

# DESIGN AND FABRICATE ROLLOVER WARNING DEVICE FOR BUS



# BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (AUTOMOTIVE TECHNOLOGY) WITH HONOURS

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Faculty of Mechanical and Manufacturing Engineering Technology



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Bachelor of Mechanical Engineering Technology (Automotive Technology) with Honours

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# DESIGN AND FABRICATE ROLLOVER WARNING DEVICE FOR BUS

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Faculty of Mechanical and Manufacturing Engineering Technology

# UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2022

# **DECLARATION**

I declare that this thesis entitled "Design and Fabricate Rollover Warning Device for Bus" is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



# 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.



#### **DEDICATION**

First of all, I would like to express my gratitude to Allah for providing me with the strength necessary to complete this research and see my thesis become reality. This study and research are dedicated to my beloved parents, Mansi bin Md Arif as well as Hayati binti Muda @ Hamid, 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.

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#### ABSTRACT

Accidents involving bus rollover can be classified as one of the most fatal types compared to other types of vehicle accidents. There are various aspects that lead to occupant injury and fatality. This thesis discusses the design and fabricate of a Rollover Warning Device (RWD) for road vehicles, particularly those with a higher center of gravity height to track width ratio. The RWD use rollover index algorithm to basically learn dynamics of a road vehicle as well as estimate its immediate roll stability of dynamic states of the vehicle. The condition of dynamic roll stability, especially load transfer ratio (LTR), is applied as an input to an RWD based on the rollover index algorithm for the purpose of determining the value of rollover index. The project was developed using computer simulations and proved using testal data. Due to the device's passive nature, which requires the driver to take corrective action, its effectiveness is restricted to assisting with risky moves that build gradually, such as those encountered during on-ramp maneuvers. MatLab software is used to modify and optimize the parameter of the block model of the rollover index algorithm. Meanwhile, TruckSim software is used to analyze the presented rollover trend warning system. This rollover index algorithm is developed based on the fastest time response proposed by previous researchers. The simulation of step steering maneuvers at different velocitys uses the MATLAB/Simulink software to determine the rollover index. As a consequence of the results, it can be concluded that Odenthal's rollover index algorithm gives the fastest rollover index based on the early warning indicator on the vehicle unit. The efficiency of the rollover index needs to be improved by using the Odenthal rollover index algorithm, which was modified and optimized using Particle Swarm Optimization (PSO). Finally, instead of lateral acceleration, a rollover index algorithm is proposed that integrates the modified Odenthal rollover index algorithm with driver steering and vehicle velocity inputs. The modified Odenthal rollover index algorithm's capability is tested by simulating step steering maneuvers at different velocitys and loads using the Hardware-in-the-Loop (HIL) simulation in the TruckSim driving simulator and the MATLAB/Simulink software. The test results show that the modified Odenthal rollover index algorithm provides a driver with a 12.36% faster Time-To-Warn (TTW) than the Odenthal rollover index and an enough Time-To-Respond (TTR) to take corrective measures. Thus, the modified Odenthal rollover index algorithm provided a more effective early warning system that significantly reduces rollover accidents.

### ABSTRAK

Kemalangan yang melibatkan bas bergolek boleh dikategorikan sebagai kemalangan paling bahaya jika dibandingkan dengan jenis kemalangan yang lain. Terdapat pelbagai aspek yang menyebabkan kecederaan dan kematian kepada penumpang. Tesis ini membincangkan reka bentuk dan rekaan peranti golekan amaran (RWD) untuk kenderaan jalan raya, terutama yang mempunyai nisbah pusat graviti yang tinggi hingga nisbah lebar yang lebih tinggi. RWD menggunakan algoritma indeks golekan untuk asasnya mempelajari kenderaan jalan raya yang dinamik dan juga menganggarkan kestabilan golekan segera terhadap keadaan dinamik kenderaan. Keadaan kestabilan golekan dinamik, terutamanya nisbah pemindahan beban (LTR), diaplikasikan sebagai input ke RWD berdasarkan algoritma indeks golekan untuk tujuan menentukan tahap kepekaan output. Projek ini dibangunkan menggunakan simulasi komputer dan dibuktikan dengan menggunakan data eksperimen. Oleh kerana sifat pasif peranti ini, yang memerlukan pemandu untuk melakukan tindakan pembetulan, keberkesanannya adalah terhad untuk membantu pergerakan berisiko yang berkembang secara beransur-ansur seperti yang dihadapi semasa pemanduan di jalan. Perisian Matlab digunakan untuk mengubah dan mengoptimumkan parameter blok model algoritma indeks golekan manakala perisian TruckSim digunakan untuk menganalisis sistem ramalan yang cenderung untuk bergolek. Algoritma indeks golekan ini dikembangkan berdasarkan tindak balas daripada masa terpantas yang dicadangkan oleh penyelidik sebelumnya. Simulasi pemanduan stering berperingkat dengan pelbagai kelajuan telah dijalankan menggunakan perisian MATLAB/Simulink bagi mendapatkan indeks golekan. Berdasarkan permerhatian daripada keputusan simulasi, ianya boleh disimpulkan bahawa algoritma indeks golekan yang telah dicadangkan oleh Odenthal menghasilkan indeks golekan yang paling pantas berdasarkan kepada pengesanan amaran awal pada unit kenderaan. Kecekapan prestasi indeks golekan ditambah baik dengan menggunakan algoritma indeks golekan Odenthal yang telah diubahsuai dan dioptimumkan menggunakan Pengoptimuman Kawanan Zarah (PSO). Akhirnya, selain dari pecutan sisi, algoritma indeks golekan telah dicadangkan dengan mengintegrasikan algoritma indeks golekan Odenthal yang diubahsuai dengan masukkan stering pemandu dan halaju kenderaan. Prestasi algoritma indeks golekan Odenthal yang diubahsuai diuji secara simulasi yang melibatkan pemanduan stering berperingkat, dengan pelbagai kelajuan dan beban melalui penyelakuan Hardware-in-the Loop (HIL) dalam simulator pemanduan TruckSim dan perisian MATLAB/Simulink. Hasil keputusan eksperimen menunjukkan bahawa algoritma indeks golekan Odenthal yang diubahsuai menghasilkan masa-untuk-amaran 12.36% lebih pantas berbanding indeks golekan Odenthal kepada pemandu dan menawarkan masauntuk-bertindak yang mencukupi untuk memulakan pergerakan pembetulan. Oleh itu, algoritma indeks golekan Odenthal yang diubahsuai mencadangkan sistem amaran awal yang lebih baik dan boleh mengurangkan kemalangan golekan dengan lebih berkesan.

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# LIST OF SYMBOLS AND ABBREVIATIONS

ABC	-	Artificial Bee Colony
ABS	-	Anti-lock Braking System
ACO	-	Ant Colony Optimization
ADKEY	-	Ad Port
AS	-	Ant System
COPs	-	Combination Optimization Problems
CPU	-	Central Processing Unit
DHIL	-	Driver-Hardware-in-the-Loop
ESC	- 11	Electronic Stability Control
GA	and the second s	Genetic Algorithm
GND	E.	Ground
GSA	1	Gravitational Search Algorithm
HIL	Ten a	Hardware-in-the-Loop
LTR		Load Transfer Ratio
MIROS	ملاك	Malaysian Institute of Road Safety Research
MORI	_	Modified Odenthal Rollover Index
NHTSA	UNIVE	National Highway Traffic Safety Administration
No.	-	Number
NRP	-	Network Routing Problem
PSO	-	Particle Swarm Optimization
RI	-	Rollover Index
RSC	-	Roll Stability Control
RSF	-	Roll Safety Factor
RWD	-	Rollover Warning Device
SIL	-	Software-in-the-Loop
SOP	-	Sequential Ordering Problem
SPK	-	Speaker
SSF	-	Static Stability Factor
SUV	-	Sport Utility Vehicle

TSP	-	Traveling Salesman Problem
TTW	-	Time-To-Warn
TTR	-	Time-To-Respond
VCC	-	Voltage Common Collector
WHO	-	World Health Organization
YSC	-	Yaw Stability Control



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#### **CHAPTER 1**

#### **INTRODUCTION**

## 1.1 Background

In this current situation around the world, the statistics of road accidents are increasing day by day even though the latest technology related to vehicle safety is still growing well. Accidents on the highway are things that won't go down because they always happen every day. Statistics from the World Health Organization (WHO) have reported more than 1.17 million deaths every year worldwide and 20 to 50 million are injured by road accidents. In addition, what's more balanced is that the majority involved in the accident are adolescents between the ages of 5 and 29. Every year, 1.17 million deaths are caused in traffic crashes which contribute for 70% of the total. Pedestrians are involved in 65% of deaths with children contributing for 35% of those killed and around 23 to 34 million people are involved in traffic accidents around the world as per estimates. That is almost twice as many as was currently estimated. It is estimated that more than 200 United State people die each year as a result of road fatalities abroad. Besides that, in Europe, more than 50,000 people are killed in traffic crashes, and then another 150,000 are injured. Meanwhile, the overall number of road injuries in Malaysia exceeded 223,000 in 1999 who 16 peoples were killed in traffic accidents according to (Kareem, 2003).

In Malaysia, road accident involves buses was one of the most accident happened at road too. Around 2007 and 2010, 47% of MIROS-investigated incidents resulted in deaths, with fatalities of 1 until 3 people being the most popular, and accidents involving minor

injuries contributing for at least 22%. From this statistic, express buses have the greatest traffic accidents and deaths and as compared to other types of routes, highways have a higher accident rate. From the journal have stated that the main cause of mechanical failure among all types of vehicle buses was reported as brake breakdown, for around 56% of overall mechanical failure, and about 52% of all commercial buses were involved in traffic accidents with an average annual of 3.8 accidents per commercial bus according to (Kareem, 2003).

There are several reasons that caused accident that happened on road such as plays gadget while driving, drunkenness, change routes without signaling, driving at high velocity, violate the red light, rollover during cornering and many more. Among all of these factors, there is one factor contributes to road accident which is rollover.

According to (Matolcsy, 2007), the most serious bus crash is rollover incident. According to injury figures collected by the author from over 300 incidents, the total casualty rate is 25 accidents. In a rollover, four main injury mechanisms can endanger the occupants which are penetration, projection, absolute and partial ejection. To prevent these types of accidents, various methods of safety can be used. The seriousness of a rollover crash can be specified in two ways which are dependent on the number of victims, and the other evaluates the circumstances of the rollover.

## **1.2 Problem Statement**

A rollover involves of any vehicle rolling over a true longitudinal or lateral axis of 90° or more referring to Figure 1-1 below. A rollover occurs as a vehicle loses control on two wheels and moves to one side. Any vehicle may be affected, but those with a high vertical profile, such as heavy trucks, SUVs, and buses, are at a much higher risk. A few factors such as sudden steering, drastic path changes, or rapid curves at high velocitys may

cause a vehicle's Center of Gravity to shift it to the side and turn while for a bus with too much weight will becomes an even greater possibility to rollover.



Figure 1-1 Axis of Motion and Movement (Bae et al., 2019)

According to (Oluwole et al., 2015), statistics obtained from the Malaysian Institute of Road Safety (MIROS) for the period 2003 until 2012 regarding bus accidents, 47 % of cases investigated by MIROS during 2007 and 2010 lead to death, with death rates of one until three victims being the most frequent, and cases with minor injuries having at least 22 %. Meanwhile, express and single deck buses have the highest crash and death rates at highway.

Besides that, the National Highway Traffic Safety Administration (NHTSA) reports around 280,000 rollover accidents (NHTSA Rollover Ratings) every year. In 2004, 31,693 occupants of passenger vehicles were killed in car accidents, with 10,553 of those killed due to rollovers (Strashny & NHTSA, 2007). Indirectly, these patterns highlight the importance of researching rollover prevention and safety in today's society.

Rollover can happen only if some factors lead it to roll. One of the factors that contributed to rollover is human error or human behavior. Referring to Figure 1-2, human error is responsible for more than 80% of traffic accidents (Fai, 2015).



Figure 1-2 Malaysia Road Accident Factor from Malaysian Institute of Road Safety (MIROS) (Fai, 2015)

As a result, from the statistic above, to reduce the human error factor which contributes to rollover, vehicle assistance device is proposed by introducing the rollover warning device. This rollover warning device is to generate an early warning to the driver which helps the driver able to have an appropriate time to correct the maneuvering. Therefore, it will help to prevent the road accident. According to (Yu et al., 2013), it is expected that approximately 42 % of accidents may be prevented if the vehicles had been installed with a warning system that could assist drivers to drive buses in an appropriate manner before to a rollover. Current rollover warning device are used the output response, which the rollover algorithm and index can be identified. By using the output response as an input to the rollover algorithm, it is too late for the driver to perform the corrective action because the vehicle is tending to rollover. Once the vehicle tends to rollover, it will continuously to roll. The probability of a bus or coach rolling over is assessed using a real-time rollover prediction algorithm. Thus, this study will propose a new approach by using steering input and vehicle velocity response.

# **1.3** Research Objective

The main aim of this research is to design and fabricate rollover warning device for bus. Specifically, the objectives are as follows:

- a) To modify the rollover index algorithm for bus.
- b) To optimize the parameters of the modified rollover index algorithm for bus.
- c) To design and fabricate rollover warning device for bus.

## 1.4 Scope of Research

The scopes of this research are as follows:

- The rollover index algorithm is developed based on the fastest time response propose by previous researches.
- The selected rollover index algorithm is modified in order to improve the capability of the rollover warning system.
- The rollover index algorithm for bus is proposed by employing a modified **UNIVERSITITEKNIKAL MALAYSIA MELAKA** rollover index algorithm with vehicle velocity and driver steering input and optimize using particle swarm optimization (PSO).
- The rollover warning device is design and fabricate using a microcontroller.

### **CHAPTER 2**

### LITERATURE REVIEW

#### 2.1 Early Warning Indication

Safety is very important either on vehicle or occupant. However, they still need to be careful of human error factor such as driving recklessly, fatigue while driving, and unconcerned about environment. These errors may lead the vehicle tend to rollover. According to (Tian et al., 2018), bus rollover is a major source of concern for bus manufacturing companies as well as traffic authorities when it comes to traffic accidents. In order to address this issue, researchers and engineers have designed a variety of rollover avoidance devices. In contrast, once the phase of an oncoming rollover has begun, there is lack of time for the actuators to react appropriately, specifically in severely harmful cases. In order to avoid bus rollover issues, it is necessary to be able to estimate the rollover probability in advanced and to calculate an appropriate time. So that, rollover early warning indicator are important to alert the driver before either one of the vehicle tire start to lift up and then rollover occurs.

#### 2.2 Rollover Index

Rollover is an incident of vehicle collision in which a vehicle turns over onto its left or right side or roof. It is involves of any vehicle rolling over a true longitudinal or lateral axis of 90° or more. Rollovers are more likely to result in death than other forms of vehicle incidents. The characteristics of large vehicles itself contributed to their poor roll stability and tendency to rollover accidents. Vehicle rollover accidents are serious traffic accidents that result in loss of life and property, and they have become a major concern impacting transportation security.

## 2.2.1 Types of Vehicle Rollover

The National Highway and Traffic Safety Administration (NHTSA) classifies rollovers based on their origin There are some factors are included in the classifications such as turn-over, flips-over, climb-over, end-over-end, and bounce-over (Amirul Affiz, 2014).

Turn-over factor occurred when a vehicle performs quick turns as well as the centrifugal forces created by the turning is countered by normal surface friction, then vehicle roll in the manner seen in Figure 2-1.



Figure 2-1 Centrifugal Force Countered by Normal Surface Friction Causes the Vehicle to Turn Over (Amirul Affiz, 2014)

Flip over factor is when a vehicle comes into contact with an incline like object, such as the rear slope of a river or a downed guardrail, the vehicle rotates about its longitudinal axis. Figure 2-2 illustrates car flip-overs.



Figure 2-2 Vehicle Flip Over (Amirul Affiz, 2014)

When a car crosses over a big fixed object, such as barrier or railing, and the item is sufficiently large and tall to lift the automobile off the ground, as indicated in Figure 2-3, the climbs over factor occurs.



End over end factor is when a vehicle's lateral axis is roll. This can occur when a vehicle applies a rapid break and the load is shifted to the front. The vehicle is seen rolling on its axis in Figure 2-4.



Figure 2-4 Vehicle Rolls on its Lateral Axis (Amirul Affiz, 2014)

Bounce over factor is when a vehicle flips over after rebounding off a fixed obstacle.

As seen in Figure 2-5, the rollover must occur near to the static obstacle.



Figure 2-5 Vehicle Bounce Over After Reflect With a Static Obstacle (Amirul Affiz, 2014)

# 2.2.2 Types of Rollover Index

According to (Phanomchoeng & Rajamani, 2013), vehicle rollovers are classified into two types which are tripped which illustrated in Figure 2-6 and untripped which illustrated in Figure 2-7. Tripped rollover happen when the vehicle's tire contacts with an object, causing the vehicle's lateral motion to immediately stop and the vehicle to roll around that obstacle. Tripping obstacles are typically curbs, rocks, soils, and ramps. Meanwhile, untripped rollover is caused by steering input, velocity, and ground friction. Extreme steering maneuvers such as J-hooks, rapid turns, and fast lane changed contributed significantly to this collision. This event is unlike form tripped because a rollover happens in the absence of a trip item and is characterized by a rapid shift in center of gravity position. Existing rollover indices on the other hand are optimized for untripped rollovers and have difficulty detecting tripped rollovers. On the other hand, it still stated the same thing which an existing rollover index is based on lateral acceleration measurements and can identify only untripped rollovers caused by a sudden turn's high lateral acceleration. It is unable to identify tripped rollovers caused by external inputs like as forces generated when a vehicle collides with a curb or a road bump (Phanomchoeng & Rajamani, 2013). This statement also supported by (Kazemian et al., 2017) which stated that the standard rollover indices now used in vehicles can only identify untripped rollovers caused by excessive lateral acceleration. These indices are incapable of detecting a tripped rollover caused by vertical external forces extending in a long distance.



Figure 2-7 Untripped Rollover (Phanomchoeng & Rajamani, 2013)



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

There are several aspects that contribute to these vehicles rollover, including maneuver variation, driving situation, road condition, vehicle geometry, and vehicle capability. To trace a rollover, it is important to construct an index or scale for determining the automobile's stability. The index enables the controller to make judgments about the probability of rollover and to provide the relevant command according to (Peters, 2006). Each one of the indices is derived using input data from sensors and the vehicle's dynamic condition. It is required to calculate the value by comparing it to some established programmed values used as rollover limitations. There are two rollover indices which are static roll instability and dynamic roll instability.

The vehicle rollover index is a real time variable that may be used to identify when a wheel rises off the ground. The rollover index is defined in its simplest form as follows:

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

 $F_{zr}$  as well as  $F_{zl}$  are the vertical forces produced by the right as well as left tires respectively. When the vehicle is on the approach of rolling over, the index value is bigger

than or equal to 1. Furthermore, while the car is travelling straight, the  $F_{zr}$  and  $F_{zl}$  values are similar, and the rollover value is zero. Assuming  $F_{zl}=0$ , R=1, and the car is just on the right tire on the surface. Since the forces are not measured, the relation 2.1 cannot be applied. Researchers have made several attempts to retrieve the indices. Numerous efforts resulted in a lateral acceleration and untripped rollover index. The rollover index R may be calculated using a formula based on  $\phi$  and  $a_y$ .

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

Where  $m = m_s + m_u$ ,  $h_R$  is the height of center gravity  $m_u$  is the unsprung mass,  $m_s$  is the sprung mass,  $a_y$  is the lateral acceleration, and  $\phi$  is the rotation angle. This rollover index can be used simply for the purpose of detecting untripped rollover. Due to the difficulty of determining roll angle, several research calculated the rollover index solely on the basis of lateral acceleration (Odenthal et al., 1999). Stability control with this index may restrict the vehicle's ability to drive laterally and is also incapable of detecting rollover caused by vertical forces and road inputs.

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

The acceleration of sprung mass is also evaluated independently in the commercial form of the index (Phanomchoeng & Rajamani, 2013).

$$R_{3} = \frac{2m_{s}a_{y}h_{R}}{mgL_{w}} + \frac{2m_{s}h_{R}\tan(\phi)}{mL_{w}} + \frac{m_{u}(\ddot{z}_{ur} - \ddot{z}_{ul})}{mg}$$
(2.4)

Where  $(\ddot{z}_{ur} - \ddot{z}_{ul})$  is the difference between the acceleration of unsprung masses.

#### 2.2.3 Static Roll Instability

Some rollover indices (RIs) have been proposed to improve in detecting of rollover. Rollover measurements were initially developed using static or steady state rollover models according to (M H Harun et al., 2020). The Static Stability Factor is a well-known as static rollover index (SSF) and defined as the ratio of the vehicle's half-track to the center of gravity's height (CG) based on (Lapapong, 2010). This metric is described in terms of the geometric parameters of the vehicle. Additionally, several sources recommended revising this static RI to add suspension effects according to (Czechowicz & Mavros, 2014). The other recommended static RIs, such as the Side Pull Ratio and Tilt Table Ratio based on (Lapapong, 2010), are testally determined and are extremely close to the SSF.

However, according to (Dilich, 1997), the initial and most basic measure of a vehicle's inherent potential to overturn, which is often determined under static test circumstances, is called the static stability factor (SSF). It may also be used as an index in roll angle to identify rollover, however it is not employed as a stand-alone index and is often employed as a supplemental feature based on (Hsu & Chen, 2012).

# 2.2.4 Dynamic Roll Instability

Meanwhile, according to (Ataei et al., 2019), to improve the accuracy of rollover indicators in various conditions, several dynamic RIs including vehicle conditions are also proposed. Simple indicators generally use one of the vehicle's critical rollover states as the dynamic indication of rollover risk, such as lateral acceleration (Bo Chiuan Chen et al.,

2011), roll angle (Schofield et al., 2006), or roll rate (Beal & Gerdes, 2010). The lateral load transfer ratio (LTR) is another important RI that is commonly required in dynamic settings.

Other than that, the index lateral load transfer is another index that is defined by the forces between the tire and the road. The index is calculated by comparing the vertical forces of the left and right tires and actuating the controller if the difference exceeds a certain limit according to (R. Rajamani et al., 2009).



**Implementation and Testing** 2.3

There are two simulation were used for implementation and testing which are Hardware in the Loop (HIL) and software In the Loop (SIL). Hardware In the Loop (HIL) and Software In the Loop (SIL) solutions enable you to test your created solutions through simulations of real-world scenarios. Their utilization velocitys up development and improves quality control, while decreasing the attraction of physical prototypes and tests.

#### 2.3.1 Software In the Loop

Software In the Loop (SIL) is unit tests are performed on the code that will be applied to identify and repair system-level errors such as code generation validation. Simulating Software In the Loop (SIL) can be accomplished at the early phases of software development. It enables the execution of tests earlier to the availability of hardware, hence detecting faults (Ben Ayed et al., 2017). The benefit using software-in-the-loop modeling is that it enables pre-production testing of designs. The vehicle's dynamics generally simulated within the same vehicle programmed, based on the vehicle's characteristics. This approach is incredibly cost-efficient and effective for establishing a design's overall behavior and attributes. The accuracy of the findings given by comprehensive computer models, on the other hand, is highly relate on the model type and supporting data (Steven Robert O'Hara, 2005).

## 2.3.2 Hardware In the Loop

Hardware In the Loop is control laws connected to the simulation environment, and occasionally a genuine mechanical component in order to verify the equipment's control implementation, response time, and validation of integration. Hardware In the Loop eliminates the problems and inaccuracies appeared in developing the computer-based vehicle model by focusing on the vehicle's input commands and output outcomes. The most benefit for Hardware in the Loop testing is that it eliminates driver involvement and subjectivity by evaluating the vehicle hardware directly. By testing the hardware directly, no mathematical model of a vehicle is required, which might bring mistakes into the test (Steven Robert O'Hara, 2005).



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

#### 2.3.3 Implementation and Testing in Vehicle

According to (Svenson & Grygier, 2009) based on heavy truck, the Hardware In the Loop (HIL) method developed designed to explore the instability of heavy trucks owing to loss of control or rollover conditions with and without Electronic Stability Control (ESC) or Roll Stability Control (RSC) system for a variety of maneuvers and velocitys. The validation results indicate that the HIL's vehicle dynamics as well as hardware reactions are equivalent to those of real heavy truck test tracks, which can help identify the effectiveness of stability control systems in a variety of driving circumstances. In general, the qualitative differences between HIL simulations with test track tests were insignificant. Based on the fact as the HIL system generates correct predictions, this simulation environment can also be utilized to accurately investigate the behavior of heavy vehicles equipped with these technologies.

Including the HIL simulation, a Software In the Loop (SIL) simulation being conducted, during which Simulink control algorithms for both the Anti-lock braking system (ABS) as well as Electronic Stability Control (ESC) was created. Roll Stability Control (RSC) as well as Yaw Stability Control (YSC) are the two modes of operation of an ESC system (YSC). The roll stability mode is addressed in an ESC control system model presented in this thesis. The roll stability control monitors the bus combination's lateral acceleration and, if it exceeds a predetermined or fixed critical value, takes corrective action by using individual brakes or lowering engine torque. The yaw stability control detects and calculates the combination's yaw rate and body slip angle. When the body slip angle and vehicle slip rate surpass a certain value, the yaw stability control applies differential braking to either the steer or drive axle, depending on whether the combination of understeer or oversteer. This type is enhanced with just an ABS control module that regulates the ESC module's braking pressure in order to minimize wheel locking (Rao & Member, 2013).

#### 2.4 **Optimization Tools**

Nature-inspired computing has been recognized for its efficiency and durability in addressing complex nonlinear problems throughout the last few decades. Natural computing is a discipline that arose from or was taken from nature concept, resulting in the creation of novel computational tools of problem solving (de Castro, 2007). Nature-inspired algorithms including particle swarm optimization (PSO), gravitational search algorithms (GSA), genetic algorithms (GA), and ant colony optimization (ACO) have been investigated in a wide variety of fields, including medicine, finance, engineering, economics and biology. Throughout the years, this algorithm has been used to address a variety of nonlinearity problems that could not be handled using traditional ways.

#### 2.4.1 Particle Swarm Optimization (PSO)

According to (El-Shorbagy & Hassanien, 2018), Particle Swarm Optimization (PSO) is widely recognized as a swarm intelligence concept. PSO is connected with the research of swarms because it functions as a bird flock simulator. It is applicable to a wide variety of optimization problems, including limited optimization, constrained optimization, unconstrained optimization, multi-objective optimization, nonlinear programming,

combinatorial optimization and dimensional arrangement. Particle Swarm Optimization (PSO) is a type of evolutionary computational algorithm that is based on the swarm's intelligence. Based on (Kennedy', 1995) suggest it as a result of their study on artificial biological systems. Additionally, this is a population optimizer. The PSO process is initiated by randomly initializing a collection of possible solutions, and then repeatedly searching for the optimum.

The PSO algorithm determines the best location by following the best particles. In comparison to other algorithms, PSO also has rich intelligent history that enables it to be done more simply. Due to the advantages of PSO, it is well suited for scientific study as well as big challenges such as evolutionary computing, optimization, and a variety of other applications. PSO is a type of swarm intelligence used to address global optimization issues. In other words, PSO is related with artificial life, namely with swarming theories, social behavior modeling, and also with other algorithms. Besides that, PSO is simple to construct, computationally inexpensive, and requires little memory and CPU capability. Additionally, it does not require additional information more about objective function, such as the gradient, but just the value of the objective function. It has been demonstrated that PSO is a successful approach for resolving a wide variety of global optimization issues and, in certain circumstances, avoids the challenges encountered by other algorithms.

### 2.4.1.1 The Basic of PSO

To illustrate the PSO, consider a swarm of bees flying through an open area filled with wildflowers. The swarm's natural instinct is to seek for the largest density of blooms in this field. The swarm is unfamiliar with the field. As a result, the bees begin their quest and split in random areas. Each bee can recall the sites with the most flowers, and this knowledge may be sent to the remainder of the swarm via communication. Then, the bees are divided between returning to their prior successful flower-finding position and travelling to the place which have the most flowers reported by the remainder of the swarm. The hesitant bee goes in both directions, rerouting its flight route to fly anywhere between the two places depending on who social influence has a greater impact on its choice or not. Occasionally, a bee could fly over an area of the field that contains more flowers than any other bee in the swarm observed. Then, the entire swarm would be dragged in that direction as a component as Figure 2-11. The dashed lines in the illustration represent the routes of our fictitious bees, while the solid arrows represent the two velocity vector elements. The bee No.2 was discovered to be at the global best position. While bee No.1 has discovered one element of his velocity vector which is its personal best location, bee No.2 has discovered the other component of his velocity vector (its global best location). The bee No.3 demonstrates that even if a particle does not obtain a successful personal best, it is nevertheless pulled to the global best position. The field is therefore examined by the bees, who adjust their pace and direction of movement in response to their success in locating flowers in compared to the rest of its swarm. They are constantly checking for areas to avoid that have the lowest concentration of flowers in the hope of finding the largest concentration. Finally, the bees will have visited every location in the field and will swarm around the location with the highest flower concentration. Kennedy and Eberhart (1995a) described the behavior of PSO in a software program using a model. After that, they quickly realized that their model might be evolved into an optimization method and uses the word PSO. The phrase "particle" refers to fish, bees, birds, or any other sort of natural entity that exhibits swarming behavior based on (El-Shorbagy & Hassanien, 2018).


Figure 2-11 Simulation of PSO by Swarm of Bees Searching for Flowers (El-Shorbagy & Hassanien, 2018)

# 2.4.1.2 PSO Algorithm (PSOA)

The following are the specifics of the PSOA. If p birds or particles form a swarm, each particle represents a potential point (solution) inside the problem space Initially, (Eberhart et al., 2001) suggested that the position xi, for each particle I evolves as follows:

$$x_{k+1}^i = x_k^i + v_{k+1}^i \tag{2.5}$$

Hence the velocity  $v^i$  of the object is determined as follows:

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$$v_{k+1}^{i} = v_{k}^{i} + c_{1} \times r_{1} \times (p_{k}^{i} - x_{k}^{i}) + c_{2} \times r_{2} \times (p_{k}^{g} - x_{k}^{i})$$
(2.6)

The subscript k denotes a time increment.  $p_k^i$  denotes the particle's *i* best position at time k thus far, whereas  $p_k^g$  denotes the swarm's global best position at time k.  $r_1$  and  $r_2$ represent two random integers in the range 0 to 1.  $c_1$  and  $c_2$  are the cognitive as well as social scaling factors, respectively, which are chosen so that  $c_1=c_2=2$ , resulting in a mean of one after multiplied with  $r_1$  and  $r_2$  (Eberhart et al., 2001). When these values are used, the particles overshoot the target in half the time. Equation (2.6) is being used to calculate the *ith* particle's new velocity  $v_{k+1}^i$  at time k, whereas equation (2.5) calculates the *i*-*th* particle's new location  $x_{k+1}^i$  by adding the latest velocity  $v_{k+1}^i$  to its present location  $x_k^i$ . The update of the velocity as well as position of PSO particles in two-dimensional space is illustrated in Figure 2-12. The particle i's best fitness value labeled at  $p_k^i$  as  $f_{best}^i$  as well as the particle *i*'s best fitness value at  $p_k^g$  as  $f_{best}^g$ .



Figure 2-12 Update Velocity and Position of PSO in Two-Dimensional Space (El-Shorbagy & Hassanien, 2018)

# 2.4.2 Gravitational Search Algorithm (GSA)

According to (Sabri et al., 2013), the Gravitational Search Algorithm (GSA) represents a relatively new example of a nature-inspired algorithm capable of solving optimization issues. GSA is motivated by Newton's laws of gravity and motion. GSA has been modified for parameter optimization, setting optimization, strategy optimization, cost optimization, voltage control, and even power dispatch. Additionally, the technique has been developed to optimize controller, software, antenna, and micro grid architecture. The algorithm is classified as a population-based strategy since it is composed of many masses. The masses then sharing information based on gravitational pull in order to steer the search to an ideal location in the search area. According to (Rashedi et al., 2009), it is based on Newton's law of gravity. Among all the particles, the larger and closer particles have a

greater influence. On the other hand, increasing the distance between the two particles reduces their gravitational attraction.

Based on GSA capabilitys, there are still other applications and domains in which GSA might be used, including medical, military, financial, and economics. GSA is still in its development at the moment of typing, and its limitations are unknown. The method still needs to get improved and expanded into previously unexplored sectors, since GSA has a significant potential for solving a variety of optimization issues.

### 2.4.3 Genetic Algorithm (GA)

Genetic Algorithms are one strong search tool based on natural selection as well as natural genetics that has been successfully applied to a wide variety of issues in a variety of fields. Due to these algorithms' great endurance to high-complexity issues, they have found a growing number of applications in the disciplines of artificial intelligence, numeric as well as combinatorial optimization, business, managing, medical, computer science, and engineering according to (Chande & Sinha, 2014).

GAs operates on a population of "individuals," each of which represents a potential solution to a particular problem. Each participant is given a "fitness score" based on how well they solve the challenge. Individuals who are physically healthy are provided opportunities to "reproduce" through "cross breeding" with other members of the population. This results in the birth of new individuals known as "offspring," who share certain characteristics with each "parent." The population's least fit individuals are less likely to be selected for reproduction and therefore "die out" (Busetti, 2018).

Genetic Algorithms excel at traversing enormous, perhaps infinite search areas in search of optimal combinations of elements as well as solutions that humans may never discover. The application of genetic algorithms on huge and frequently complicated computing problems has resulted in several new applications across a range of fields. They have developed very effective, high-quality solutions to complex practical issues in a wide number of sectors.

# 2.4.4 Ant Colony Optimization (ACO)

Ant Colony Optimization (ACO) is a metaheuristic which is higher level procedure for resolving difficult combinatorial optimization problems. ACO is inspired by the pheromone or scent trail laying as well as following behavior of actual ants, who communicate via pheromones. In a similar fashion to the biological version, ACO is built on indirect communication among a colony of simple agents called (artificial) ants, which is mediated via (artificial) pheromone trails. In ACO, the pheromone trails operate like a distributed, numerical information resource that the ants apply to probabilistically create solutions to the problem at hand and the ants change during the algorithm's execution to reflect the search experience (Dorigo & Stützle, 2010).

According to (Abdullah & Tajudin, 1991), Ant Colony Optimization (ACO) is a metaheuristic based by the behavior of actual ant colonies. It is one of the more recent metaheuristic approaches presented. Ant Colony Optimization is a recently suggested metaheuristic motivated by the behavior of actual ant colonies. It enables ants to discover the shortest path among food sources as well as their nest. Ants release a material called pheromone mostly on ground when they move from foods to nest and vice versa.

# **CHAPTER 3**

### METHODOLOGY

# 3.1 Introduction

In general, rollover occurred when a sort of vehicle collision in which a vehicle turns over onto its side or roof. It is involves of any vehicle rolling over a true longitudinal or lateral axis of 90° or more. Once the phase of an oncoming rollover has begun, there is lack of time for the actuators to react appropriately, specifically in severely harmful cases. In order to avoid bus rollover issues, it is necessary to be able to estimate the rollover probability in advanced and to calculate an appropriate time.

Therefore, a rollover warning device is design and fabricates to overcome this accident problem. Its function is to give an early warning to the driver before the vehicle tends to rollover. It is design by using MATLAB Simulink to predict what will happen if some external output is acting on it.

# 3.2 Project Flowchart Process



Figure 3-1 Project Flowchart Process

# 3.3 Gantt Chart

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		WEEKS OF STUDY														
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	INTRODUCTION															
	1.1 Background															
	1.2 Problem															
2	Statement															
2	1.3Research	4														
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	3.1 Introduction															PROF
	3.2 Project Process															
4	Flowchart															
	3.3 Gantt Chart															
	3.4 Software In the															
	Loop															

Table 3.1 Gantt Chart

	SEMESTER (PSM 2)															
		WEEKS OF STUDY														
	3.5 Hardware In the															
	Loop															
	3.6 Odenthal															
	Rollover Index															
	Algorithm															
	3.7 Modified															
	Rollover Index															
	Algorithm for Bus															
	3.8 Particle Swarm															
	Optimisation (PSO)															
	3.9 Simulation	- 4	÷.,													
	Setting		CP R													
	3.10 The Test of a								1				T			
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	3.13 Limitation															
5	RESULT AND															
5	DISCUSSION															
	4.1 Introduction															
	4.2 Capability of the															
	Modified Odenthal															
	Rollover Index															
	Algorithm															
	CONCLUSION AND															
6	RECOMMENDATION															
	S															

SEMESTER (PSM 2)													
		WEEKS OF STUDY											
5.1 Conclusion													
5.2													
Recommendations													
LOGBOOK													

### **3.4** Software In the Loop (SIL)

Algorithm input will apply to software in the loop using TruckSim driving simulator as illustrated in Figure 3-2. Types of vehicle, speed, steering angle data need to be inserted into the TruckSim driving simulator software. After that, the TruckSim driving simulator will generate the input which, is steering input,  $\delta$ , and vehicle velocity, v. These two parameters will become the input for rollover index algorithm at the second block. The rollover index algorithm will apply at Matlab/Simulink software which produce the rollover index value. Evaluation either the vehicle already tends to rollover or not can be identifying from this value. When the vehicle is on the approach of rolling over, the index value is bigger than or equal to one. Once the value is greater than one, the speaker will produce sound, and the LED set will light up.



Figure 3-2 Algorithm Input Applied at Software In the Loop

### **3.5** Hardware In the Loop (HIL)

Rollover prediction can be evaluated by using simulation TruckSim software. TruckSim Software is used to get the real vehicle simulation as well as output graph to compare with the MATLAB Simulink software output graph. A set of block model is being setup first for rollover index parameter before applied to the Arduino UNO board. Next, those components are setup as below.

Based on the flowchart Figure 3-3 below, it is shown that the sketching of the rollover warning device is based on the required dimension. Each component is measured, and holes are drilled based on a specific measurement. Each soldered component and jumper was appropriately connected. Trigger output components, LED set and speaker were connected to the device. The final product is as below with three toggle switches and bulbs that indicate unladen, half-laden, and laden. At the same time, the LED set will light up when the velocity and driver steering input meet the requirement set up, which is when the rollover index crosses the RSF 0.75, the LED set will light up.



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Figure 3-3 Design and Fabricate Rollover Warning Device

# 3.6 Odenthal Rollover Index Algorithm

(Odenthal et al., 1999) generated the rollover index algorithm from the vehicle rollover model. The vertical tire force are represented by  $F_{Z,L}$  and  $F_{Z,R}$ , approximately. The rollover index RI is calculated by balancing the vertical load and roll movements. As a result, RI is shown as

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

Where  $F_{Z,L}$  represent the left side tire force while  $F_{Z,R}$  represent the right side tire force. Therefore,  $RI = RI_{Odenthal} = \frac{2m_2}{mT} \left[ (h_R + h\cos\phi) \frac{a_{y,2}}{g} + h\sin\phi \right]$ (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

$$RI_{Odenthal} = \frac{2m_2(h_{cg2})a_{y,2}}{mgT} + \frac{2m_2h\sin\phi}{mT}$$
(3.4)

# 3.7 Modified Rollover Index Algorithm for Bus

1 1 1 1 m

The body lateral acceleration,  $a_{y,2}$  and the body roll angle,  $\phi$ , contribute to the RI capability, as shown in equation (3.4) according to (Bo Chiuan Chen & Peng, 2005). The gains, K<sub>a</sub> and K<sub>r</sub>, 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

$$RI_{Modified \ Odenthal} = K_a \left[ \frac{2m_2(h_{cg2})}{mgT} \right] a_{y,2} + K_r \left[ \frac{2m_2h}{mT} \right] sin\phi$$
(3.5)

The gain of  $K_a$  is applied to handle the effect of the body lateral acceleration reaction, whereas  $K_r$  is used to control the impact of the body roll angle response, as illustrated in equation (3.5). The  $K_a$  and  $K_r$  values are obtained using a sensitivity analysis approach that (Amer, 2019) used to improve the capability of the altered Odental rollover index. The  $K_a$ and  $K_r$  values are obtained using the rollover index value, which passes one and returns to normal (Liu, 1999). To determine the values of  $K_a$  and  $K_r$ , a simulation was run using a bus model with step-steering manoeuvre motions at a velocity of 100 km/h.

Figure 3-4 illustrates the bus rollover index in relation to the time to warn (TTW). Rollover safety factor (RSF) is set at 0.75 to get an effective early warning reaction (Liu, 1999). Figure 3-4 illustrates that  $K_a$  is increased between 0.97 to 1.10 to allow the bus to back to its previous position. When  $K_a$  is 0.97, the left tire of the bus axle begins to take off at 2.15 s and goes back to previous in 2.42 s. At the time, the highest RI is 1.0046. When  $K_a$  is 0.98, the left tire of the bus axle begins to lift-off at 2.05 s and goes back to previous in 2.51 s, with the highest RI at this stage at 1.0150. Moreover, when  $K_a$  hits its greater value of 1.10, the left tire of the bus axle begins to take off at 1.74 s and returns to normal in 8.91 s. This  $K_a$  value gives a maximum RI of 1.1392. As a result, it is correct to mention that as the  $K_a$  value grows, the time for the left tire of the bus axle becomes extended. Meanwhile, the maximum RI value is rising. However, when the  $K_a$  value hits 1.11, the RI value stays greater than one, as illustrated by the dotted line in Figure 3-4. It shows that one side of the bus tire is still lift-off and that bus tends to roll over. Furthermore, the rollover index results demonstrate that the bus settling time is stable at 4.30 s for  $K_a$  values ranging from 0.97 to 1.10. It also shows that the bus is steady after 4.30 s if the  $K_a$  value is among 0.97 and 1.10.



Figure 3-4 Bus Rollover Index Affected by Ka

Meanwhile, Figure 3-5 shows the influence of  $K_a$  on the TTW. It is evident that when the value of  $K_a$  grows, the TTW becomes quicker. It demonstrates that  $K_a$  has a considerable impact on the bus's body lateral acceleration. This is because steering input causes extremely high lateral acceleration on the high friction surface during this manoeuvre (Ungoren et al., 2004). It has been showed that the  $K_a$  value has the capability to adjust the TTW. Furthermore, as shown in Figure 3-5, the optimal value of  $K_a$  achieved from this test is 1.10. If  $K_a$  exceeds 1.10, one side of the bus tire continues lift-off, and the bus begins to roll over. This behaviour finally causes the driver to be unable to improve the manoeuvre, resulting in the bus rolling over.



The sensitivity investigation approach is still being used to identify the most finest value for  $K_r$ . The optimal value of  $K_r$  is derived in the same method as  $K_a$ , where it is dependent on the RI value when it reaches 1 and revert to default. These estimates are referred on bus step-steering manoeuvres in TruckSim at 100 km/h. Figure 3-6 shows the description of the RI reaction based on the  $K_r$  effect. The  $K_r$  value is set to 4.5 until 11.0, allowing the bus to revert back to original state. When the value of  $K_r$  is 4.5, the left tire of the bus axle begins to take off at 2.04 s and returns to regular in 2.40 s. Currently, the greatest RI is 1.0064. When  $K_r$  is 5.0, the left tire of the bus axle begins to take off at 1.97 s and returns to normal in 2.48 s, with a maximum RI of 1.0170. Moreover, when  $K_r$  reaches its maximum value of 11.0, the left tire of the bus axle begins to take off at 1.57 s and recovers to the normal state in 8.81 s. This  $K_r$  value has a maximum RI of 1.1546. As a result of these conditions, as  $K_r$  grows, the time it takes for the left tire of the bus axle to begin lifting off

becomes faster, while the time it takes to return back to original state increases. Simultaneously, the greatest RI value is rising.



Figure 3-6 Bus Rollover Index Influenced by Kr

However, as the K<sub>r</sub> value approaches 11.5, the RI value stays greater than 1, as illustrated by the dotted line in Figure 3-6. It shows that one side of the bus tire is still liftoff and tends to roll over. In contrast, the rollover index results demonstrate that the bus settling time for K<sub>r</sub> values ranging from 4.5 to 11.0 is constant at 4.30 s. It also states that the bus is steady at 4.30 s and above as long as the K<sub>r</sub> value is from 4.5 to 11.0. Other than that, Figure 3-7 shows the impact of K<sub>r</sub> on the TTW. It is evident that when the value of K<sub>r</sub> grows, the TTW becomes faster. Furthermore, Figure 3-7 shows that the TTW drops dramatically to 1.19 s. As a result, the optimal K<sub>r</sub> value achieved from this test is 11.0. It demonstrates that K<sub>r</sub> has a significant impact on the bus roll impact. Nonetheless, equation (4.4) shows that the body lateral acceleration,  $a_{y,2}$  and the body roll angle,  $\phi$  is the last reaction from the roll movement that directly impacts the TTW to the driver. As a result, the driver has less time to adjust the manouevers. As a result, the steering and vehicle velocity inputs are evaluated in this investigation to enhance the TTW.



Figure 3-7 Impact of Kr to TTW

From this study, the MORI algorithm is used in this work to combine the steering and vehicle velocity inputs. (Gillespie et al., 1992) developed the equation for steering and vehicle velocity inputs utilised in this investigation. However, according to (Gillespie et al., 1992), during a cornering driving ability, the steering angle caused by the driver may be viewed as inputs and the vehicle motion variables such as lateral acceleration as outputs. Moreover, the bus is moving at a constant velocity and radius curve. As a result, (Gillespie et al., 1992) formulated the steering and vehicle velocity inputs formula as

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$$a_{y} = \left[\frac{\frac{v^{2}}{57.3Lg}}{1 + \frac{Kv^{2}}{57.3Lg}}\right]\delta$$
(3.6)

Where v is the vehicle velocity, L is the wheelbase, K is the steer gradient, and  $\delta$  is the front-wheel steer angle. However, roll angle estimation is taken to consider to derive the roll angle response. The roll angle is determined using an observer and a dynamic model of the vehicle's roll dynamics (Hac et al., 2004). Roll angle estimate (Rajesh Rajamani et al., 2011) is distinct as

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

Where  $I_{xx}$  is the roll inertia.

### **3.8** Particle Swarm Optimisation (PSO)

The algorithm begins with a fixed-size starting swarm population. It starts at a random place and randomly velocity across a multidimensional search space to seek the best optimal location. Each particle will have its own best, based on optimum 127 fitness values other than best position memory ( $p_{best}$ ) and best overall position ( $g_{best}$ ). The memories will be used to determine how particles will move to their following location. This guarantees that the agents do not move too quickly, confusing the local optimum solutions. While each particle at i<sub>th</sub> travels with velocity *v* in each of its dth dimensions, the next position,  $x_{id}(t+1)$ , is defined by Eq (3.8). Eq. 3.9 determines the subsequent velocity, v(t+1). To make sure that the solution does not become trapped within a local optimum, near-neighbour interactions have been implemented (Veeramachaneni & Osadciw, 2003) by evaluating the particle's optimal position within a sub-swarm of neighbours. With additional iteration, the population's average fitness level will improve. The solution will converge in this situation, and the fittest candidates will be identified.

$$x^{(t+1)}{}_{id} = x^t{}_{id} + v^{(t+1)}$$
(3.8)

$$v^{(t+1)} = iw x v^{(t)} + c x rand(0,1) x (P_{best}^{(t)} - x^{(t)}_{id}) + s x rand(0,1) x (g_{best}^{(t)} - x^{(t)}_{id})$$
(3.9)

Where, rand(0,1) is sample of a uniform random distribution from 0 to 1 while t is represent as relative time index. Cognitive coefficient is represent as c, social coefficient indicated as s and inertia weight represent as iw.

To enhance the ability of the modified Odenthal rollover index algorithm's gain settings, PSO was applied in an offline tuning operation. Each particle is positioned by the number of variables to be optimised. Additionally, the fitness of each particle is determined using the modified Odenthal rollover index's quickest response.

# 3.9 Simulation Setting

Based on (Mohamad Hafiz Harun et al., 2021), when simulating the bus model, the  $K_a$  and  $K_r$  are modified to provide the best capability for each load 131 situations using Particle Swarm Optimization (PSO). Table 5.2 shows the optimised  $K_a$  and  $K_r$  parameters under different load conditions. These were used to conduct studies under various bus weight circumstances.

Load Condition	Ka	Kr
Unladen	1.2083	4.0049
Half-Laden	1.4934	4.2213
Laden	1.8775	4.2327

Table 3.2 Optimize Parameter values of K<sub>a</sub> and K<sub>r</sub> for each load conditions

# 3.10 The Test of a Modified Odenthal Rollover Index for Bus

This section contains the testal technique used in this study to analyze the MORI's capability. The test approach includes using the TruckSim driving simulator, a bus model, and the MORI algorithm, which is linked with the buzzer limit to create the final rollover warning system. A driver-hardware-in-the-loop (DHIL) real-time simulation stage in the TruckSim driving simulator is used in this test to analyze the capability of the bus rollover index (Wang & He, 2015). Figure 3-8 illustrates the layout of the test procedure. The test's input data contain bus steering wheel angle and velocity created by the TruckSim driving simulator. The capability of the MORI is determined in this study from an test done using the TruckSim driving simulator and Matlab/Simulink of 60° step steering manoeuvres at velocitys ranging from 60 to 100 km/h. These velocitys are selected depending on the SAE-932949 velocity categorization for low, medium, and high velocity until the tire reaches the lift-off state, and the RI value exceeds one. In addition, the bus involved in this test is loaded

in laden (12,600 kg), half-laden (11,300 kg), and unladen (10,000 kg) states. In this study, the RSF for an early warning indication is set at 0.75. Figure 3-9 shows the bus model used in the TruckSim driving simulator during step-steering manoeuvres. The parameters chose test are based on (Liu, 1999). Table 3 presents the bus parameters. The bus model and MORI algorithm are simulated using the Heun solver with a static step size of 0.01 s. (Hudha et al., 2008).



Figure 3-8 Bus in TruckSim Driving Simulator with Rollover Index Algorithm in Matlab/Simulink



Figure 3-9 Bus in TruckSim for Step Steering Manouevers Test

# 3.11 Parameters

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

 Table 3.3 Scania Parameter

Parameter	Value
Sprung mass, <i>M<sub>s</sub></i>	6,360 kg
Unsprung mass, <i>M<sub>u</sub></i>	530 kg
Tire stiffness, $K_t$	900,000 N/m

Parameter	Value
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, <i>C</i> <sub>sr</sub>	26,000 N/m
Track width, <i>t</i>	2.6 m
length, l	7.9 m
a	3.012 m
b	4.9 m
Height, h	2920 m
I <sub>xx</sub>	7,695.6 kg.m <sup>2</sup>
I <sub>yy</sub>	$30,782.4 \text{ kg.m}^2$

# 3.12 Equipment

There is some equipment being used during this project. TruckSim Software was the most important tool to use as it is being used to get the real vehicle simulation and output graph to compare with the MATLAB Simulink software output graph. Meanwhile, cordless drill, files and screwdriver are also important tools to used during fabricate therollover warning device.

# 3.13 Limitation of Proposed Methodology

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Single deck bus was the famous transportation vehicle that is used for a huge amount of occupants, especially in Malaysia. Since it is widely used as transportation, this paper project is focusing on this type of bus, which is a single deck bus, to overcome rollover incidents. Meanwhile, this paper project was held as an testal lab session only.

### **CHAPTER 4**

### **RESULT AND DISCUSSION**

### 4.1 Introduction

Odenthal's rollover index algorithm was the best algorithm based on the previous researchers, according to (Mohamad Hafiz Harun et al., 2021), which required 0.51 seconds TTW for the driver to detect an oncoming rollover. The time required might be considered late, as the optimum driver response time for an appropriate response is around 0.70 to 0.75 seconds (Green, 2000). As a result, a better algorithm is required to provide an early warning and an appropriate TTR to take remedial actions in the situation of an oncoming rollover. Section 4.3 describes and presents the proposed algorithm, namely the modified Odenthal rollover index (MORI), to overcome this issue. The suggested approach is developed from the previous Odenthal rollover index algorithm as implied by the name.

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# 4.2 Capability of the Modified Odenthal Rollover Index Algorithm

The research investigates MORI response's capability compared to the original Odenthal rollover index. This research considers two rollover index response criteria, known as TTW and TTR. The time taken by the rollover index (RI) to generate an early warning reaction to the driver due to the unstable vehicle movement is defined as TTW. Meanwhile, TTR is the time for the driver to overcome the manoeuvre situation, such as decreasing the vehicle velocity or adjusting the steering input, once the TTW has been responded to. In this study, TTW is determined to provide the driver's earliest response, whereas TTR can get enough time for the driver to overcome their manoeuvres. This is further verified by (B. C. Chen & Peng, 2001). They state that the driver is frequently careless of the bus's rollover instability and fails to take appropriate steps immediately before it is too late.

Capability of the MORI is derived in this study from an test done with a TruckSim driving simulator and Matlab/Simulink software. As a manoeuvring procedures, a step-steering manoeuvre with a velocity of 60–100 km/h is used. In this test, the bus is loaded with a full load or laden (12,600 kg), half-laden (11,300 kg), and unladen (10,000 kg) states. These settings are used on the bus to determine the MORI's capability. Simultaneously, the early warning indicator sets a rollover safety factor (RSF) of 0.75. Figure 4-1 compares the capability of MORI reactions to the Odenthal rollover index. The bus is unladen, with 60° step-steering manoeuvres and a velocity of 60 km/h, which matches (Das, N.S., Suresh, 1993). The maximum rollover index obtained by the MORI and Odenthal rollover indices is 0.57 when the fast steering input is supplied at 11.35 s. Both rollover indices do not exceed the RSF line at this low velocity of 60 km/h. As a result, the driver receives no early warning indicator. On the other hand, the MORI line generates a quicker TTW than the Odenthal rollover index.

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

Meanwhile, even when the bus velocity is raised to 80 km/h (Kamnik et al., 2003), the MORI and Odenthal rollover index lines do not meet the RSF line in Figure 4-2.

However, as the velocity rises from 60 km/h to 80 km/h, the rollover index obtained by the MORI and the Odenthal rollover index increases to 0.72. Despite the increased velocity under this situation, it is still less than the RSF limit of 0.75; hence the rollover warning system does not notify the driver.



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

Simultaneously, when the velocity is rose from 80 to 100 km/h, the MORI and Odenthal rollover index lines intersect the RSF line. The bus can achieve a high velocity of 100 km/h when unloaded or in unladen conditions. As shown in Figure 4-3, when the instant steering input is applied at 6.4 seconds, the Odenthal produces a rollover index of 1.26 and crosses the RSF line at 7.28 seconds. Simultaneously, the MORI's maximum rollover index is 1.48, crossing the RSF line at 6.38 s. MORI produced TTW 12.36% quicker than Odenthal. It is clear that the MORI's responsiveness significantly modified the TTW when the bus reached high velocitys.(Hussain et al., 2005) demonstrated a substantial connection between velocity and lateral force while manoeuvring a heavy vehicle. Furthermore, the MORI's rollover index is bigger than Odenthal's. When the rollover index line intersect the RSF line, the early warning indicator generates a warning signal and a buzzer sound. Due to the MORI's faster response time, the driver has enough time to improve the manoeuvre by reducing velocity or steering input.



Figure 4-3 Unladen State with a Velocity of 100km/h

Then, a load of 11,300 kg or half-laden is placed on the bus to test the MORI's capability. As indicated in Figure 4-4, when the bus is driven at 60 km/h, and an immediate steering wheel input is applied at 10.4 seconds, the greatest rollover index calculated by MORI and Odenthal is 0.61. The rollover index value increases by 0.04 in this state compared to the unladen state. This co-occurs with an increase in load, which rises the centrifugal force created by the bus during cornering. (Hussain et al., 2005) prove that the centrifugal force rises as well when the load increases. Thus, the bus is stable without receiving a rollover warning from the rollover warning system, as the rollover index generated is less than 0.75.



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

The rollover index values are shown in Figure 4-5 once the bus velocity increase from 60 to 80 km/h in half-laden situations. When an immediate steering input is delivered in 13.8 s, the bus rollover index begins to increase. The Odenthal rollover index produces a greatest rollover index value of 0.82 and intersects the RSF line at 15.03 s. Compared to the Odenthal, the MORI created a maximum rollover index of 0.83 and crossed the RSF line 0.84 s earlier. The bus is considered unstable at specific rollover index values, and the rollover warning system warns the driver. As a result, the rollover warning of 5.59% quicker TTW than the Odenthal rollover index which critical for the driver to overcome the manoeuvring state.



The MORI and Odenthal rollover index values for a half-laden bus are shown in Figure 4-6 when the velocity is raised by 100 km/h. This velocity was decided referred on preliminary research conducted using the TruckSim driving simulator, which indicated that the bus would roll over at more than 100 km/h. As shown, the rollover index's MORI estimation is quickest TTW than the Odenthal estimation. This will result in a significant improvement in TTW when compared to Odenthal. At 100 km/h and an immediate steering input of 6.43 s, Odenthal's rollover index value reached a high of 1.11 and intersected the RSF line at 7.19 s. Meanwhile, the MORI measured a greatest rollover index of 1.16 and

intersect the RSF line 0.65 s or 9.04 % quicker than Odenthal. These maximum rollover index values indicate that one side of the bus tire has lifted off, directly threatening the driver and other road users. As a result, the MORI reaction, which is 9.04 % faster than Odenthal's, allows the driver to adjust the manoeuvre before one of the tires begins to take off.



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

The MORI's capability is also examined in the fully loaded or laden state with 12,600 kg (Liu, 1999). When fully loaded or laden state, the bus travels at a velocity of 60 km/h with a 60° immediate steering input beginning at 9.2 seconds, as seen in Figure 4-7. At 9.2 s, the MORI and Odenthal rollover indices started rising in this condition. Since the highest rollover index value created by both rollover indexes is 0.57, both RI lines do not intersect the RSF line. Additionally, it is found that the MORI has a quicker TTW reaction compared to the Odenthal. The rollover warning system does not send a warning to the driver in this situation. As seen in Figure 4-7, the bus remains constant at this velocity even when laden condition and subjected to immediate steering input. As a result, it can be mentioned that bus maintains stability at low velocitys.



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

In other cases, when the vehicle's velocity is rose to 80 km/h when laden condition and a 60° immediate cornering is applied, it is seen that the two rollover index lines begin to climb at 6.57 s, as illustrated in Figure 4-8. At 7.7 s, the Odenthal line crossed the RSF line, resulting in a rollover index of 0.91. Furthermore, the MORI meet RSF line 0.49 s faster TTW than the Odenthal with 0.94 rollover index. This circumstance results in an imbalanced force distribution on both sides of the bus. As a result, the rollover warning system will be activated to alert the driver.



Figure 4-8 Laden State with a Velocity of 80km/h

Additionally, the MORI's capability is evaluated in the laden state at high velocity of 90 km/h. The greatest velocity of 90 km/h is chosen for this loaded state referred on inspection from a driving simulator that the bus would face dangerous rollover when the

velocity exceeds 90 km/h. At 90 km/h with a 60° immediate steering input, Figure 4-9 shows that the MORI and Odenthal lines rose at 7.82 s. At 8.50 s, the Odenthal passes the RSF line and progressively increases to a greatest rollover index of 1.09. MORI is beginning to exceed the RSF line at 7.95 s, which is 0.55 s quicker compared to Odenthal TTW. For this manoeuvre, the MORI continues to generate a greatest rollover index value of 1.19. As illustrated in Figure 4-9, the MORI response is 6.47 % faster TTW than the Odenthal response. The rollover index value was more than one, indicating that one side of the tires had been completely took off. When one of the vehicle's tires is in the lift-off position, the vehicle can either roll over or return to its regular position, liable on the vehicle's following condition.(Smith, 2002) supports this by stating that once in motion, inertia will keep the centre of gravity travelling in a straight path until acted upon by another force. As a result, an early warning indicator must be sent to the driver before the tire take off. This early alert allows the driver to have enough time to overcome his manoeuvring by reducing the vehicle's velocity or steering input.



Figure 4-9 Laden State with a Velocity of 90km/h

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

Table 4.1 Modified Odenthal and Odenthal Rollover Index Time Reactions

The MORI and Odenthal rollover index time reaction are shown in Table 4 for unladen, half-laden, and laden circumstances. It was demonstrated in all situations that the RI increases with increasing velocity. As a result of the data in Table 2 and Figures 4-1 until 4-9, it is clear that MORI gives a faster RI prediction than Odenthal.

### **CHAPTER 5**

### **CONCLUSION AND RECOMMENDATION**

# 5.1 Conclusion

Instead of lateral acceleration, a rollover index method for the bus has been developed that integrates the MORI algorithm with driver steering and vehicle velocity input. The MORI's capability was tested through tests done with the help of a TruckSim driving simulator and Matlab/Simulink software. Step-steering manoeuvres at varying velocitys and loads were used to test the MORI's capability. The test demonstrates that the MORI reaction is 12.36 % faster TTW than the Odenthal response. Additionally, the MORI proved highly effective at high velocitys. As a result, the MORI can create quicker TTW and provide the driver with sufficient TTR to make corrective actions. As a result, a rollover accident or crash can be prevented.

The MORI algorithm's overall capability for the bus when vehicle velocity and driver steering input are used to enhance the driver's TTW. The quickest TTW created by the MORI in this investigation is 0.9 seconds, compared to 0.95 seconds obtained by the previous researcher, which gives the driver sufficient time to take appropriate action to correct the manoeuvres. The rollover warning system's capability in providing a timely response can help the driver respond to the rollover warning. Thus, when integrated with vehicle velocity and driver steering inputs, the MORI algorithm produces the quickest early warning system and is capable of considerably preventing rollover accidents.

# 5.2 **Recommendations**

The MORI algorithm's capability was evaluated by vehicle velocity and driver steering inputs through a DHIL TruckSim driving simulator and MATLAB/Simulink. To simulate actual bus combinations, the DHIL TruckSim driving simulator was employed. Since this MORI method's capability was determined using the DHIL TruckSim simulator and MATLAB/Simulink, the test including the MORI algorithm may be carried out on a real bus. The test involving aggressive driving on a real bus, on the other hand, demands a highly efficient facility with a high degree of safety. This is to ensure driving safety and to prevent property damage.



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## APPENDIX

Appendix A Vehicle Velocity for 60km/h



Appendix B Vehicle Velocity for 80km/h

-		/x80 - 1	Votepad			
	File	Edit	Format	View	Help	
	80					
-	79.9	9211	121			
-	79.9	8390	961			
-	79.9	97541	809			
	79.9	96675	11			
	79.9	95798	492			
-	79.9	94915	771			
-	79.9	94025	421			
	79.9	3128	204			
	79.9	92224	121			
	79.9	91315	46			
	79.9	90397	644			
	79.8	9477	539			
	79.0	58558 7644	197			
-	79.0	26725	144 616			
A AVE.	79.0	25.213	1/1			
MALAI OIA	79.9	212013	139			
S. S.	79.8	3985	901			
S.	79.8	3074	188	_	_	
ă .	79.8	32165	527			
	79.8	31259	155			
2	79.8	303 <mark>52</mark>	02			
*85	79.7	79445	648			
'a/wn	79.7	78540	802			
She hund	79.7	7639	008	_		ە ئىم س
	U		18			

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Appendix C Vehicle Velocity for 90km/h

	, <u> </u>	vx90 - I	Notepad			
	File	Edit	Format	View	Help	
	90					
	89.9	99028	3778			
	89.9	98023	224			
	89.9	96979	523			
	89.9	95900	726			
	89.9	94786	072			
	89.9	93630	981			
	89.9	92432	404			
	89.9	91186	523			
	89.8	39891	.815			
	89.8	88545	99			
	89.8	87149	811			
	89.8	85703	278			
	89.8	34207	916			
ALAYSI	89.8	32664	49			
- min- ra	89.8	31076	505			
Y	89.7	79443	359			
2	89.7	77770	233			
ــــــ	89.7	76058	896			
-	89.7	74312	2592			
S	89.7	/2532	2654			
Alwo	89.1	70/22	961			
/	89.6	20000	803			
Malune.	89.0	5/024	1231 . 2		in and an	1
	89.0	22222	262		. S. V.	9
	69.6	03237	702		17	_
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Appendix D Vehicle Velocity for 100km/h

🧾 vx100 - Notepa	ad
File Edit Forma	t View I
100	
99.98822784	
99.97608185	
99.96341705	
99.95013428	
99.93611908	
99.92125702	
99.90546417	
99.88868713	
99.87090302	
99.85209656	
99.83227539	
99.8114/003	
99.789711	
99.76704407	
99.74351501	
99.71918488	
99.69411469	
99.00053022	
99.64190014	
99 58752441	
99 5596083	
99 53127289	
99 50259399	
99,47360992	
194	

## Appendix E TruckSim Home Appearance Setting

	and the second	a the second of the second of the second sec	
E) [TruckSim2016.1_Data] TruckSim Run Control; {	* * Quick Start Guide Example } Baseline	15.V	
File Edit Datasets Libraries Go To View To	ols Help		1.
Back Forward Home Previous Next Duplicat	Undo 78/50 Lib Teol Parefie	3 X 1.36 Peter AL AVSIA ME	Sdebar Refresh Help Lock
Use this example when you follow the steps in the	Simulated Test Specifications	Run Control: Built-In Solvers	Analyze Results (Post Processing)
Quick Start Guide. (This was last revised for	Vehicle Configuration: S_S	Bun Math Model     Models	Video + Plot Set color
Open the Quick Start Guide from the Help menu;	Tour Bus 5.5T/10T		6 deg. Azimuth, Veh. Ref.
it's field the potton.	Procedure	Do not set output type here      Vite all outputs	Plot More plots: 0 -
Go to Help -> Release Notes -> TruckSim 2016	60 deg. Step Steer @ 90 km/h		
version of the software.	Show more options on this screen Miscellaneous Data		
Note: this example has the box checked to "Write all outputs "That simplifies the use of this run as a	Miscellaneous:	<b>-</b>	
reference for comparisons with other runs that		Set time step here Time step (s) Freq. (Hz)	
might have different plot settings.	C Montenant I	Math model 100 100	
	Miscellaneous:	000por He. 0.01 100	
TruckSim Run Control: Baseline		Do not set time, station, or direction here 💌	
Animator: Lamera Setup: 6 deg. Azmuth, Ve Vehicle: Land Unit with 2 Anles: Tour Rue 5	Miscellaneous:	-	
Procedures: Left / Right Bumps	Set driver controls here		
		Advanced settings	Overlay animations and plots with other runs
		Continue from an existing run	
		(No dataset selected)	
*		< F	
• III •	trucksim	Overriding data:	
Expand Collapse Refresh Reset	MECHANICAL SIMULATION-		View Echo file with initial conditions 🔻

## Appendix F Vehicle Appearance Setting



Appendix G User Interface



Appendix H Turnitin Originality Report

## DESIGN AND FABRICATE ROLLOVER WARNING DEVICE FOR BUS

by HILMI ZAINUDIN

Submission date: 27-jan-2022 11:36AM (UTC-0600) Submission ID: 1749382034 File name: BMMA\_B091810215\_Muhammad\_Zulfadhli\_Bin\_Mansi\_NEW\_THESIS.pdf (1.62M) Word count: 14699 Character count: 75572 DESIGN AND FABRICATE ROLLOVER WARNING DEVICE FOR BUS ORGINALITY REPORT



Jabatan Teknologi Kejuruteraan Mekanikal Fakulti Teknologi Kejuruteraan Mekanikal dan Pembuatan Universiti Teknikal Malaysia Melaka

Signature Main Supervisor Date:28/1/2022

Signature Student

Date:18/1/2022

التونيرسيق تتحتيجان بليسيا الا UNIVERSITI TEKNIKAL MALAYSIA MELAKA					
BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA					
TAJUK: DESIGN AND FABRICATE ROLLOVER WARNING DEVICE FOR BUS					
SESI PENGAJIAN: 2021/22 Semester 1					
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