the Side Pull Ratio and Tilt Table Ratio, are determined via experimentation and have a high degree of similarity to the SSF.

Nevertheless, as stated by Gildin (1997), the static stability factor is the primary measure of a vehicle's inherent susceptibility to overturning, often evaluated using the Static Stability Factor (SSF). Additionally, it may serve as a roll angle indicator for detecting rollovers. However, it is seldom used as a standalone indicator and is often used as a supplementary feature, as stated by Hsu and Chen (2012)

2.3.4 Dynamic Roll Instability

(Ataei et al, 2019) propose the implementation of many dynamic risk indicators (RIs) related to vehicle circumstances to enhance the precision of rollover indicators across different situations. Commonly, fundamental vehicle rollover criteria like lateral acceleration, roll angle, or roll rate are used as indications of the probability of a rollover. Another crucial parameter that is often necessary in dynamic situations is the lateral Load Transfer Ratio (LTR).

In addition, the interaction between the tire and the road surface determines the magnitude of lateral load transmission. The index is determined by quantifying the vertical forces exerted by the left and right tires, then engaging the controller when the disparity is above a certain threshold (Rajamani et al, 2009).

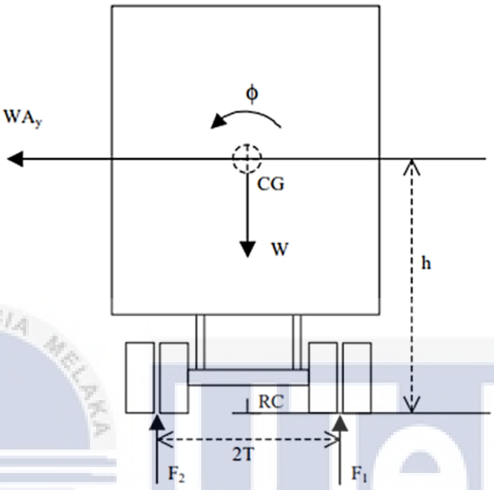


Figure 2-9 Rigid Vehicle Model (Goldman, 2001)

2.4 Implementation and Testing

Regarding implementation and testing, two simulations were used, namely Hardware in the Loop (HIL) and Software in the Loop (SIL). The use of Hardware in the Loop (HIL) and Software in the Loop (SIL) methodologies enables the evaluation of developed solutions using simulations that accurately replicate real-world conditions. Their use boosts development and improves quality control while reducing the need for physical prototypes and testing.

2.4.1 Software In the Loop (SIL)

Unit tests are conducted on code to detect and rectify system-level problems, such as validating code creation. Software-in-the-loop (SIL) may be conducted in the first phases of software development. It permits the execution of tests before activating hardware functionality, facilitating the discovery of faults. The citation is from the research paper published by Ben Ayed et al in 2017. One benefit of using Software-in-the-Loop (SIL) is that it allows for testing of design before production. The vehicle's features frequently result in the replication of dynamics inside the same vehicle. According to Steven Robert O'Hara (2005), this technique is both cost-effective and successful in analyzing the behavior and overall features of a complex computer model. However, its effectiveness relies heavily on the specific kind of model and the quality of the supporting data.

2.4.2 Hardware In the Loop

Hardware-in-the-loop (HIL) encompasses the control rules related to the simulated environment, as well as the control implementation, reaction time, and integration verification of the equipment. Hardware-in-the-loop (HIL) addresses the challenges and inaccuracies that occur from computer-based vehicle model development by emphasizing the vehicle input instructions and vehicle output outputs. An important benefit of Hardware-in-the-Loop (HIL) testing is that it removes the need for driver participation and personal judgment by directly examining the vehicle's hardware. By directly assessing the hardware, there is no need for a mathematical representation of the vehicle since it might potentially introduce inaccuracies throughout the test. The source cited is Steven Robert O'Hara's work from 2005.

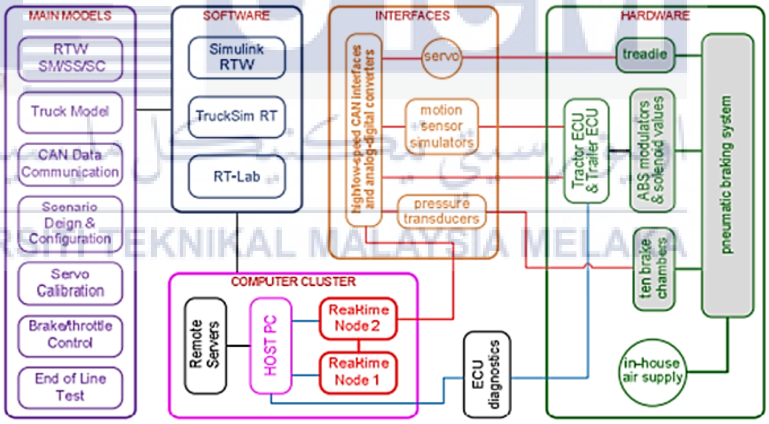


Figure 2-10 Hardware In the Loop System (Svenson & Grygier, 2009)

2.4.3 Implementation and Testing in Vehicle

The study conducted by Svenson and Grygier (2009) focused on the application of the Hardware-in-the-Loop (HIL) method in analyzing the instability of heavy trucks under different conditions. Specifically, the researchers examined the effects of Electronic Stability Control (ESC) or Roll Stability Control (RSC) systems on the truck's stability during loss of control or rollover situations. The study considered various motions and velocities to provide a comprehensive analysis. The validation results indicate that the vehicle dynamics and Hardware-in-the-Loop (HIL) response closely resemble those seen on actual heavy truck test tracks. This enables the assessment of the stability control system's effectiveness across different driving scenarios. The qualitative test track tests are often of a small size. Given the HIL's ability to provide dependable forecasts, this simulation environment is capable of scrutinizing the performance of sizable vehicles that are outfitted with this cutting-edge technology.

Simulations were conducted using SIL (Software-in-the-Loop) methodology, in which Simulink control algorithms were created for both ABS (Anti-lock Braking System) and Electronic Stability Control (ESC). The ESC system consists of two distinct operating modes: Roll Stability Control (RSC) and Yaw Stability Control (YSC). This thesis focuses on selecting an ESC control model system that specifically targets the roll stability mode. The roll stability control system continuously monitors the total sideways acceleration of the vehicle. If this acceleration is above a certain threshold, the system responds by either applying brakes to specific wheels or limiting the engine's power output. The yew stability control system operates by sensing and calculating the combined yaw rate and body slip angle. Yew stability control is activated when the vehicle's body slip angle and slide rate surpass certain thresholds.

The application of differential braking to the steering or driving axles depends on whether the vehicle is experiencing understeer or oversteer. The addition of the ABS control module is the only enhancement for this kind, aimed at minimizing wheel lock-up. Rao and Member conducted a study in 2013.

2.5 Internet of Things (IoT)

The Internet of Things (IoT) refers to a network of interconnected devices and equipment capable of wirelessly transmitting and receiving data without human intervention, using Wi-Fi connectivity. It is a software component that establishes a connection between tangible and widely used objects and the internet. Computers equipped with IoT technology may establish internet connections with one other and be taught to perform a wide range of tasks. The Internet of Things (IoT) will facilitate the provision of secure and streamlined transportation. The reason for this is that IoT systems are operated by event-driven programs that accept inputs in the form of sensed data, user feedback, or other external stimuli. This information is acquired by several internal sensors, which are sophisticated devices designed to detect and react to electrical and other signals.

2.5.1 Smartphones

(Varma Sri Krishna Chaitanya, 2013) Provides instructions on using smartphones for automated collision tracking. Automated collision warning systems have been incorporated by BMW and General Motors. The accident occurrence is analyzed by using sensors installed in their vehicles, including accelerometers and airbag deployment indicators. The collected data is then sent to a reaction center via integrated cellular radios. Regrettably, the majority of automobiles lack an automatic collision alert system. Consequently, the device has been replaced with a smartphone that is capable of identifying injuries and promptly notifying the appropriate authority. Utilizing smartphones as opposed to automated collision warning systems has several benefits, such as the capacity for swift transportation and the provision of accident alarm notifications in various vehicles, including bicycles and motorbikes. Moreover, due to the association of each mobile device with its respective owner, the process of identifying the perpetrator is straightforward. During an accident, a smartphone's sensors collect data on the vehicle's GPS position, altitude, and auditory footprint. This information is then sent to a centralized server via the smartphone's built-in cellular network. From there, the data is sent to the emergency department.

2.5.1.1 GSM and GPS

In the article by V Praveena (2014), the author describes the process of using GSM and GPS technology to identify and promptly transmit a message in the event of an accident. GPS satellites are used to precisely determine the precise location of the crash, as well as its elevation, distance, and orientation. A conventional road accident detection and communication system, which is based on a microprocessor, uses an infrared sensor to detect and identify objects. When an accident occurs, the machine utilizes the GPS module to calculate the precise longitude and latitude of the accident's location. Subsequently, it transmits a distress signal to the emergency department, providing the precise coordinates of the vehicle.

2.5.1.2 Vehicular As-hoc Network (VANET)

In the study conducted by Bruno Fernandes in 2015, VANET was used as a technology for accident warning. This was achieved by incorporating two sensors, namely a collision sensor and an airbag device. Once these sensors detect an injury, the data is sent to a device that is based on a microcontroller. The crash site is determined by GPS, and the device broadcasts the coordinates to a designated recipient over GSM. The signal is sent to the rescue team using VANET, an ad hoc network that establishes connections between mobile vehicles. The message is sent by the VANET to the rescue team. Initially, a source node broadcasts a cautionary message to all vehicles along the route.

2.5.2 Technology for Mobile Devices

According to the eCall architecture (Tvrzský, 2011)The eCall architecture, as described by Tvrzsk (2011), facilitates communication between the vehicle involved in an event and the Public Service Answering Point (PSAP) via the GSM cellular network. To provide seamless roaming throughout all of Europe, the eCall service will use the standardized pan-European emergency call number E112. The eCall architecture, as defined by the eCall Driving Group, consists of three main components: the vehicle, the network, and the PSAP. Additionally, there is a flow of voice and data calls established between the car and the PSAP in case of an emergency.

Fig. 2 Architecture of the eCALL service and eCALL IVS

The standardization attempts about the technology solution for implementing the architecture shown in Figure 2a address two primary concerns: the transport protocol used for transmitting the Minimum Set of Data (MSD) to the Public Safety Answering Point (PSAP) via the cellular network, and the specific content and format of the MSD. The European Telecommunications Standards Institute (ETSI) is responsible for developing standards for eCall support. The definition of the MSD is presently being established by CEN/TC 278 WG15 (eSafety), while the transmission of the MSD is being specified by the ETSI-MSG and the 3GPP standardization bodies. The MSD message, as specified in the Road transport document from 2008, has a maximum size of 140 bytes. It includes the timestamp and geographical coordinates of the accident, the indication of whether the eCall activation was done manually or automatically, the type of vehicle and its identification number (VIN), the number of passengers, and any additional optional data.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Typically, a car rollover occurrence happens when a vehicle crashes with another vehicle and overturns onto its side or roof. Commercial vehicle rollovers result from excessive speed when navigating a bend, leading to an imbalanced distribution of weight and subsequent loss of control. A vehicle that rolls on its pure longitudinal or lateral axis of 90 degrees or more is referred to be such. During the rollover period, the actuator lacks sufficient time to respond adequately, particularly in highly destructive circumstances. To mitigate the risks associated with commercial vehicle rollovers, it is crucial to have the ability to evaluate potential rollovers and predict them with enough advance notice.

Consequently, warning shift devices are designed and manufactured to overcome these accident concerns. The purpose is to give an early warning to the driver before the car rolls over. It is built with MATLAB Simulink to predict what will happen if some external input is applied to it.

3.2 Project Flowchart Process

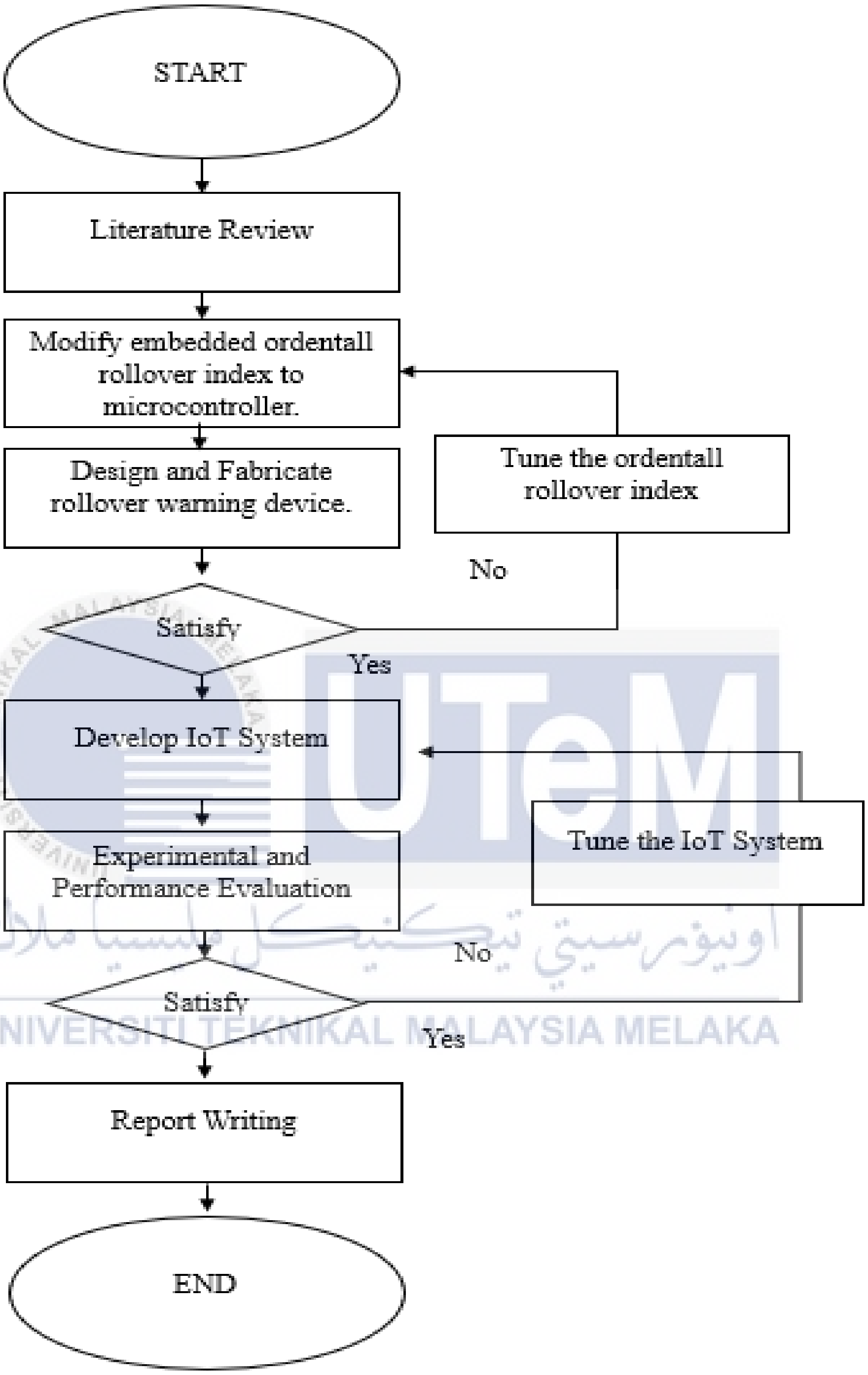
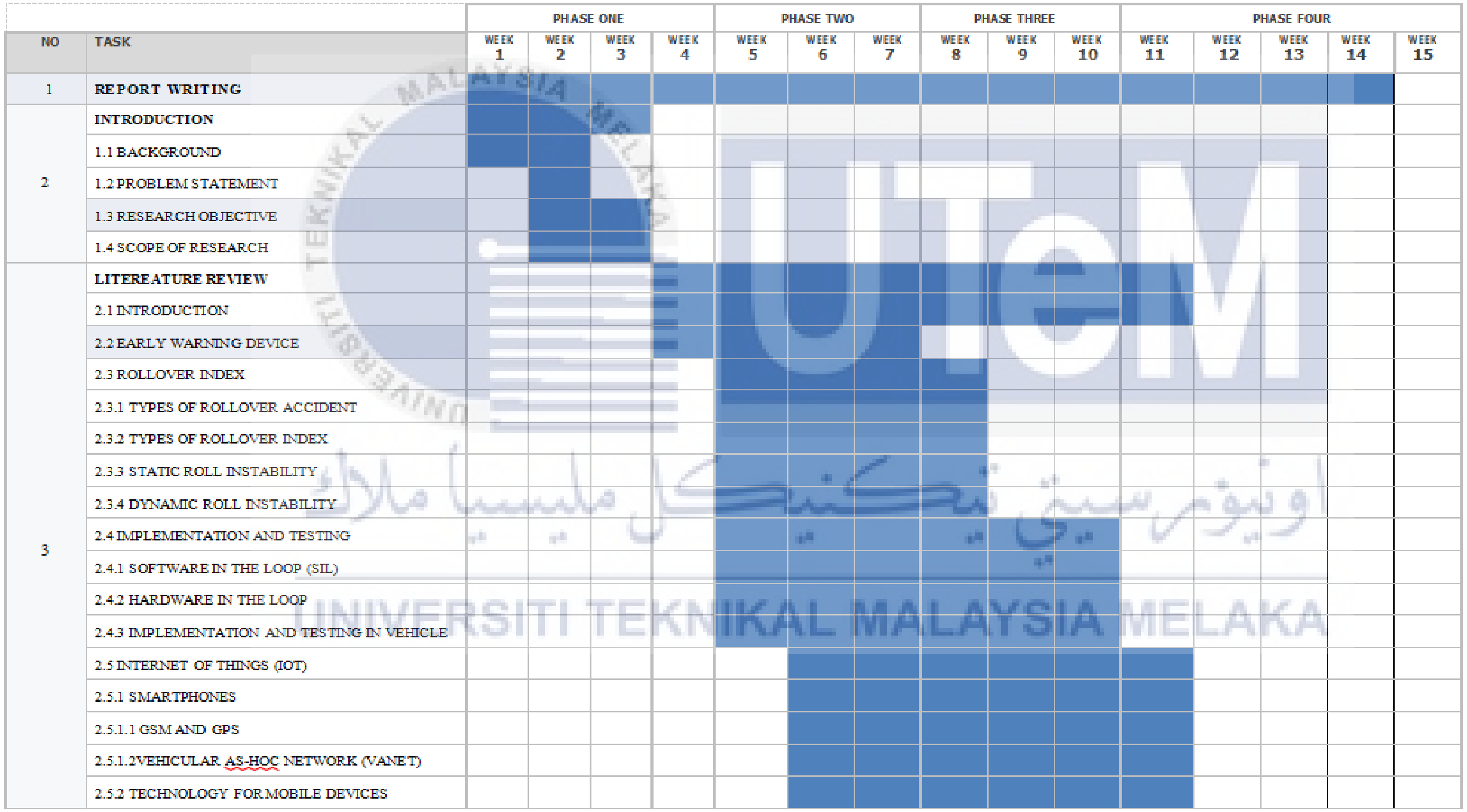


Figure 3-1 Project Flowchart Process

3.3 Gantt Chart (PSM 1 & PSM 2)

PROJECT NAME	PROJECT LEAD	PROJECT START DATE	PROJECT END DATE
DESIGN AND FABRICATE ROLLOVER WARNING DEVICE FOR COMMERCIAL VEHICLE	ABDUL ALIM MUHAMMAD BIN AZMI	29 Mac 2023	12 JAN 2024



NO	TASK	PHASE ONE				PHASE TWO			PHASE THREE			PHASE FOUR				
		WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	WEEK 6	WEEK 7	WEEK 8	WEEK 9	WEEK 10	WEEK 11	WEEK 12	WEEK 13	WEEK 14	WEEK 15
1	**REPORT WRITING**	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
2	**INTRODUCTION**	■	■	■												
	1.1 BACKGROUND	■	■													
	1.2 PROBLEM STATEMENT		■													
	1.3 RESEARCH OBJECTIVE		■	■												
	1.4 SCOPE OF RESEARCH		■	■												
3	**LITEREATURE REVIEW**				■	■	■	■	■	■	■	■				
	2.1 INTRODUCTION				■	■	■	■	■	■	■	■				
	2.2 EARLY WARNING DEVICE				■	■	■	■								
	2.3 ROLLOVER INDEX					■	■	■	■							
	2.3.1 TYPES OF ROLLOVER ACCIDENT					■	■	■	■							
	2.3.2 TYPES OF ROLLOVER INDEX					■	■	■	■							
	2.3.3 STATIC ROLL INSTABILITY					■	■	■	■							
	2.3.4 DYNAMIC ROLL INSTABILITY					■	■	■	■							
	2.4 IMPLEMENTATION AND TESTING					■	■	■	■	■	■					
	2.4.1 SOFTWARE IN THE LOOP (SIL)					■	■	■	■	■	■					
	2.4.2 HARDWARE IN THE LOOP					■	■	■	■	■	■					
	2.4.3 IMPLEMENTATION AND TESTING IN VEHICLE					■	■	■	■	■	■					
	2.5 INTERNET OF THINGS (IOT)						■	■	■	■	■	■				
	2.5.1 SMARTPHONES						■	■	■	■	■	■				
	2.5.1.1 GSM AND GPS						■	■	■	■	■	■				
	2.5.1.2VEHICULAR AS-HOC NETWORK (VANET)						■	■	■	■	■	■				
	2.5.2 TECHNOLOGY FOR MOBILE DEVICES						■	■	■	■	■	■				

4	**METHODOLOGY**							■	■	■					
	3.1 INTRODUCTION							■	■	■					
	3.2 PROJECT FLOWCHART PROCESS							■	■	■					
	3.3 GANTT CHART							■	■	■					
	3.4 SOFTWARE IN THE LOOP (SIL)			■	■	■	■	■	■	■	■	■	■	■	■
	3.5 HARDWARE IN THE LOOP (HIL)			■	■	■	■	■	■	■	■	■	■	■	■
	3.6 ORDENTHAL ROLLOVER INDEX ALGORITHM								■	■	■	■			
	3.7 MODIFIED ROLLOVER INDEX ALGORITHM								■	■	■	■	■		
	3.8 THINKSPEAK								■	■	■	■	■		
	3.9 MIT APP INVENTOR								■	■	■	■	■		
	3.10 SIMULATION SETTING								■	■	■	■	■	■	
	3.11 MORI TEST FOR COMMERCIAL VEHICLE										■	■			
	3.12 PARAMETERS										■	■			
	3.13 EQUIPMENT										■	■			
	3.14 LIMITATION OF PROPOSED METHODOLOGY												■	■	
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**											■	■		

PSM 2 REPORT
WRITING
11/10/2023-
10/1/2024

3.4 Software In the Loop (SIL)

The input method will be used for Software-in-the-Loop (SIL) using the TruckSim driving simulator, as seen in Figure 3-2. The TruckSim driving simulator program requires input of vehicle type, speed, and steering angle data. Thus, the Trucksim driving simulator will generate input and vehicle velocity, v. The two parameters in the second block will serve as input for the rollover index technique. The rollover index algorithm will be implemented in the MATLAB/Simulink program to create the rollover index technique. This diagram may be used to ascertain if the vehicle has the propensity to have a rollover event or not. The index value is ≥ 1 when the vehicle is on the verge of rolling over. If the value exceeds one, the speaker will emit a warning sound and the LED set will flash.

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

3.5 Hardware In the Loop (HIL)

TruckSim Simulation software was used to analyze the rollover predictions. The TruckSim program is used to get the actual truck simulation as well as the output graph to compare with the output graph of the MATLAB Simulink software. Before using the Andrino DUE board, a block model collection is created for the rollover index parameter.

3.6 Ordenthal Rollover Index Algorithm

Odenthal et al. (2015) devised a methodology for calculating a rollover index by using a vehicle rollover model. The vertical force is approximately denoted by FZL and FZR. The roll index RI is calculated by equilibrating vertical loads and rolling motion. Consequently, RI is shown as

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

FZL represents the force exerted on the left tyre, whereas FZR represents the force exerted on the right tyre.

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

Equation (3.2) is utilized to evaluate the rollover index's capabilities based on Odenthal's fastest warning response time. In conclusion, according to (Odenthal et al., 2015)

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

As a result, the equation (3.2) can be modified 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 Commercial Vehicle

Equation (3.4) demonstrates that both the lateral acceleration of the body, ay,2, and the roll angle of the body, φ, contribute to the capacity of the RI (Chen & Peng, 2005). The use of Gains Ka and Kr enhances the sensitivity and capability of the existing Odenthal rollover index. Thus, the MORI algorithm is stated as follows:

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

As shown by equation (3.5), Ka is used to control the sideways acceleration resulting from the applied force on the body, while Kr is utilized to manage the response impact of the body's roll angle. Thus, Ka and Kr are parameters derived from the sensitivity analysis technique, as proposed by (Hafizah Amer et al., 2021), to enhance the effectiveness of the modified Odenthal rollover index. The rollover index, which transitions from one (1) and reverts to its original state, is used in the computation of Ka and Kr values (Presented & Fulfilment, 1999). To determine the values of Ka and Kr, a simulation is conducted using a truck model executing a step-steering maneuver at a velocity of 100 km/hr.

The commercial vehicle rollover index shown in Figure 3-3 is associated with the Time To Warn (TTW). The Rollover Safety Factor is established at 0.75 to provide a very efficient first reaction (Presented & Fulfilment, 1999). Figure 3 - 4 illustrates the rise in Ka from 0.97 to 1.10, enabling the vehicle to return to its initial position. At a Ka value of 0.97, there is a steady upward movement on the left side of the vehicle axle that lasts for 2.15 seconds, followed by a return to its original position in 2.42 seconds. The highest refractive index (RI) recorded during that period was 1.0046. With a Ka value of 0.98, the left side of the vehicle axle begins to elevate at 2.05 seconds and reverts to its initial position at 2.15

seconds. The highest RI recorded during this period is 1.0150. Moreover, as Ka exceeds the threshold of 1.10, the tires on the vehicle's axle begin to accelerate at 1.74 seconds and then return to their normal state at 8.91 seconds. The maximum RI value for this Ka is 1.1392. Therefore, it is accurate to assert that as the Ka value grows, the duration for the left tire of the vehicle axle to begin lifting decreases, but the time to return to normal increases, while the maximum value of the RI increases. When the Ka value hits 1.11, the RI value stays above one (1), as seen by the dotted line in Figure 3 – 4. It demonstrates that one side of the tyre of the vehicle remains elevated, resulting in the vehicle's rotation. Furthermore, the results of the rollover index values indicate that for Ka values between 0.97 and 1.10, the vehicle consistently takes 4.30 seconds to settle.

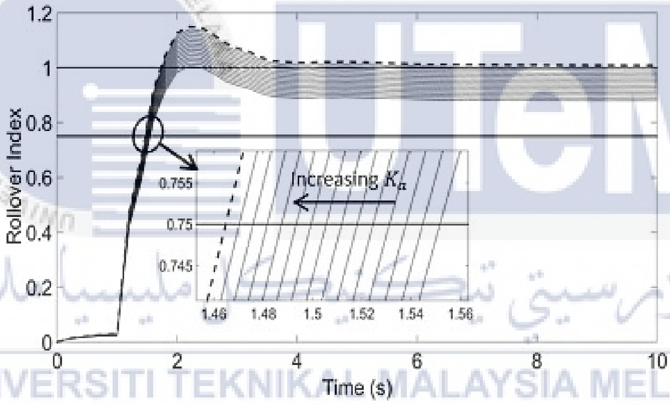


Figure 3-3 Commercial Vehicle Rollover Affected by K_a

Figure 3 - 4 illustrates the impact of Ka on TTW. This demonstrates a positive correlation between the rise in the value of Ka and the corresponding increase in TTW. Ka has a significant impact on the lateral acceleration of the vehicle body. This is a result of the significant lateral acceleration generated by the steering input on the high-friction surface

during this maneuver. The citation is from Ungoren et al., 2004. Empirical evidence demonstrates that Ka values may be used to fine-tune the adjustment of TTW. Furthermore, according to the data shown in Figure 3 – 5, the optimal Ka value determined from this experiment is 1.10. If the value of Ka surpasses 1.10, it will cause one side of the automobile tire to rise, resulting in the vehicle initiating a roll-over motion. This conduct eventually hinders the driver from enhancing the maneuver and will lead to the car overturning.

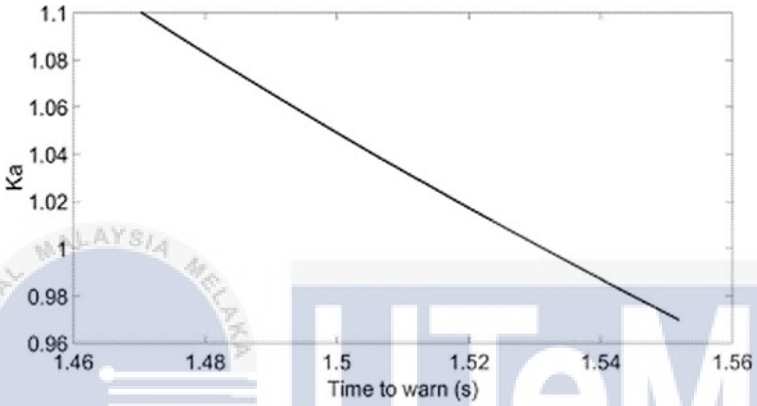


Figure 3-4 K_a influnce on TTW

The sensitivity research approach is still used to get the optimal value for Kr, ensuring maximum value for money. The optimal value for Kr is found using the same method as Ka, whereby it relies on the value of I and returns the result once it hits 1. The provided data is derived from the step-steering manoeuvre conducted in TruckSim at a speed of 100 kilometres per hour. Figure 3 - 6 depicts the reaction of the refractive index (RI) as defined by the Kr effect. The value of Kr is adjusted within the range of 4.5 to 11.0 in order to restore the vehicle to its initial condition. At a Kr value of 4.5, the left tyre of the vehicle axle begins to lift off at 2.04 and returns to its usual position at 2.40. The maximum value seen throughout the RI is 1.0064. At a Kr value of 5.0, the vehicle axle takes 1.97 seconds to lift the tyre and 2.48 seconds to return to its original position. The maximum RI is 1.0170. At the point when Kr hits the threshold of 11.0, the left axle of the vehicle tyre begins to elevate at 1.57 seconds and reverts back to its original position at 8.18 seconds. The maximum refractive index (RI) value for Kr is 1.1546. Due to this circumstance, when the Kr value grows, the duration for the left axle of the vehicle tyre to start lifting off reduces, but the duration to return to the previous state increases. Simultaneously, the maximum refractive index value likewise increases..

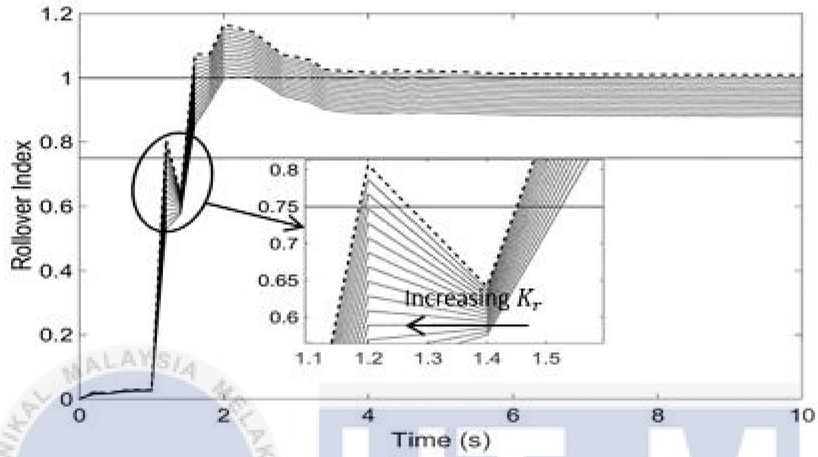


Figure 3-5 Commercial Vehicle Rollover Index Influenced by K_r

Consequently, the driver has less opportunity to adapt his movement. Hence, this study focuses on examining the impact of steering angle and velocity input on enhancing the time-to-rollover (TTW) performance.

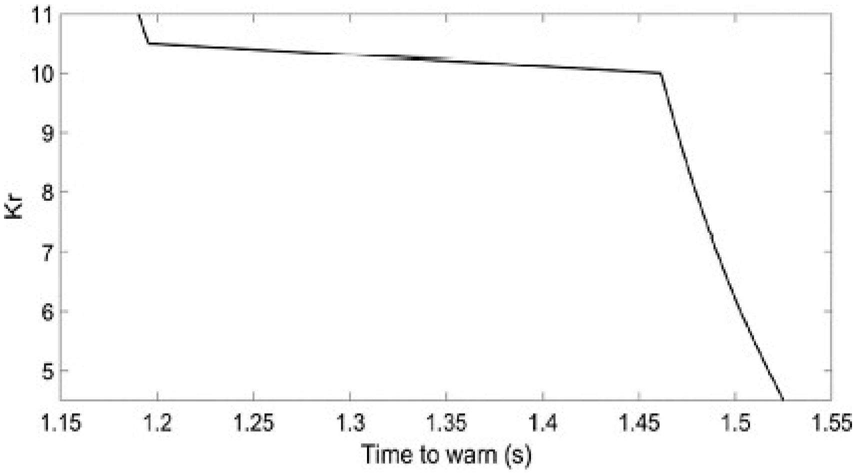


Figure 3-6 K_r influence to TTW

Based on the findings of this research, the MORI algorithm is used to combine steering input and vehicle velocity. Equations to combine the steering wheel with the vehicle velocity inputs are used in this observation that was created by (Gillespie,1992). However, (Gillispie, 1992) stated that when the driver turns, the steering angle may be driven by the driver's ability to see is expressed as input and the vehicle's movement factors such as lateral acceleration as output. In addition, the vehicle follows a constant velocity and radial curve. As a result, (Gillespie, 1992) developed the steering and vehicle velocity inputs formula as stated below: -

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

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

Nevertheless, the predicted roll angle is used to compute the roll angle response. The dynamic model of vehicle rolls dynamics (Hac et al., 2004) is used to derive the observer and roll angles. Roll angle estimation, as described by Rajamani et al. (2011), is distinct from other methods.

3.8 Thinkspeak

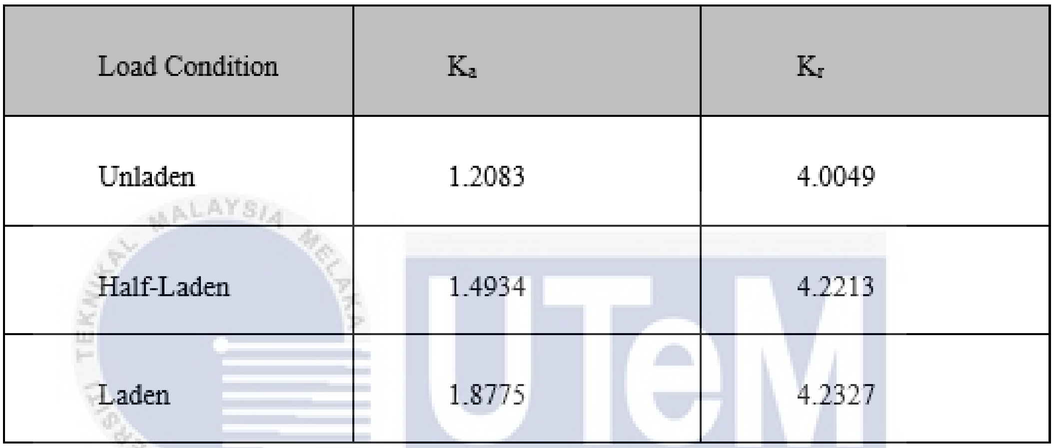
In a study, ThinkSpeak is an Internet of Things (IoT) platform that effortlessly connects with Simulink, a sophisticated environment for simulation and modelling. Simulink enables engineers and researchers to create and simulate intricate systems. By integrating ThingSpeak, they can expand their simulations to the Internet of Things (IoT) realm. ThinkSpeak functions as a cloud-based storage facility for gathering and examining data from sensors, devices, and simulations. The interaction with Simulink enables users to transmit simulation data to ThingSpeak, facilitating real-time monitoring and analysis of system behavior. This combination enables the investigation of practical implementations, such as observing physical phenomena, carrying out experiments, or verifying control algorithms in real-life situations. The combination of Simulink and ThingSpeak offers a robust framework for connecting simulated models with real-world data and Internet of Things (IoT) applications.

3.9 MIT App Inventor

MIT App Inventor is a user-friendly and visually-oriented programming environment that enables anybody, especially those without significant coding expertise, to develop mobile apps for Android devices. This platform, created by the Massachusetts Institute of Technology, streamlines app creation by using a drag-and-drop interface. Users may build and prototype apps by graphically constructing blocks that represent different features. MIT App Inventor enables a diverse group of users, such as students, educators, and hobbyists, to transform their app concepts into reality without requiring advanced coding abilities, emphasizing accessibility. The platform's capability encompasses the integration of hardware features, utilisation of sensors, and connection to online services, providing a flexible and user-friendly tool for app development.

3.10 Simulation Setting

In the study conducted by Mohamad Hafiz Harun et al. (2021), the vehicle model is simulated, and the parameters Ka and Kr are optimized using Particle Swarm Optimization (PSO) to achieve optimal performance under different load conditions. Table 5.2 displays the refined values of the Ka and Kr parameters under different load conditions. They were used to conduct studies under different vehicle weight situations.



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

Table 3-1 Optimize Parameter value of Ka and Kr for each load condition

3.11 The Modified Ordenthal Rollover Index (MORI) Test for Commercial Vehicles

This section outlines the testing methodology used in this study to assess the capabilities of MORI. The final rollover warning system is constructed by using the TruckSim driving simulation, a commercial truck, and the MORI algorithm in the testing phase. This system is then integrated with a buzzer limit. The TruckSim driving simulation's driver Hardware-in-the-loop (DHIL) uses the real-time simulation stage to assess the vehicle's potential for rollover index.

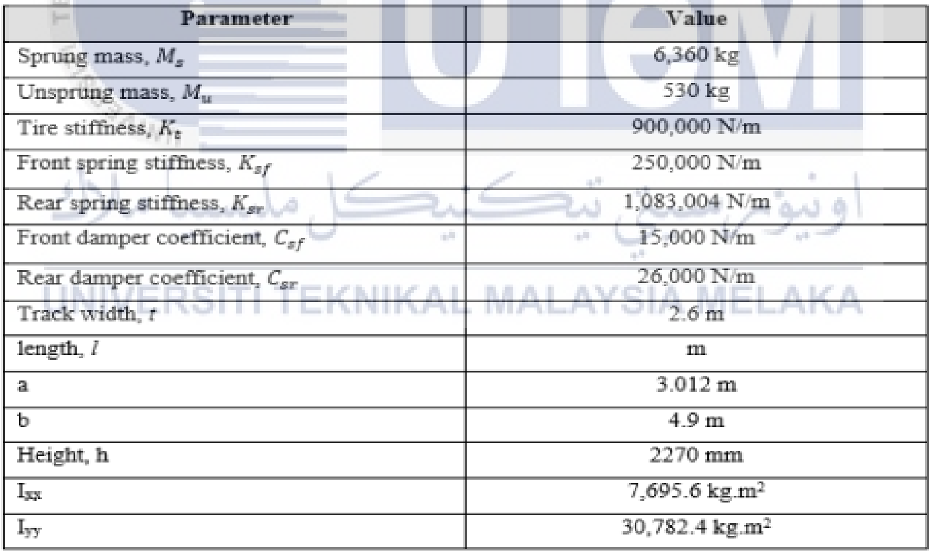
The reference is from Wang and He's work published in 2015. The testing methodology is shown in Figure 3 – 8. The input data for this test consists of the vehicle's steering wheel angle and velocity, which were created using the TruckSim driving simulator. The researchers evaluated the MORI capability by doing 60 motion steering maneuvers at velocities ranging from 60 to 100 km/hr, using TruckSim and Simulink. The velocity values were selected according to the SAE-932949 velocity categorization for low, medium, and high velocity until the tire lifted and the RI value above 1. In addition, the vehicle used for this test is loaded under three different conditions: burdened (12,600 kg), half-laden (11,300 kg), and unladen (10,000 kg). The reliability score factor (RSF) assigned to the early warning indication for this investigation is established as 0.75. The steering maneuver in the TruckSim driving simulator is performed using the vehicle model seen in Figure 3-9. The test criteria used were derived from (Presented & Fulfilment, 1999). The vehicle's specs may be found in Table 3.2. The vehicle model is simulated using the Heun solver with a fixed time step of 0.01s, and the MORI method (Hudh et al., 2008) is used.

Figure 3-7 Simulink Trucksim Driving Simulator with Rollover Index Algorithm

Figure 3-8 Truck in Trucksim

3.12 Parameters

The parameters for this research are using HINO specification as follows>-



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	m
a	3.012 m
b	4.9 m
Height, h	2270 mm
I_{xx}	7,695.6 kg.m^2
I_{yy}	30,782.4 kg.m^2

Table 3-2 Parameter

3.13 Equipment

This project requires the utilization of certain equipment. The most important tool is TruckSim Software, which was used to obtain the real vehicle simulation and output graph to compare with the MATLAB Simulink Software output graph. Meanwhile, a cordless drill, files, and a screwdriver are the tools needed to build the rollover device.

3.14 Limitation of Proposed Methadology

Commercial vehicles are well-known transport vehicles used to transport goods or furniture to other places in Malaysia. Since it is widely used as a mechanism of transportation, this project paper will focus on this type of vehicle to overcome rollover incidents. However, this project paper is carried out as an experimental lab session only.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

According to previous researchers, Odenthal's rollover index (RTI) algorithm is the most efficient algorithm. According to the findings of Mohammad Hafiz Haroun et al. 2021, Odenthal's RTI algorithm required 0,51 seconds for a driver to detect an oncoming rollover. Since the speed of the lead vehicle significantly impacted the response time, in this case, the response time increased by only 70 ms, or 0,70 seconds for every 10 km/s, the required response time may be considered too long (Mutual, 2017). Therefore, the proposed method will need an improved algorithm to generate advanced warnings and appropriate TTR in the event of a rollover. As the name indicates, the method is based on an older version of the Odenthal RTI algorithm. The modified Odenthal RTI is described and presented in section 4.3 below.

4.2 The Operation of the Modified Odenthal Rollover Index Algorithm

The TTR (Tilt Table Ratio) and the RI (Resistance Index) are widely used techniques for assessing the likelihood of rollovers. Upon first examination, the study literature has several RIs. However, there are subtle discrepancies in the factors that impact rollover, resulting in some RIs being more suitable for certain rollover scenarios, while others are less successful in other conditions. For instance, during a comprehensive study inquiry, the primary emphasis is placed on untripped rollover hazards. Simultaneously, there is a lack of focus on tripped-rollover conditions, which are crucial for off-road and autonomous driving applications. These conditions are significant because they reflect the most dangerous situation for the vehicle, as they are influenced by disturbances from the surrounding environment. The released study also discusses the use of AI technologies to enhance preventative capabilities against rollovers. This was corroborated by (Tota et al., 2022).

The research used the TruckSim driving simulator and evaluated the MORI's capacity using Matlab/Simulink software. The car is maneuvered utilizing a step-steering technique at a speed ranging from 60 to 120 km/h. The bus is carrying a total weight of 11,500 kg of cargo, with 8,500 kg being partially loaded and 5,000 kg being unloaded. These combinations are used to ascertain the truck's reaction capabilities. Simultaneously, the early warning indicator creates a rollover safety factor of 0.75. Fig. 4-1 presents a comparison between the response capabilities of the Mori and the probable rollover index. The truck in this instance is travelling at a speed of 60 kilometers per hour while executing 120 step-steer movements. The MORI and Odenthal rollover index determine that the greatest rollover index is 0.56 when quick steering inputs occur every 2 seconds.

The reason for this is that the MORI and Odenthal rollover indices have an additive property. At a velocity of 60 km/h, none of the rollover indices are above the RSF threshold. Consequently, the driver is not informed of a rollover collision. Conversely, the TTW determined by the MORI line is much less than the TTW determined by the Odenthal rollover index.

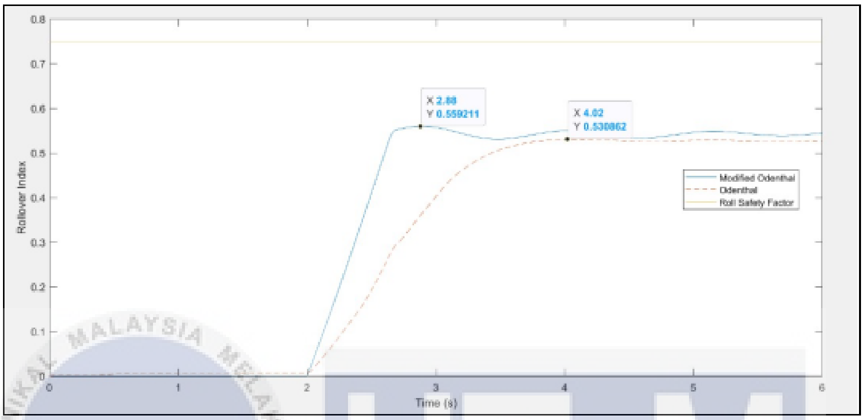


Figure 4-1 Unladen State with a Velocity of 80km/h

Despite the truck's speed reaching 90 km/h, neither the MORI nor the Odenthal rollover index lines surpassed the RSF line. Figure 4-2 provides visual evidence of this. When the velocity rises from 60 kilometres per hour to 90 kilometres per hour, both the MORI rollover index and the Odenthal rollover index attain a value of 0.72. The absence of a warning from the rollover protection system is due to the fact that the vehicle's speed remains below the rollover stability factor limit of 0.75.

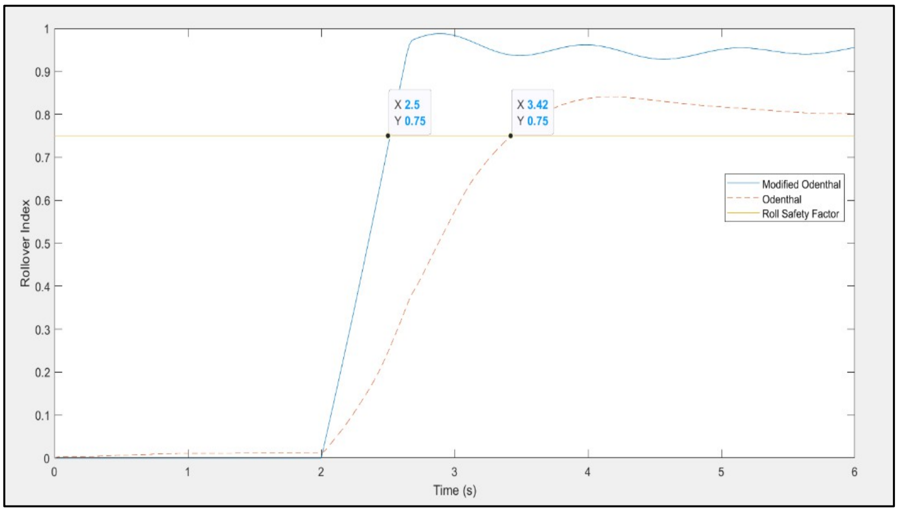


Figure 4-2 Unladen State with a Velocity of 90km/h

When the speed goes up from 90 km/h to 120 km/h, both the MORI rollover index line and the Odenthal rollover index line intersect with the RSF line simultaneously. At its maximum velocity, the truck may achieve a speed of 120 kilometers per hour while it is not carrying any load. According to the data shown in Figure 4-3, when an instantaneous steering input is made after 2 seconds, Odenthal's rollover index is 1.2 and she crosses the RSF line after 2.72 seconds. This phenomenon arises when the steering input is brief or transitory. At the point that MORI attains its peak rollover index of 1.26, there is a period of 2.38 seconds till the RSF line is reached. MORI was able to decrease the manufacturing time for TTW by 12.5% in comparison to Odenthal. The influence of the MORI reaction on the TTW became evident when the vehicle reached high velocities. In addition, MORI's rollover index surpasses that of Odenthal. Once the early warning indicator identifies that the rollover index line is on the verge of intersecting the RSF line, it will promptly emit a warning signal and activate a buzzer sound.

This phenomenon arises when the early warning indicator identifies that the rollover index line is on the verge of intersecting its RSF line. The enhanced responsiveness of MORI allows the driver to have more time to make the required modifications to the maneuver.

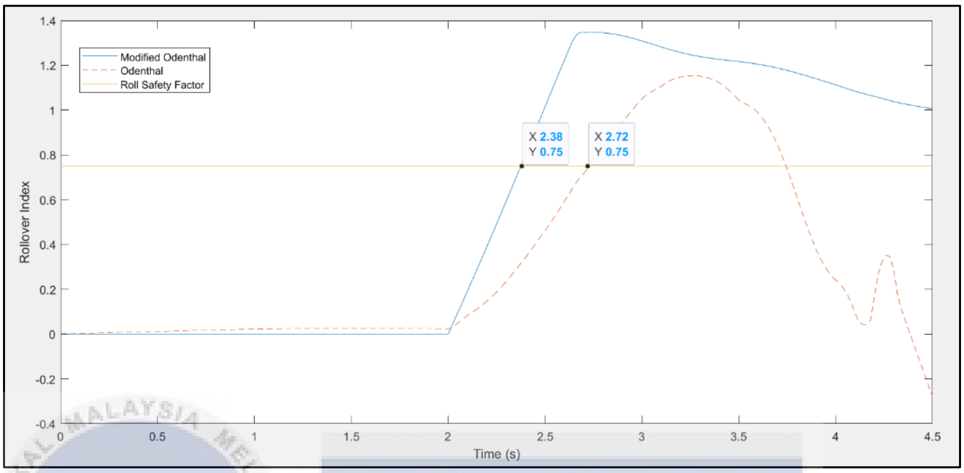


Figure 4-1 Unladen State with 120kmh of Velocity

To determine MORI's weight capacity, a load of 3,500 kg is added to the truck, resulting in a total weight of 8,500 kg. This represents 50% of the maximum load. Mori and Odenthal's study revealed that a rollover index of 0.64 is attained by driving at a speed of 60 km/h and rotating the steering wheel for 4 seconds. In the loaded state, the rollover index rises by 0.08 points compared to the no-load condition. Simultaneously, as the truck's weight grows, there is a concomitant increase in the centrifugal force produced on the vehicle when cornering. Based on a study conducted by Universitesi et al. (2021), centrifugal force is not an actual force, but rather a fictitious force that arises from inertia and causes a spinning object to move away from its center of rotation. Simultaneously, the ground forces exert pressure on the wheels directed towards the center of the curve, generating a centripetal force throughout the truck's turning motion. When the centripetal and centrifugal forces are in equilibrium, the vehicle can navigate the curve with ease.

Nevertheless, if the centrifugal force surpasses the centripetal force, the track will begin an outward rotation. The computed rollover index is below 0.75, indicating that the vehicle is safe to operate, and the rollover warning system is not engaged.

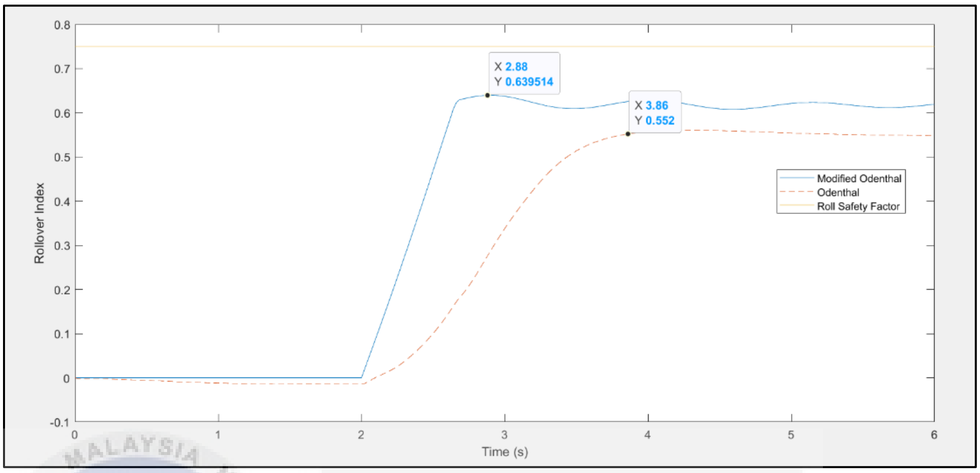


Figure 4-2 Half-Laden State with a Velocity of 60km/h

Figure 4-5 displays the rollover index values as the speed of the vehicle rises from 60 km/h to 90 km/h in a situation where the truck is half-loaded. Steering input given within 2 seconds causes an instantaneous rise in the truck's rollover index. Odenthal obtained a rollover index of 0.82, crossing the RSF line in 3.38 seconds. MORI, on the other hand, scored the greatest rollover index of 0.92 and passed the RSF line 0.86 seconds quicker than Odenthal. Once the rollover index value reaches a certain threshold, the truck is deemed unstable, prompting the rollover warning system to notify the driver to decrease speed in order to mitigate the likelihood of a rollover incident. This indicates that the rollover alert is 25.44 times greater than the Odenthal rollover index. It is crucial for drivers to navigate challenging driving circumstances.

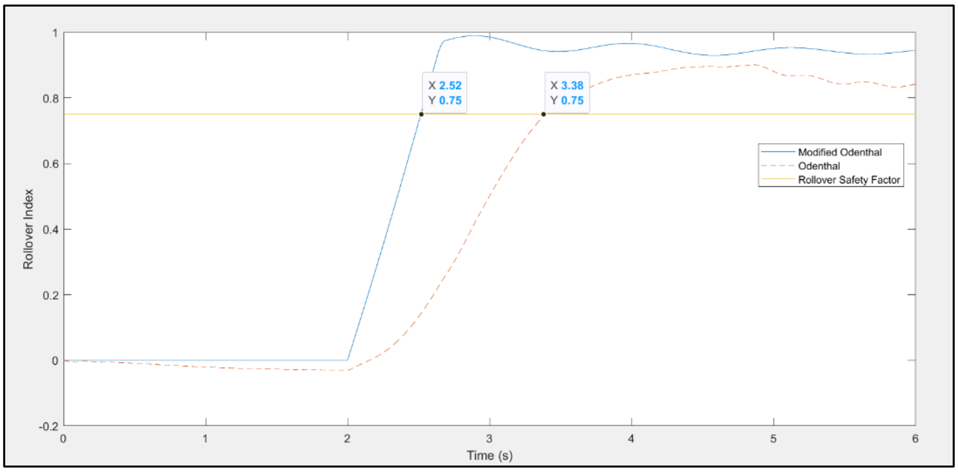


Figure 4-3 Half-Laden State with a Velocity of 90km/h

Figure 4-6 displays the MORI and Odenthal rollover index values for a vehicle that is half-loaded, as the speed rises by 120 km/h. The speed was established from a previous study using the TruckSim driving simulator, which revealed that trucks will experience rollovers when exceeding speeds of 120 km/h. As shown, the MORI estimate of the rollover index exhibits a quicker time-to-wear (TTW) than the Odenthal estimate. In comparison to Odenthal, this results in a substantial improvement in Time-to-Work (TTW). The rollover index value of Odenthal reached its highest point at 1.11 while the vehicle was traveling at a speed of 120 km/h. This occurred after 3 seconds of sudden steering input. The vehicle then crossed the RSF line in 3.18 seconds to rectify the maneuver before the tires started to lose grip. Conversely, MORI surpasses the RSF threshold in just 2.36 seconds, enabling timely alerts to drivers to avert rollover accidents.

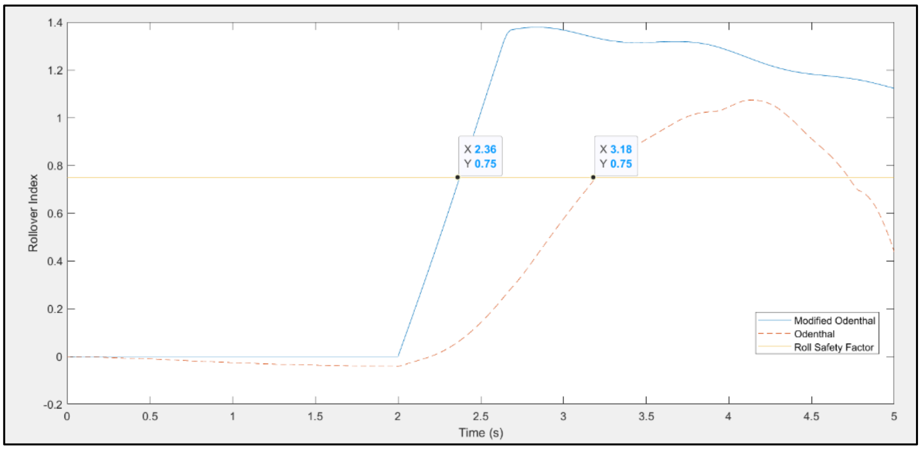


Figure 4-4 Half-laden State with 120km/h of Velocity

MORI achieves its maximum capacity when loaded with a total weight of 11,500 kg. The truck reaches a velocity of 60 kilometers per hour while it is carrying its maximum capacity, and the steering system responds with quick intervention after a delay of 2 seconds. Figure 4-7 displays this information. Under these circumstances, the rollover exponents of MORI and Odenthal started to increase by 2 seconds each. The RSF lines do not align with the highest value of any rollover index, so the RI lines do not intersect. In addition, MORI demonstrated a quicker time-to-wake (TTW) reaction compared to Odenthal. The rollover safety system will not notify the driver in this specific scenario. Figure 4-7 demonstrates that the vehicle is capable of maintaining its pace even while carrying a heavy load and receiving sudden steering commands. Consequently, it may be said that the truck maintains its equilibrium while travelling at low to moderate velocities.

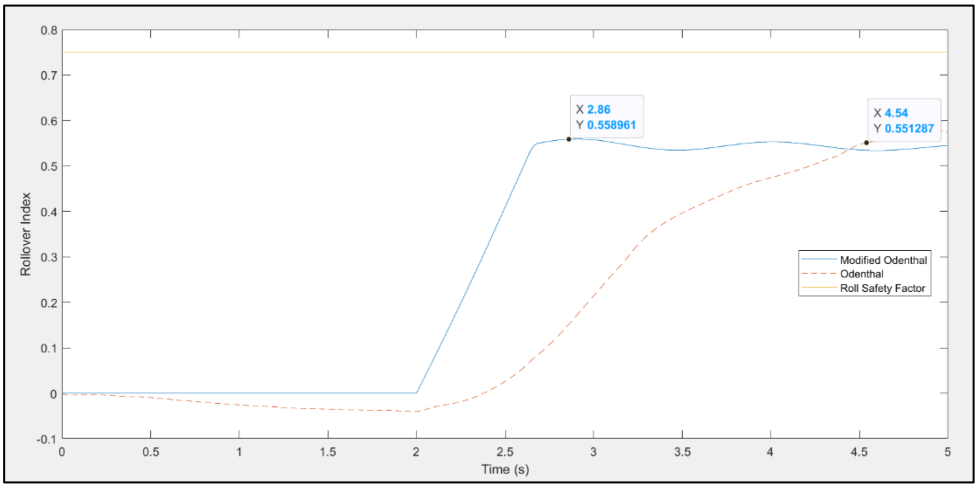


Figure 4-5 Laden State with 60km/h of Velocity

Figure 4-8 demonstrates that when a heavily laden vehicle accelerates to 90 km/h and has a sudden change in direction lasting 4 seconds, it almost rolls over. The MORI line ascends in 2.58 seconds. At a time 2.58 seconds before the crossing of the RSF line by the Odenthal line, the rollover index was measured to be 0.75. In addition, Odenthal's rollover index is equivalent to MORI's at 0.75. However, Odenthal's findings indicate that he hits the RSF line 1.32 seconds after MORI. Hence, the different components of the vehicle interact to different extents. During this scenario, the truck undergoes an early phase of rolling over, when only one side of the vehicle is in touch with the ground. In the event of a truck tipping over, the driver will get a notification via an alarm system integrated into the vehicle.

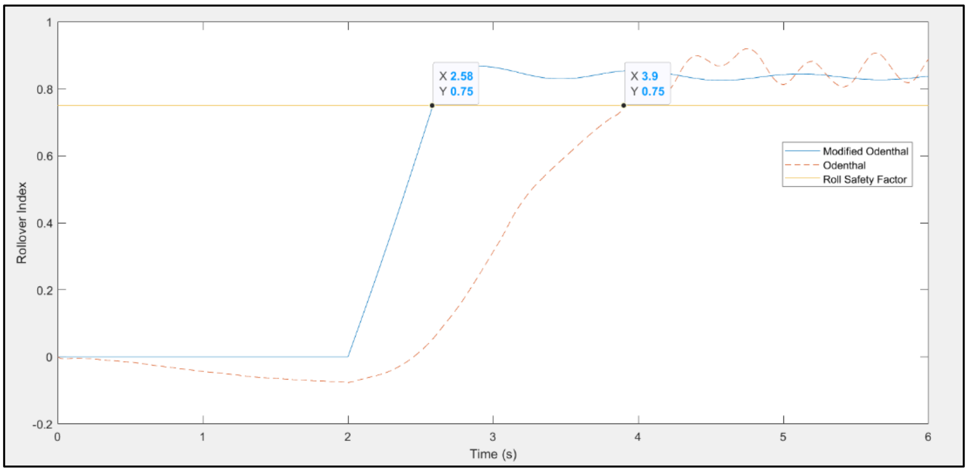


Figure 4-6 Laden State with 90km/h of Velocity

In addition, MORI's performance is assessed under conditions of maximum load and a velocity of 120 kilometers per hour. The maximum speed restriction of 120km/h was determined via experimentation using a driving simulator, due to the potential danger of the truck tipping over while carrying a full load at higher speeds. Figure 4-9 demonstrates that while traveling at a speed of 120 km/h and making a sudden steering input of 120°, MORI's rollover index rapidly rises within 2 seconds after the steering input, whereas Odenthal's vehicle starts to lose control. The steering input was initiated. At 2.26 seconds, the MORI line intersects the RSF line and steadily increases until the maximum rollover index hits 1.6. Odenthal initiates the crossing of his RSF line at a time interval of 3.28 seconds, which is 1.02 seconds later than his MODI TTW.MORI consistently identifies 1.4 as the maximum achievable rollover index for this programmed. Figure 4-9 demonstrates that the MORI reaction is 31.1 percentage points more rapid than the Odenthal reaction. A rollover index over 1 signifies total detachment of one side of the tire. If the tires are elevated, the car may either roll over or restore to its usual alignment, depending on the following events. When vehicles carrying the same weight but with varying heights of the center of gravity travel at the same speed and negotiate a similar curve, the truck with a greater center of gravity is more prone to overturning (Üniversitesi et al., 2021). Consequently, drivers must possess knowledge about the height of the vehicle they are operating and get the prior notification in the event of a tire blowout. Early notice enables drivers to promptly make essential modifications to their maneuvers, such as decreasing velocity or modifying steering inputs.

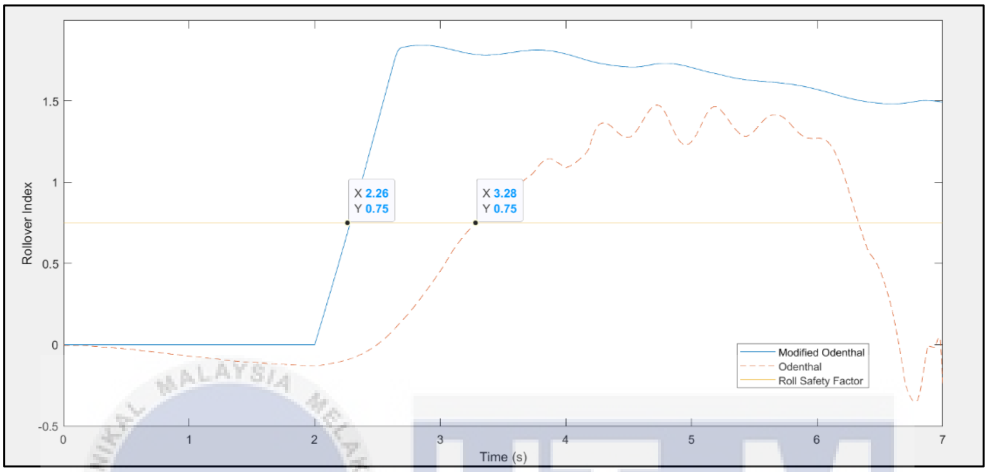


Figure 4-7 Laden State with 120km/h of Velocity

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	-	-	-	-
	90	-	-	-	-
	120	2.38	2.72	0.34	12.5%
Half-Laden	60	-	-	-	-
	90	2.52	3.38	0.86	25.44%
	120	2.36	3.18	0.82	25.79%
Laden	60	-	-	-	-
	90	2.58	3.90	1.32	39.5%
	120	2.26	3.28	1.02	31.1%

Table 4.1 displays the reaction times of MORI and Odenthal rollover index at different load scenarios. Each scenario indicated a direct correlation between increased speed and a higher rate of RI. Based on the information shown in Table 2 and Figures 4-1 to 4-9, MORI demonstrates much quicker predictive capabilities for RI compared to Odenthal.

4.3 Conclusion of the Result

Based on the aforementioned findings, this research may deduce that varying outcomes can be attained based on the circumstances of the road, the angle at which the steering is turned, and the weight of the truck. while a truck is not carrying any cargo, its weight is lower than that of a vehicle that is partially loaded. As a result, the truck may easily tip over while travelling at very high speeds, causing an uneven distribution of the load and a shift in the centre of gravity. This is particularly crucial while operating a truck carrying hazardous material. The rollover warning system serves to alert drivers of an imminent truck rollover, therefore reducing the risk of fatal accidents on the road.

Furthermore, drivers may use several measures to proactively avert rollovers, in addition to using the rollover warning system. This entails possessing a comprehensive understanding of the vehicle and its equipment, using a vehicle equipped with ABS, ESP, and/or similar assistance systems, and considering the loading/terminal staff or the most recent driver of the vehicle. This entails engaging in consultations with the client and ensuring meticulous adherence to the principles of load security and loading procedures. Strategizing optimal travel paths to mitigate potential hazards resulting from external factors such as inclement weather or road conditions.

The state of the driver must also be considered. Examples include age, monthly health reports, truck driving experience, strategies for avoiding driver distractions, and more. Utilize your phone, GPS, or mobile device only while the car is stationary, and the engine is off.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The MORI algorithm, driver steering input, and vehicle speed are the three fundamental components that provide the foundation of the rollover index methodology. Trucks use this technique as an alternative to measuring lateral acceleration. The efficacy of MORI was evaluated by using the TruckSim driving simulator in conjunction with the Matlab/Simulink program. MORI underwent rigorous testing by executing a range of step-steering maneuvers at different speeds and weights. The data indicate that the MORI reaction exhibits a 39.5% higher rate of reaction compared to the Odenthal reaction. MORI demonstrated not just efficient functionality at high velocities, but also the ability to endure such velocities. This enables MORI to provide a more rapid Time-to-Warn (TTW) and offer the driver sufficient Time-to-React (TTR) to execute evasive actions. This enables the prevention of collisions and accidents caused by rollover incidents.

Using road speed and driver input steering to further improve TTW allows the MORI bus algorithm to reach its full potential. This study found that MORI's fastest TTW was 1.32 seconds. This gives the driver enough time to make any necessary adjustments to the maneuver. If the rollover warning system reacts quickly enough, the driver may be able to prevent the vehicle from rolling over. Therefore, his MORI algorithm, which combines vehicle speed and driver steering input, is the most effective at preventing rollover accidents.

5.2 Recommendations

The MORI algorithm's performance was evaluated using MATLAB/Simulink and DHIL TruckSim, a driving simulator. The evaluation focused on analysing the algorithm's response to variations in vehicle speed and driver steering inputs. The DHIL TruckSim driving simulator was used to accurately replicate a practical truck setup. The MORI method's performance was assessed by using the DHIL TruckSim simulator and MATLAB/Simulink. This enabled the execution of MORI algorithm tests on actual trucks. In order to successfully complete a practical driving examination on an actual truck, it is essential to have access to a facility that is very efficient and prioritises your safety during the test. The objective of this legislation is to guarantee the security of drivers and their possessions.

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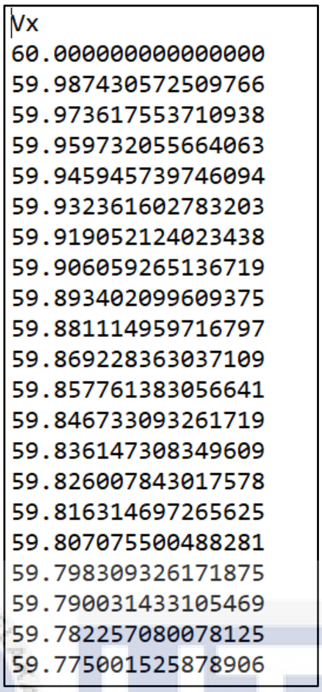
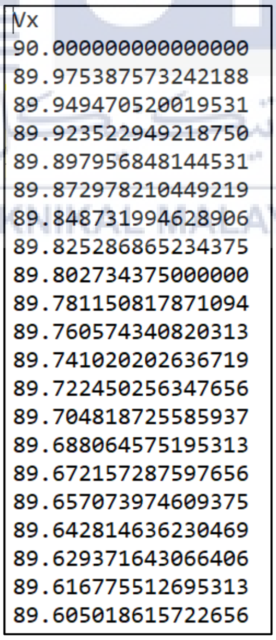
APPENDIX



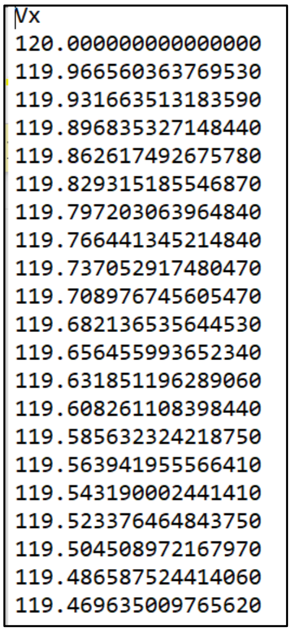
```
Vx
60.000000000000000
59.987430572509766
59.973617553710938
59.959732055664063
59.945945739746094
59.932361602783203
59.919052124023438
59.906059265136719
59.893402099609375
59.881114959716797
59.869228363037109
59.857761383056641
59.846733093261719
59.836147308349609
59.826007843017578
59.816314697265625
59.807075500488281
59.798309326171875
59.790031433105469
59.782257080078125
59.775001525878906
```

Appendix 1 Velocity of 60km/h



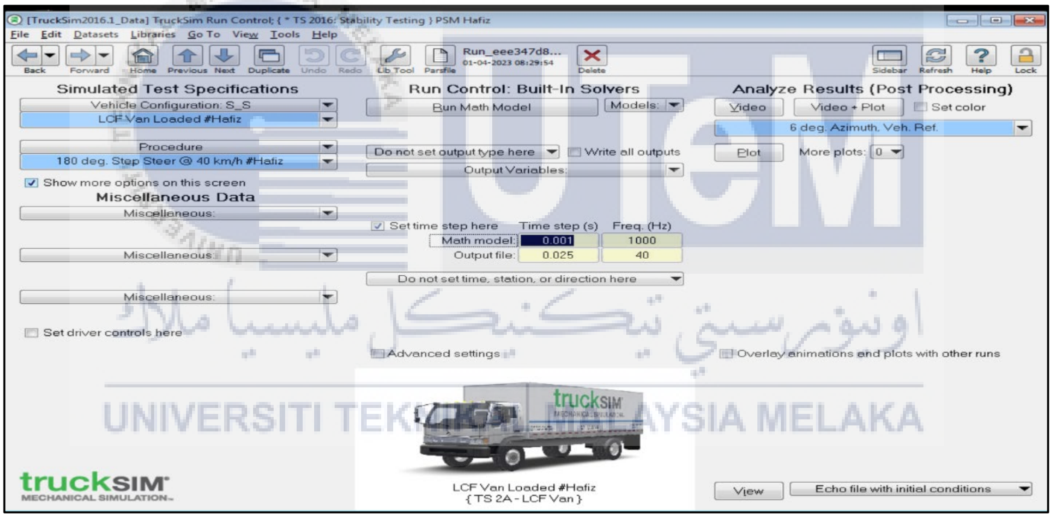
```
Vx
90.000000000000000
89.975387573242188
89.949470520019531
89.923522949218750
89.897956848144531
89.872978210449219
89.848731994628906
89.825286865234375
89.802734375000000
89.781150817871094
89.760574340820313
89.741020202636719
89.722450256347656
89.704818725585937
89.688064575195313
89.672157287597656
89.657073974609375
89.642814636230469
89.629371643066406
89.616775512695313
89.605018615722656
```

Appendix 2 Velocity of 90km/h



```
Vx
120.000000000000000
119.966560363769530
119.931663513183590
119.896835327148440
119.862617492675780
119.829315185546870
119.797203063964840
119.766441345214840
119.737052917480470
119.708976745605470
119.682136535644530
119.656455993652340
119.631851196289060
119.608261108398440
119.585632324218750
119.563941955566410
119.543190002441410
119.523376464843750
119.504508972167970
119.486587524414060
119.469635009765620
```

Appendix 3 Velocity of 120km/h



[TruckSim2016.1_Data] TruckSim Run Control; { * TS 2016: Stability Testing } PSM Hafiz

Run_eee347d8...
01-04-2023 08:29:54

Simulated Test Specifications

Vehicle Configuration: S_S
LCF Van Loaded #Hafiz

Procedure
180 deg. Step Steer @ 40 km/h #Hafiz

☑ Show more options on this screen

Miscellaneous Data

Miscellaneous:

Miscellaneous:

Miscellaneous:

☐ Set driver controls here

Run Control: Built-In Solvers

Do not set output type here
☐ Write all outputs
Output Variables:

☑ Set time step here

	Time step (s)	Freq. (Hz)
Math model:	0.001	1000
Output file:	0.025	40

Do not set time, station, or direction here

☐ Advanced settings

Analyze Results (Post Processing)

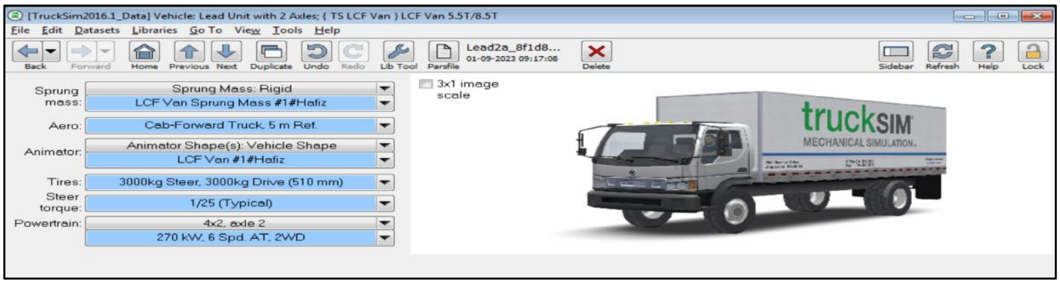
☐ Set color
6 deg. Azimuth, Veh. Ref.
More plots: 0

☐ Overlay animations and plots with other runs

LCF Van Loaded #Hafiz
{ TS 2A - LCF Van }

Echo file with initial conditions

Appendix 4 Trucksim home appearance setting



[TruckSim2016.1_Data] Vehicle: Lead Unit with 2 Axles; { TS LCF Van } LCF Van 5.5T/8.5T

Lead2a_8f1d8...
01-09-2023 09:17:08

Sprung mass: Sprung Mass: Rigid
LCF Van Sprung Mass #1#Hafiz

Aero: Cab-Forward Truck, 5 m Ref.

Animator: Animator Shape(s): Vehicle Shape
LCF Van #1#Hafiz

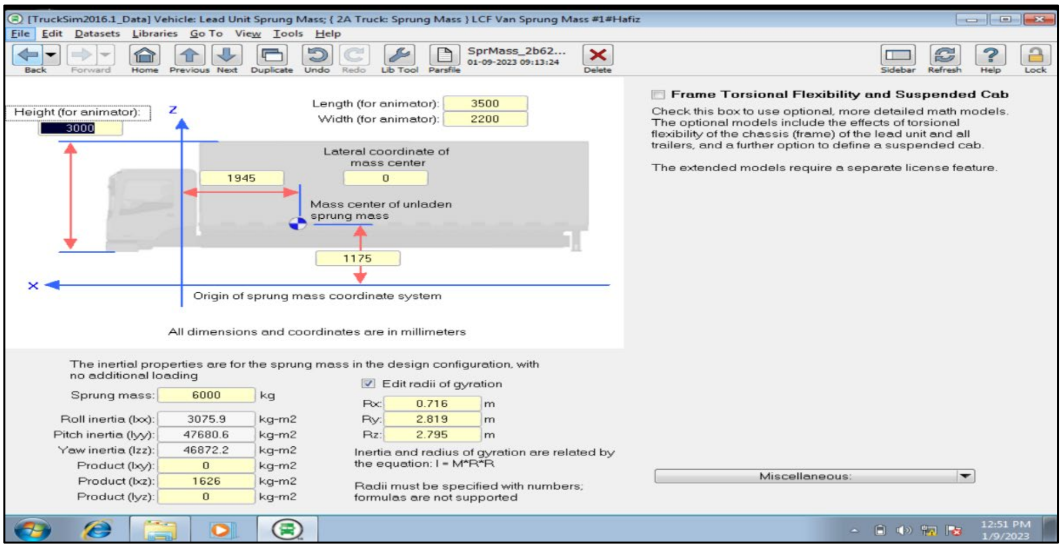
Tires: 3000kg Steer, 3000kg Drive (510 mm)

Steer torque: 1/25 (Typical)

Powertrain: 4x2, axle 2
270 kW, 6 Spd. AT, 2WD

☐ 3x1 image scale

Appendix 5 Vehicle appearance setting



Height (for animator): 3000

Length (for animator): 3500

Width (for animator): 2200

Lateral coordinate of mass center: 0

1945

Mass center of unladen sprung mass

1175

Origin of sprung mass coordinate system

All dimensions and coordinates are in millimeters

☐ **Frame Torsional Flexibility and Suspended Cab**

Check this box to use optional, more detailed math models. The optional models include the effects of torsional flexibility of the chassis (frame) of the lead unit and all trailers, and a further option to define a suspended cab.

The extended models require a separate license feature.

The inertial properties are for the sprung mass in the design configuration, with no additional loading

Sprung mass: 6000 kg

Roll inertia (Ixx): 3075.9 kg-m2

Pitch inertia (Iyy): 47680.6 kg-m2

Yaw inertia (Izz): 46872.2 kg-m2

Product (Ixy): 0 kg-m2

Product (Ixz): 1626 kg-m2

Product (Iyz): 0 kg-m2

☑ Edit radii of gyration

Rx: 0.716 m

Ry: 2.819 m

Rz: 2.795 m

Inertia and radius of gyration are related by the equation: I = M*R*R

Radii must be specified with numbers; formulas are not supported

Miscellaneous:

Appendix 6 Truck interferance setting