DESIGN AND FABRICATION OF COMMERCIAL VEHICLE'S EMERGENCY BRAKE SYSTEM USING AUXILIARY BRAKING SYSTEM

EZEKIEL ERNATH A/L ELLAPEN

B092110340

BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (AUTOMOTIVE TECHNOLOGY) WITH HONOURS

2024

Faculty of Mechanical and Manufacturing Engineering Technology

Design and Fabrication of Commercial Vehicle’s Emergency Brake System using an Auxiliary Braking System

Ezekiel Ernath A/L Ellapen

Bachelor of Mechanical Engineering Technology (Automotive Technology) with Honours

2025

Design and Fabrication of Commercial Vehicle's Emergency Brake System using an Auxiliary Braking System

EZEKIEL ERNATH A/L ELLAPEN

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

Faculty of Mechanical and Manufacturing Engineering Technology

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2025

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

TAJUK: **Design and Fabrication of Commercial Vehicle's Emergency Brake System using an Auxiliary Braking System**

SESI PENGAJIAN: **2024-2025 Semester 1**

Saya **Ezekiel Ernath A/L Ellapen**

mengaku membenarkan tesis ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Tesis adalah hak milik Universiti Teknikal Malaysia Melaka dan penulis.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja dengan izin penulis.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (✓)

☐	TERHAD	(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia sebagaimana yang termaktub dalam AKTA RAHSIA RASMI 1972)
☐	SULIT	(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)
√	TIDAK TERHAD	

Disahkan oleh:

Alamat Tetap:

Cop Rasmi:

Tarikh: 13/1/2025

Tarikh: 13/1/2025

** Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh laporan PSM ini perlu dikelaskan sebagai SULIT atau TERHAD.

DECLARATION

I declare that this dissertation entitled "Design and Fabrication of Commercial Vehicle's Emergency Brake System using an Auxiliary Braking System " is the result of my own research except as cited in the references. The dissertation has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	
Name	:	EZEKIEL ERNATH A/L ELLAPEN
Date	:	9/1/2025

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.

Signature :

Supervisor Name : IR. TS. DR. MOHAMAD HAFIZ BIN HARUN

Date : 9/1/2025

DEDICATION

This thesis is dedicated to my parents, whose support has been my foundation, and to my supervisors, IR. TS. DR. Mohamad Hafiz Bin Harun, whose guidance and belief in me have been invaluable. Thank you for shaping my journey and helping me reach this milestone.

ABSTRACT

Commercial vehicles, such as buses and heavy-duty trucks, are essential parts of today's transport network because they make it easier to transfer people and products over great distances. However, assuring these vehicles' safety and dependability on the road offers a difficult engineering problem due to their intrinsic size, weight, and operational requirements. The development and application of efficient braking systems that can quickly and safely stop these massive trucks, especially in emergency situations. Brake failure in commercial trucks is a significant concern to road safety and can result in catastrophic accidents, especially given their size and weight. Braking system failure can be caused by a variety of circumstances, such as mechanical faults, hydraulic failures, inadequate maintenance, or driver mistakes. Understanding the causes and effects of brake failure is critical for developing effective preventive measures and assuring road users' safety. As a result, a suggested system incorporates supplementary braking techniques, such as exhaust braking, which was chosen for its efficacy and dependability in a range of operational scenarios. The functionality of the suggested system was created using MATLAB Simulink software. As things stand, the outcome will show the stopping distance of the commercial vehicle of three conditions (unladen, half-laden, full-laden).

ABSTRAK

Kenderaan komersial, seperti bas dan trak berat, merupakan bahagian penting dalam rangkaian pengangkutan hari ini kerana mereka memudahkan pemindahan orang dan produk melalui jarak yang panjang. Walau bagaimanapun, memastikan keselamatan dan kebolehpercayaan kenderaan ini di jalan raya menawarkan masalah kejuruteraan yang sukar kerana saiz, berat dan keperluan operasi mereka. Pembangunan dan penggunaan sistem brek yang cekap yang boleh cepat dan selamat menghentikan trak-trak besar ini, terutamanya dalam keadaan kecemasan. Kegagalan brek dalam trak komersial merupakan masalah yang penting untuk keselamatan jalan raya dan boleh menyebabkan kemalangan yang dahsyat, terutamanya mengingat saiz dan berat mereka. Kegagalan sistem brek boleh disebabkan oleh pelbagai keadaan, seperti kerosakan mekanikal, kegagalan hidraulik, penyelenggaraan yang tidak mencukupi, atau kesilapan pemandu. Memahami sebab-sebab dan kesan kegagalan brek adalah penting untuk membangunkan langkah pencegahan yang berkesan dan memastikan keselamatan pengguna jalan. Akibatnya, sistem yang disyorkan menggabungkan teknik brek tambahan, seperti brek exhaust, yang dipilih kerana kecekapan dan kebolehpercayaan dalam pelbagai senario operasi. Fungsi sistem yang disyorkan telah dicipta menggunakan perisian MATLAB Simulink. Seperti yang berlaku, hasil akan menunjukkan jarak berhenti kenderaan komersial dalam keadaan (tanpa muatan, separuh beban, sarat penuh).

ACKNOWLEDGEMENTS

I extend my deepest gratitude to all those who have contributed to the completion of this project. Firstly, I am immensely thankful to my supervisor, IR. TS. DR. Mohamad Hafiz Bin Harun, for their invaluable guidance, unwavering support, and insightful feedback throughout this journey. Their expertise and encouragement have been instrumental in shaping the direction and quality of this work. I am also indebted to my parents for their unconditional love, encouragement, and sacrifices. Their unwavering belief in me has been a constant source of motivation and strength. I am grateful to my friends for their encouragement, understanding, and support throughout this journey. Lastly, I would like to thank Universiti Teknikal Malaysia Melaka (UTEM) for its financial support, which enabled this research. I genuinely appreciate all of your contributions to this project, as each one has been crucial in moulding it.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SYMBOLS AND ABBREVIATIONS

LED	-	Light-Emitting Diode
LCD	-	Liquid Crystal Display
ABS	-	Antilock Braking System
EBS	-	Emergency Brake System
TCS	-	Traction Control System
ESC	-	Electronic Stability Control
ACU	-	Air Bag Control Unit
ECU	-	Electronic Control Unit
DC	-	Direct Current
PWM	-	Pulse-width modulation
USB	-	Universal Serial Bus
ICSP	-	In Circuit Serial Programming
MHz	-	Megahertz
AC	-	Alternating Current
PIC	-	Peripheral Interface Controller
V	-	Volt
mA	-	Milliampere
KB	-	Kilobyte
LKA	-	Lane Keeping Assistance
ACC	-	Adaptive Cruise Control
Mm	-	Milimeter
Ω	-	ohm
ms	-	Millisecond
AEB	-	Autonomous Emergency Braking
VCC	-	Voltage Common Collector

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Commercial vehicles, such as heavy-duty trucks and buses, are crucial parts of today's transportation network because they allow the transportation of people and goods across long distances. But due to their very nature and size, along with the demands made on them when operating, creating a vehicle capable of both driving as we know it and working as an autonomous vehicle has proven to be an engineering conundrum. The heart of this problem is making a braking system that can stop the massive truck quickly and safely, especially if the truck needs to stop in a hurry.

Figure 1.1 Example of Commercial Vehicles (Hatfield Temple, 2024)

It is impossible to stress how crucial emergency braking systems are for commercial vehicles. They need to have a capacity to rapidly decelerate and to prevent collision so as to protect both people and assets on the road handling multiple road conditions, unexpected traffic situations, varying loads etc. Unfortunately, while they perform great in normal situations, conventional brake systems are simply not enough in a chaotic emergency scenario, when there are sudden hazards, hard stops, or failures in brake components. (NHTSA, 2015).

To address these concerns, auxiliary braking systems have emerged as potential substitutes for primary braking systems in heavy-duty trucks. An auxiliary braking system is the other mechanism which can bring a vehicle to a stop or reduce its speed in case of a brake failure (Shinde et al., 2023). In essence, auxiliary brakes increase safety margins and control under emergency braking situations by supplementing the braking power and redundancy inherent in traditional brake systems (SAE, 2018). While it is never a one-size-fits-all solution, auxiliary brakes, such as the engine brake, exhaust brake, and electromagnetic retarder, there one can develop custom emergency braking solutions according to the specific requirements of heavy commercial vehicles.

There has been a significant amount of research and development of auxiliary braking systems to make them more powerful and reliable in emergency scenarios. Hence, their expected applications and market penetration in the future have been a subject of interest for many researchers to demonstrate the performance characteristics, reliability, and integration challenges of different existing AB technologies for commercial vehicles (Joshi et al., 2020). Also, with the development of materials science, control systems, and vehicle dynamics in the automotive fields, it now implies that there are more possibilities in mastering the design and performance of auxiliary braking systems in emergency scenarios (Jin da Choi et al., 2019).

In this context, the thesis "Design and Fabrication of Commercial Vehicle's Emergency Brake System Using Auxiliary Braking System" explores the adaptation of the technology of auxiliary braking for the commercial vehicle emergency braking systems. The purpose of this study is to fill this gap by performing a computational investigation into the feasibility of using existing vehicles as a means of rapidly arresting commercial vehicles under adverse conditions by combining first-principle analysis, computational modelling and empirical knowledge to create a robust emergency braking system.

This thesis aims to discuss the auxiliary brake powered emergency braking system design considerations, fabrication process, and performance evaluation mechanisms through mechanical engineering, automotive design and system integration principles. By moving policy beyond pilot projects, this research takes aim at continuous improvement of the technology available to commercial vehicle fleets through innovation and collaboration, paving the way for a safer and more durable transportation ecosystem for all stakeholders.

1.2 Problem Statement

Commercial truck brake failure poses a big road safety hazard, and with the sheer size and weight, it can also lead to severe accidents. Brake system failure can happen due to a number of reasons, mechanical failure, hydraulic problems, not enough maintenance or drivers error. It is important to know the reasons why brakes fail and to examine the impacts of brake failure on braked structures in order to develop effective preventive approaches and to protect other road users.

To understand the causes of brake failures in commercial vehicles, a study by Lai et al. The researchers were able to identify that wear of brake components, leaks in the hydraulic system and incorrect adjustment were the main causes of brake failures found in commercial vehicle vehicles and buses. They have also found that brake failure in commercial trucks is much more prevalent if they had poor maintenance procedures and inspect it less frequently.

In addition to mechanical issues, human instigators might also result in brake failure, such as the mentioned driver fatigue, distraction, inappropriate use of the braking system, etc. However, (Zhang et al., 2019) study highlighted the importance of training and education of drivers in mitigating brake-related accidents with commercial vehicles. The study also emphasized that "for minimizing brake detection longitudinal crashes, it is important for drives to have awareness about how to brake properly, have routine brake maintenance, and have knowledge of proper emergency response.

Plus, a commercial vehicle without an auxiliary brake is a serious safety liability, particularly when it comes to emergency braking situations. Commercial truck brake failures, longer stopping distances, and even loss of vehicle control are all possible without secondary stopping force and redundancy provided by auxiliary braking systems, increasing the potential likelihood of accidents or crashes. Commercial vehicle safety was adversely impacted by not having auxiliary brakes (Smith et al., 2017). The study found that trucks and buses without automatic braking systems have increased brake-related accident rates and longer stopping distances than vehicles with automatic braking.

1.3 Research Objective

The objective of this research is to address the problem to reducing the accident rate associated with commercial vehicle brake failure focusing on driver, driver, and other road user safety first. Additional safety features for commercial vehicles like trucks and buses due to an auxiliary braking system. This operates in conjunction with the standard braking system. When an emergency occurs, it applies additional braking power either automatically or manually to facilitate immediate hard stops. The latter is no easy task, as it requires quick-acting actuators to respond to rapid stabs at the brake pedal. These goals, more specifically established as:

a) To develop an auxiliary braking system model for commercial vehicle .

b) To fabricate a model prototype of an auxiliary braking system for commercial vehicle.

1.4 Scope of Research

Auxiliary braking systems such as exhaust brakes into commercial vehicles in consecutive years has drawn substantial attention because of its potential in enhancing safety and control in an emergency braking scenario. To address such a global requirement of having better stopping techniques used in all the commercial vehicles, this research project aims to design and fabricate an EBS (Emergency Brake System) prototype which is assisted by an alternative mechanism for auxiliary braking system which is nothing but the exhaust brake. To the end, this project will blend the performance advantages of exhaust brakes with the response times of conventional braking in order to provide a more complete and effective solution for reducing the hazards of emergency braking situations on commercial vehicles. The scope of this research is as follows:

- The parameter of the commercial vehicle braking system model is developed based on a 1:16 commercial vehicle RC model scale
- The commercial vehicle exhaust braking system model is developed in Matlab Simulink software.
- The prototype of the exhaust braking model is developed on the electronic circuit board.
- The performance of the proposed exhaust braking model is evaluated through the experiment.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Commercial Vehicle Braking System is an essential part of efficient and safe operation of large-scale transportation systems, and is also a very attractive topic for thesis research. The system, made of a myriad of mechanical, pneumatic and hydraulic components, is specifically designed to stop vehicles with a high gross weight rating, heavy trucks and buses, or light trailer based on Miller (2010). Commercial vehicles have more durable braking systems that have been spec'ed to take a beating and are built to handle high payloads and different operating conditions than what passenger automotive hardware can handle. And one of the most important part of it is service brakes, which are usually pneumatic or hydraulic.

Air Brakes, typically found in many larger commercial vehicles, are the most common form of heavy vehicle braking by using compressed air to force braking chambers which in turn applies pressure to drums or discs. In hydraulic brakes, which are more common in light commercials, hydraulic fluid is used to transfer the pressure from the brake pedal to the brake assemblies at each wheel. Commercial Vehicles also have the secondary service brakes;these are the parking brakes, the most important when the vehicle is stopped and are generally mechanically or electronically operated.

Moreover, more and more advanced safety technologies, such as Antilock Braking Systems (ABS), Electronic Stability Control (ESC), or Traction Control Systems (TCS) which can improve stability, traction and overall braking performance (e.g. Zhang D, 2014), are equipped on modern commercial vehicles as also mentioned by several interview partners. The efficiency and performance of these systems is due in part through proper upkeep, in which brake components such as pads, rotors, drums, and brake fluid should be inspected on a regular basis (He R, 2019).

2.1.1 Distinction of Air Brake and Hydraulic Brake

In terms of commercial vehicle braking systems, two main technologies stand out, air brakes and hydraulic brakes. These systems have different operating principles, components, maintenance requirements, performance attributes, and regulatory compliance.

Commercial vehicles equipped with air brakes rely on air pressure to put their brakes to work. The driver initiates this by hitting the brake pedal, which in turn releases compressed air stored in tanks. Air pressure then goes to brake chambers, where it pushes brake shoes onto brake drums or pads against brake discs, causing the vehicle to loosen up. Air brake systems, which consist of compressors, reservoirs, brake chambers, and pneumatic valves, need regular maintenance in order to function at optimal. In addition, whereas air brakes ensure reliable brake force and better-heat dissipation performance, operational issues associated with the system design (e.g. air leakage and pressure fluctuation) are unavoidable (Akshar, 2017)

Figure 2.1 Air Brake (Sharp Brake, 2018)

In contrast, hydraulic brakes, which are used in smaller commercial vehicles, use hydraulic fluid to impart braking force. When the driver depresses the brake pedal, hydraulic pressure builds up in the brake lines, activating pistons in the brake callipers or wheel cylinders. The pistons apply pressure to brake pads or shoes, which press against rotors or drums to slow down the vehicle. Hydraulic brake systems are easier to build, consisting of a master cylinder, brake lines, fluid reservoir, and brake calipers/wheel cylinders. While hydraulic brakes provide quick braking and a nice pedal feel, they require routine maintenance to check fluid levels, inspect for leaks, and maintain the proper operation of hydraulic components (Sean Bennett, 2016).

Figure 2.2 Hydraulic Brake (Ryan Chang, 2021)

2.1.2 Advanced Safety Technologies

The advanced automotive safety device known as an antilock braking system (ABS) shortens stopping distances and improves vehicle control by keeping wheels from locking up while applying pressure, especially on slick or uneven roads. Wheel speed sensors are used by ABS to continuously measure each wheel's rotational speed. An Electronic Control Unit (ECU) processes the data and looks for possible wheel lockup scenarios. The ECU uses hydraulic modulators and valves to control brake pressure when it senses impending lockup, quickly adjusting the pressure to each wheel to preserve maximum traction. By allowing the driver to maintain steering control during emergency braking, this procedure greatly lowers the possibility of sliding and collisions(Khorasani-Zavareh et al., 2013).

Figure 2.3 Antilock Braking System (Wheels Wisdom, 2024)

Designed to prevent passengers from sliding or skidding due to sudden turns or inclement weather, ESC represents one of the first advancements of the latest Electronic Stability Control (ESC) system is found in vehicles today. ESC uses a number of sensors including those measuring the speed of the vehicle, the steering angle of the vehicle, and the overall lateral acceleration, and continually measures these factors (Wåhlberg & Dorn, 2024).

Figure 2.4 Electronic Stability Control (Wap Car, 2021)

Traction Control System (TCS) This is one of those systems crucial for car safety: it is designed to prevent wheels from spinning and ensures that the car maintains maximum grip when driven, such as when it is driven on slippery or uneven terrain. What the system does is, it continuously monitors the rotational speed of each wheel with the help of its sensors. When a wheel starts to slip the TCS steps is by reducing engine power or applying brake force to the spinning tire, or both. As a result, this torque redistribution ensures that the power is transmitted to the wheel with better grip, as well as assisting the vehicle regain stability (Jin et al., 2018). Traction Control System (TCS): The TCS prevents the excessive wheel spin during the acceleration and hence it helps the vehicle to prevent skidding or losing the control.

Figure 2.5 Traction Control System (Adrian Chia, 2018)

2.2 Evolution of Braking System in Commercial Vehicle

The early braking systems for commercial vehicles were all mechanical and applied force directly to the wheels using a complex lever and rod configuration. Drivers had to put in a lot of physical work with these early braking systems, frequently applying a lot of pressure to the brake pedal in order to produce even a slight slowdown. Even though the mechanical linkage system was innovative at the time, its basic braking power was restricted, making it difficult to quickly and safely stop large vehicles (Moritz Nolte, 2018).

The mechanical brakes also required regular maintenance and modifications to guarantee they continued to work because they were prone to wear and tear. This ongoing maintenance requirement was a big disadvantage because any wear or misalignment in the parts might seriously impair stopping power and endanger safety (Buckminster Fuller, 2020). Despite these difficulties, mechanical brakes were a significant advancement in vehicle-stopping technology and set the stage for the creation of later, more advanced and efficient systems.

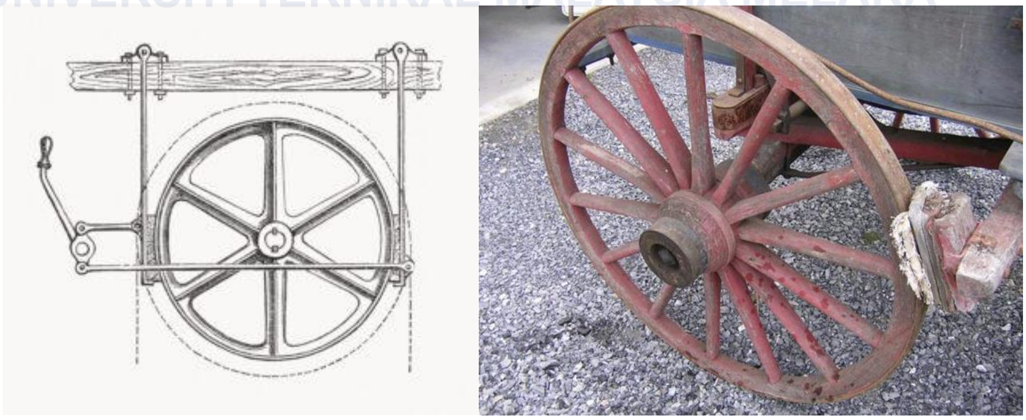


Figure 2.6 Mechanical Brake (ABE Brakes, 2024)

Drum brakes, which offered a major improvement over the previous mechanical systems, were introduced in the 1920s, marking a significant advancement in braking technology (Buckminster Fuller, 2020). Brake shoes press outward against a rotating drum that is mounted to the wheel to activate drum brakes. The braking system is now more effective and efficient due to this creative design. Drum brakes lessened the amount of physical effort needed from drivers, improving both safety and general driving enjoyment in contrast to fully mechanical brakes.

Drum brakes can also allow cars to stop faster and more consistently with the heavier weights common on commercial vehicles than disc brakes can because they have improved braking ability. For about 10 years or more, drum brakes were the default design on most commercial vehicles. They were less susceptible to damage and maintenance than the older mechanical systems, which contributed to them being so widely used (Baba et al., 2018). Selected throughout all vehicle braking systems, all drum brakes symbolized a major advance in braking security along with overall performance.

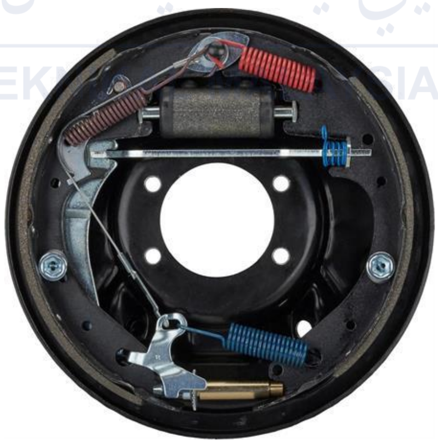


Figure 2.7 Drum Brake (Mark Houlahan, 2021)

Hydraulic braking systems were introduced in the 1930s, it has significantly improved the way cars braked and it guarantees efficiency and reliability that was not achieved before with mechanical and drum brakes. Hydraulic brakes, meanwhile, deliver stopping force from the brake pedal to the brake shoes or pads by hydraulic pressure, which is created within a sealed system. This advanced system allowed for much more efficient brake application to multiple wheels, resulting in a more consistent and balanced braking operation. Consequently, whether the wheels were slipping or not, no matter the load or speed of the vehicle, the result was a much more consistent and reliable level of braking force (Schroeder, 2009).

Driver effort was greatly decreased by hydraulic systems, resulting in more sensitive and smoother braking. The safety and operational efficiency of commercial vehicles were significantly improved by this advancement in braking technology. Because the hydraulic braking system was included it was less prone to wear and environmental contamination, which reduced the need for regular maintenance and adjustments (Svensson, 2013). The introduction of hydraulic brakes in commercial vehicles signalled a turning point towards more secure, dependable, and effective modes of transportation and established the framework for contemporary braking systems that are still developing today.

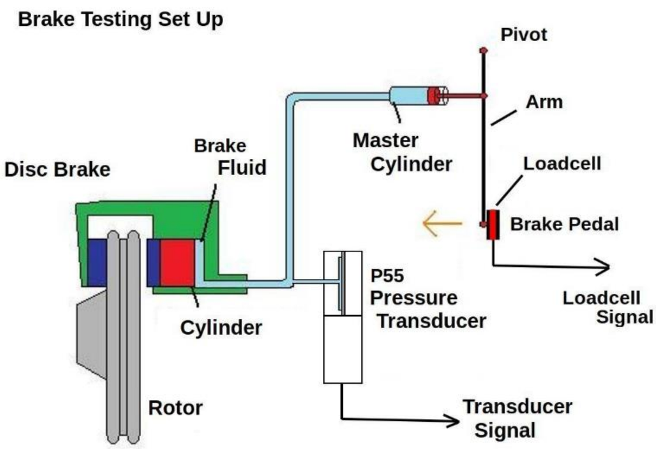


Figure 2.8 Hydraulic Braking System (Validyne Engineering, 2024)

The invention of air brakes in the 1940s transformed heavy-duty commercial trucks and buses by becoming a standard feature(Diesel Repair, 2022). These air brake systems were created especially to handle the higher needs of huge trucks, which frequently transported heavy loads over long distances. Instead of using hydraulic fluid, these systems use compressed air. This part emphasized that a comprehensive description and study of these components are necessary as Brake chambers, valves, reservoirs and air compressors make up an air brake system and all of them work together to ensure powerful and reliable braking capability (Athul, 2024). Their durability is one of air brakes best characteristic and due to this air brakes are best suited for heavy duty and long distance operations (Athul, 2024). Air breaks offer a more robust solution than hydraulic systems that can leak fluid and needs careful servicing. Resistant to wear and tear, air brake systems are likely to outlast the serious pressure and heavy usage typical to the daily operation of a large-sized passenger bus or commercial truck.

Air brakes have two other important characteristics; reliability and frequent utilization in proper functioning which are critical for the safety and utility of HGVs. More responsive braking offers control and stability even when things get dicey, and compressed air allows for a quicker, more efficient brake response. This reliability, due in part to the redundancy built into air brake systems on many air tanks and lines ensures that one failure cannot take out entire brake system also speaks to the dependability of the technology.

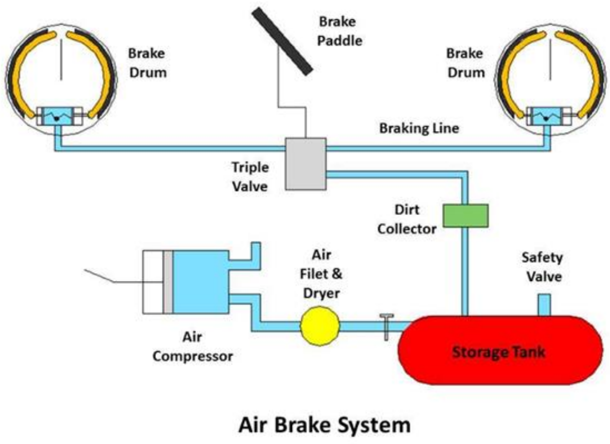


Figure 2.9 Air Brake System (Mech4study, 2021)

When disc brakes were first installed on front axles of commercial vehicles in the 1970s, the technology represented a major leap in braking systems that eventually extended to all wheels (John Carney, 2021). The shortcomings of conventional drum brakes were addressed with disc brakes, which offered more stopping power, better heat dissipation, and decreased brake fade. Their method of operation was clamping brake pads onto a wheel-mounted rotor to provide a more efficient and direct braking action (Matt Bell, 2018). Better heat dissipation was made possible by this design by default, which is important in circumstances involving hard or extended braking.

Ventilated discs were added to improve performance even more. These discs had internal air-flow channels that greatly improved cooling, especially during severe braking (John Carney, 2021). By preventing excessive heat buildup, this invention preserved brake function and increased the component's lifespan. The introduction of disc brakes was a significant advancement in commercial vehicle braking technology, resulting in increased efficiency, safety, and dependability as well as new industry standards for braking systems (Matt Bell, 2018)

Figure 2.10 Disc Brake (AutoBahn, 2020)

Commercial cars began to use Antilock Braking Systems (ABS) in the 1980s. ABS technology modulates brake power to prevent wheel lockup during braking, which helps retain traction and steering control (Derek Fung, 2014). It offers a good illustration of a common modern commercial vehicle safety technology, and a great way to improve safety, particularly in slick conditions.

The 1990s saw the advent of the Brake Assist (BA) and Electronic Brakeforce Distribution (EBD) systems (Akshat Ajeya, 2018). The EBD redistributes the braking force in order to enhance the braking power of the wheels and minimise over and understeer tendencies, thus ultimately improve the vehicles stability. Brake Assist helps drivers in emergency situations by automatically applying more brake and evaluates that immediate pressure on the brake pedal (Ajeya, 2018).

Since the 2010s, braking systems or Advanced Driver Assistance Systems (ADAS) have been combined. Another key innovation that vehicles were assessed on is their Autonomous Emergency Braking (AEB) feature, which is like a last line of safeguard that assumes control over when your response time falls behind; just the same that you'll see on your TV when there are robots battling aliens (Guo et al., 2022). In this way, the integration provides the benefits of proactive brake assistance in increasing the level of safety of the vehicle.

2.3 Importance of Emergency Braking System in Ensuring Vehicle Safety

A pillar of modern automotive safety, emergency braking systems attempt to prevent crashes or lessen their severity. This is crucial as it offers drivers a reliable method of slowing their cars quickly, so much needed in case of the primary brakes failing or when unexpected nasty conditions emerge on the road (Keith Barry, 2024). They can often occur from unexpected brakes, being on the phone while driving or miscalculation of the space between cars.

This issue is managed by EBS which monitors the speed at which the gap is approaching and distances to the car in front through sensors (Derek Fung, 2014). The system activates the brakes automatically if it recognizes that the car is moving too rapidly towards an object, thus avoiding an accident (with a lessened impact speed in case of impossibility to do so). Emergency braking systems are able to achieve rapid deceleration, increasing the likelihood of preventing rear-end collisions which are one of the most common crash types on highways (Tan et al., 2020).

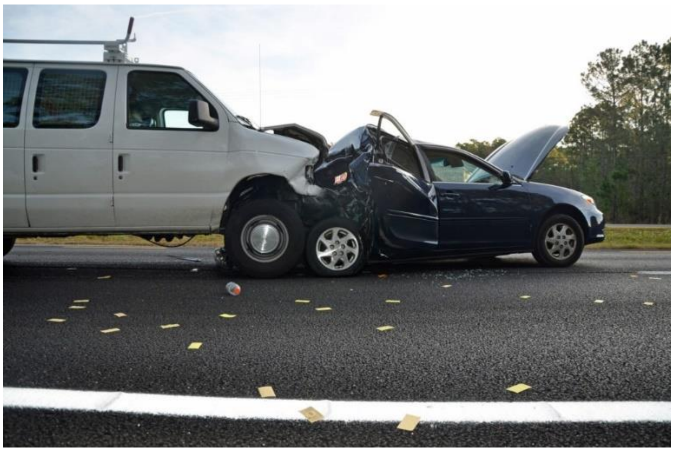


Figure 2.11 Example of Rear-End Collision (Berman & Simmons, 2021)

One of the main advantages of an emergency braking system is its ability to react faster than human drivers. 1.5 seconds is about what a human will react in, but this may not be fast enough to avoid a crash in sudden or high-speed situations. Time is of the essence in these pressing situations, and near-instant responsiveness of these systems stand to make the difference between a near-miss and a crash (Emergency Braking Systems, 2023). Automated emergency braking could slow the start of an accident enough to save lives and reduce the chance of serious injury, starting the brake faster than a human driver can. All of this with the modern advancements too, like automatic emergency braking making vehicles even safer. Automatic detection of obstruction for applying break using these technologies enhances the safety by providing an additional layer of security and thereby reducing the collisions.

Other than a lone driver and his vehicle, emergency braking system is needed to secure the vehicle during operations. As a result, these devices can greatly improve the general safety of roads by reducing the likelihood of crashes and accidents, which protects not only the driver and passengers, but also other road users such as cyclists, pedestrians and other drivers (Tan et al., 2020). This group benefit is critical in densely populated areas or with a lot of traffic which increases the probability of accidents.

Because the Emergency Braking Systems (EBS) are accepted as the final safe braking system, this fact highly increases the driver confidence level. This in turn promotes safer and more enjoyable driving (Burton et al., 2004). To combat this, many drivers experience increased feelings of stress and fatigue while operating in high-stress driving environments, such as in heavy traffic or inclement weather. Slower response time due to lower RT in a fast-moving high-risk environment where mistakes are more likely. Drivers might feel a litlte more secure in the knowlede that their vehicle has EBS (Electromagnetic Brake) support, and it still are vigilent through and always up to the road and instantly ready for anything. This assurance can reduce the cognitive load on drivers, enhancing their capacity to focus and maintain a neutral facial expression during the operation of an automobile (Burton et al., 2004).

So, to build a full-fledged safety ecosystem, Emergency Braking Systems(EBS) are integrated in a manner where EBS can communicate gracefully with other Advanced Driver Assistance Systems (ADAS) like Lane-Keeping Assistance(LKA) and Adaptive Cruise Control(ACC) in the car. Using sensors to gauge the speed and distance of the car in front, Adaptive Cruise Control keeps the car at a safe following distance by automatically adjusting the vehicle speed. If the car in front of you unexpectedly halts or reduce speed, ACC is supposed to take off the speed for you (Greenwood et al, 2022). If there is no response from the driver immediately, EBS is able to enhance the braking system to avert a collision (Tan et al., 2020).

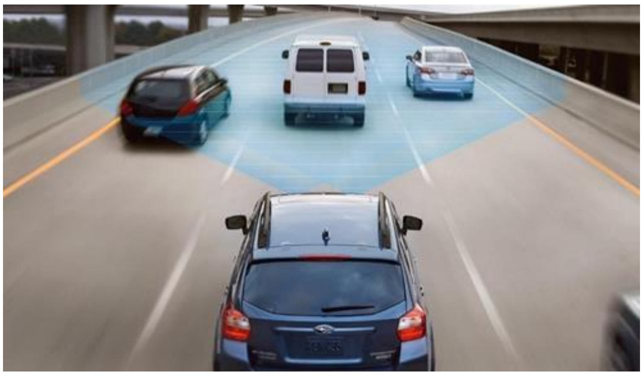


Figure 2.12 Adaptive Cruise Control (Matsumoto Naoki, 2021)

Lane-keeping assistance uses cameras and sensors to ensure the car stays in the lane and is able to correct the steering control if the car drifts out of its lane without signaling a turn. While EBS controls vehicle longitudinal movement by maintaining a safe distance from other cars, LKA controls the vehicle lateral position on the road (Karthikeyan et al., 2020). This two-level defense uses ACC and LKA further strengthened by EBS and provides a layered approach to safety that results in a decrease the probability of accidents even if one of the systems fails.

Figure 2.13 Lane-Keeping Assistance (John Kelly, 2021)

2.4 Advancements in Emergency Brake System Technologies

Autonomous parking that is a Technological advancements in crash-avoidance systems have revolutionized the way we keep cars safe with new ways of preventing accidents and faster driver reaction times (Barry, 2024). Advanced sensors and electronic controls automatically detect potential hazards and engage the brakes on these technologies. Some of these technologies are brake-by-wire, predictive emergency braking, and autonomous emergency braking (AEB) systems. These advances reduce the risk and severity of accidents on the road and integrate technology like augmented reality displays for drivers that allow them to be as informed as possible when it comes to precision and reliable braking (Ian Duncan, 2024).

2.4.1 Autonomous Emergency Braking (AEB)

Autonomous emergency braking (AEB) systems provide a proactive way to prevent crashes and are considered to be the most significant development in automotive safety technology since the introduction of Electronic Stability Control (ESC). They contain several sensors such as lidars, radars, and cameras that constantly survey their surroundings to identify any potential collision threats. When a vehicle, pedestrian or obstacle is detected, the AEB system checks whether a collision is imminent and if there is no driver input, applies the brakes. If the risk is above a certain level then the system brakes the car on its own to at least decrease the impact, avoid it all together (Tan et al, 2020).

This rapid response can be crucial in cases were the human reaction time is insufficient to avoid a crash (Hulshof et al., 2013). Additionally, more sophisticated forms of AEB operate at higher speeds and also have object recognition capabilities so they can be used over a broader range of speeds and to detect items such as bicycles as well as stationary obstructions like barriers or road debris. Consequently, accidents both caused by, and seriously injuring drivers and passengers are significantly less likely, and AEB systems provide a crucial layer of protection when this technology combines sophisticated sensors and computer-based algorithms (Evans, 2021). AEB systems are based on complex algorithms and a network of sensors that will detect bicycles and people, as well as other cars. Such systems are capable of distinguishing among different types of drivers and may modulate the brake pressure to prevent collisions or limit their intensity (Ackodrive, 2024).

Despite their rather revolutionary safety advantages, autonomous emergency braking (AEB) systems may also have a few drawbacks. The system's dependability is one issue since it can lead to false alarms or the system braking too hard, which can happen when sensor data is interpreted incorrectly. This can result in sudden, unplanned stops that might annoy drivers or cause accidents (Earl Lee, 2021). On the other hand, it comes with a risk (the system not braking when it should) especially in bad weather or with dirty or blocked sensors. In addition, some obstacles smaller in size such as small animals or complicated scenarios of multiple moving objects or high speeds could reduce the success of AEB systems. AEB systems in general tend to be complex and expensive, which may translate into higher vehicle prices and maintenance costs (American Automobile Association, 2022).

2.4.2 Intersection Collision Avoidance System

Intersection Collision Avoidance System (ICAS) : This unique safety feature is designed to prevent intersection collisions, which often induce traffic accidents. To collect and exchange real time information about the vehicles positions, speeds, paths, traffic signals and other crucial infrastructures, these system use vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communication (Basma et al.

By analysing the knowledge the systems are able to predict potential crash scenarios and alert drivers in a well timed manner (Basma et al., 2009). For example in addition to alerts on the screen the system can send some signals to the driver to warn them of a red light runner or another car coming from a side street with the right of way. With top of the line versions, in case the driver does not react, no matter why, the car can automatically apply the brakes to avoid or mitigate the collision (Raksincharoensak et al., 2013). And in the end, this technology makes intersections safer for everyone vehicles, pedestrians, cyclists, and drivers by reducing many of the most common intersection conflicts like red-light violations and arguments over who should have the right-of-way.

Intersection collision avoidance system (ICAS), while it does provide a significant improvement to safety, also has a number of drawbacks. One of the major reasons is that the system depends on precise and comprehensive data obtained from sensors that can be compromised by poor weather, obstacles in the path of the sensors, and a lack of maintenance. This might generate false alarms, in which the system reacts unnecessarily, inciting to sudden breaking or reckless actions that could distract or frighten other drivers as well as themselves (Grover, 2008).

By contrast, however, errors may occur, such as when the system does not identify a collision threat - especially in complex, chaotic intersection scenarios with many moving vehicles, cyclists, and pedestrians. ICAS installation can be costly, adding to the price of the car whilst putting extra load on the engine and potentially demanding expensive maintenance (Toru Fujiwara & Kazutaka Takechi, 2021) Additionally, the performance of ICAS may vary depending on the quality and technological maturity of the system, thereby providing different performance levels across car model and manufacturers.

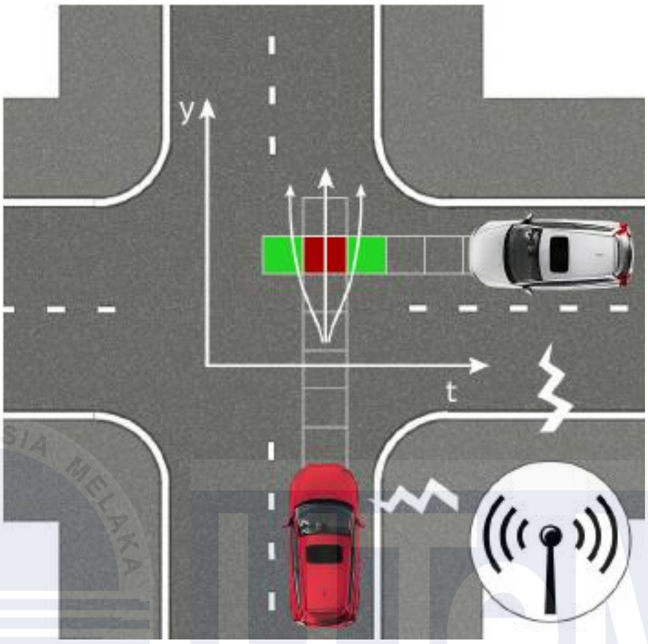


Figure 2.14 Intersection Collison Avoidance System (Denis Osipychev, 2015)

2.4.3 Brake by Wire Technology

The brake-by-wire technology changes vehicle braking, removing the need for traditional hydraulic and mechanical linkages. Rather than this, the driving input to brake is identified to an electronic control unit (ECU) via electronic sensors. This ECU directs the actuators at each wheel to apply the brake force according to the processed signals (Wang et al., 2021). While that's shaped by the MQB electronics, the system is excellent at precisely, silky-smoothly, responsively adjusting braking pressure.

It also seamlessly links with advanced driver-assistance systems (ADAS) like Electronic Stability control (ESC) and Anti-lock braking systems (ABS), ensuring greater vehicle safety and performance. By eliminating the mechanical parts used in a traditional braking system, brake-by-wire systems contribute to the overall weight reduction of the vehicle and simplified maintenance, further improving vehicle reliability, and fuel economy (Xiao et al. 2021). Additionally, made it possible to use the car's brake system more precisely and more consistently, enabling future advances in autonomous driving.

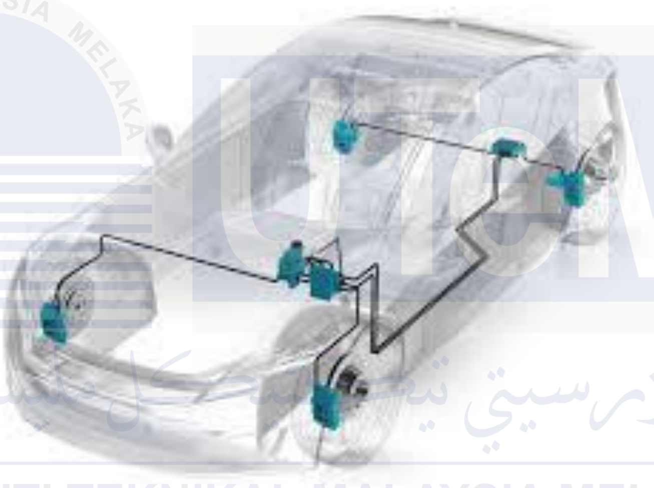


Figure 2.15 Brake by Wire (Daniel Triolo, 2021)

There are several drawbacks to brake-by-wire, however, in addition to its benefits. One major concern is the use of electronic systems which can be susceptible to malware, hacking or power cut off, ultimately resulting in a brake failure (Dieter Schramm et al. 2020). Moreover, the expense of developing, installing, and maintaining the technology could exceed that of traditional braking systems, leading to higher costs for buyers. Moreover, because RFID is a nascent technology, concern has been raised regarding its permanence and long-term reliability (Abhishek Ramesh, 2008). Also, brake-by-wire systems might not have the same rough and ready feel that drivers are expecting when they hit the stoppers, something they will need to get used to.

2.5 Types of Auxiliary Brake

The term "secondary brake" or "retarder" also includes at times an auxiliary braking system employed to supplement the primary (friction) braking system:For example, on a long steep downgrade road, a driver may wish for a supplementary such as an exhaust brake or compression release brake as such a primary brake system may be overwhelmed with heat damage. They are necessary to prevent overheating and too much wear and tear on the primary brakes in long lasting braking, for example at long downhills (Södertälje 2016).

Auxiliary brakes improve vehicle safety and efficiency by offering extra braking force, which keeps the primary brakes ready for emergencies and fast stops. Additionally, they aid in preserving improved stability and control throughout lengthy descents, which can be difficult for cars that are highly loaded (Voorburg, 2022).

2.5.1 Engine Brake

The engine brake, sometimes known as the Jake brake after the company Jacobs Vehicle Systems, who invented the technique, is a popular kind of auxiliary brake. The Jake brake, which is primarily utilised in diesel engines, functions by altering the way exhaust valves operate to significantly increase engine back pressure (Vigna, 2018). Exhaust valves are opened close to the peak of the compression stroke during braking in order to release compressed air and stop it from pulling the piston back down. In effect, this turns the engine into a compressor that absorbs power and slows down the car (Vigna, 2018). Heavy trucks benefit greatly from the immense braking power that jacked brakes provide without having to worry about the primary brakes overheating. **Table 2.1** summarizes the pros and cons of engine braking.

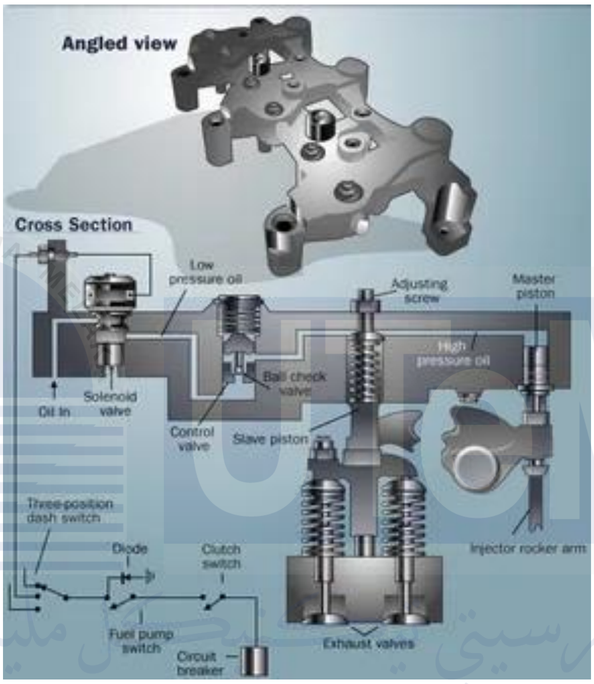


Figure 2.16 Engine Brake (HowStuffWorks, 2008)

PROS	CONS
• Reduced brake wear • Enhanced control, especially on descents • Effective heat management • Potential fuel efficiency in certain conditions • Emergency backup braking capability	• Noise • Reduced efficiency on flat terrain • Potential increased engine wear • Learning curve for drivers • Limited effectiveness at low speeds

Table 2.1 Pros and Cons of Engine Brake (ZerotoHundred, 2016)

2.5.2 Exhaust Brake

Compared to Jake brakes, exhaust brakes work on a simpler concept. They function by blocking the engine's exhaust gas flow, which produces back pressure and causes the engine to slow down. An exhaust system valve that is triggered causes a partial closure, which raises the engine's resistance and exhaust pressure (Balasubramaniam & Senthil Kumar, 2019).

The engine and the car are slowed down by this additional resistance. To improve total braking performance, exhaust brakes are frequently utilised in conjunction with other braking systems. Although they are not as strong as Jake brakes, many medium-duty vehicles and buses choose them since they are quieter and simpler to install (Palanisamy et al., 2018).

Figure 2.17 Exhaust Brake (PakWheels, 2003)

PROS	CONS
• Exhaust brake is the least expensive. • Exhaust brakes emit minimum noise.	• Half the stopping force of brakes on conventional engines with compression. • Limited settings available (only ON & OFF). • Braking force at low rpms are limited.

Table 2.2 Pros and Cons of Exhaust Brake (TheDieselStop, 2006)

2.5.3 Retarders

Another type of auxiliary brake that can be used independently of the primary brakes is called a retarder. Retarders come in two primary varieties, hydraulic and electromagnetic. Advanced brake systems called hydraulic retarders are mostly seen in heavy-duty commercial vehicles. They reduce wear and tear on the primary braking system by providing additional braking force (Kui Yang Wang, 2014). These retarders work by using a specific hydraulic fluid or the gearbox fluid of the vehicle. Within the retarder unit, the fluid is driven through a number of chambers or vanes, generating resistance that causes the vehicle to slow down(Martin Macánek, 2019). Through this process, the vehicle's kinetic energy is transformed into heat, which the fluid dissipates.

The capacity of hydraulic retarders to provide steady and seamless braking performance is one of their main benefits, as it improves driver comfort and safety. They work especially well in stop-and-go traffic and lengthy descents when traditional brakes would likely overheat (Martin Macánek, 2019). Furthermore, hydraulic retarders help to decreased maintenance costs and extend lifespan of braking components by lowering dependency on the primary brake system. For long-haul trucks, buses, and other large commercial vehicles that need dependable and effective braking solutions, this makes them an indispensable component (Kui Yang Wang, 2014). **Table 2.3** summarizes the pros and cons of hydraulic retarder.

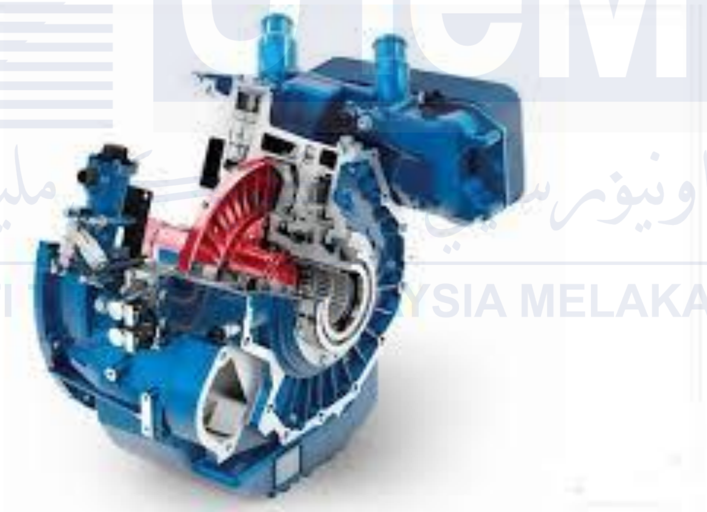


Figure 2.18 Hydraulic Retarder for a Truck (CLVehicle, 2019)

PROS	CONS
• Strong and smooth braking • Reduced brake wear • Effective heat dissipation • Increased safety, especially on long descents • Reliability and low maintenance	• Initial cost • Added weight • Complexity in integration and maintenance • Fluid maintenance requirements • Limited effectiveness at low speeds

Table 2.3 Pros and Cons of Hydraulic Retarder (Abdul Khaliq, 2015)

On the other hand, another type of advanced braking system employed in heavy-duty trucks is electromagnetic retarders that supply consistent and reliable stopping capability. And these retarders works on electromagnetic induction principles to produce resistance (Shreyansh Meshram, 2022). When the vehicle drops speed a retarder generates electromagnetic fields to forces flow of eddy currents through a metal disk or drum The resulting braking force slows the car down. Because other engine brakes reduce their output with the decrease in engine lugging, making them unpredictable in such a way as to when the maximum braking could respond.(IEnumerable Sanjay Katarey, 2022, MaxErbatic).

They are also efficient and have low maintenance needs to make them a cost-effective choice for commercial fleets. This reduces wear on brake components, ultimately saving maintenance costs and promoting vehicle safety, as it reduces the load on the primary brake system. In essence, electromagnetic retarders are an appealing solution for heavy-duty vehicles that coupled with a rugged environment variability have strong consistent braking power with a low maintenance brake system which is proven to deliver excellent performance (Avinash Patel, et al. 2015). Among electromagnetic retarders, the advantages and disadvantages are summarized in Table 2.4.

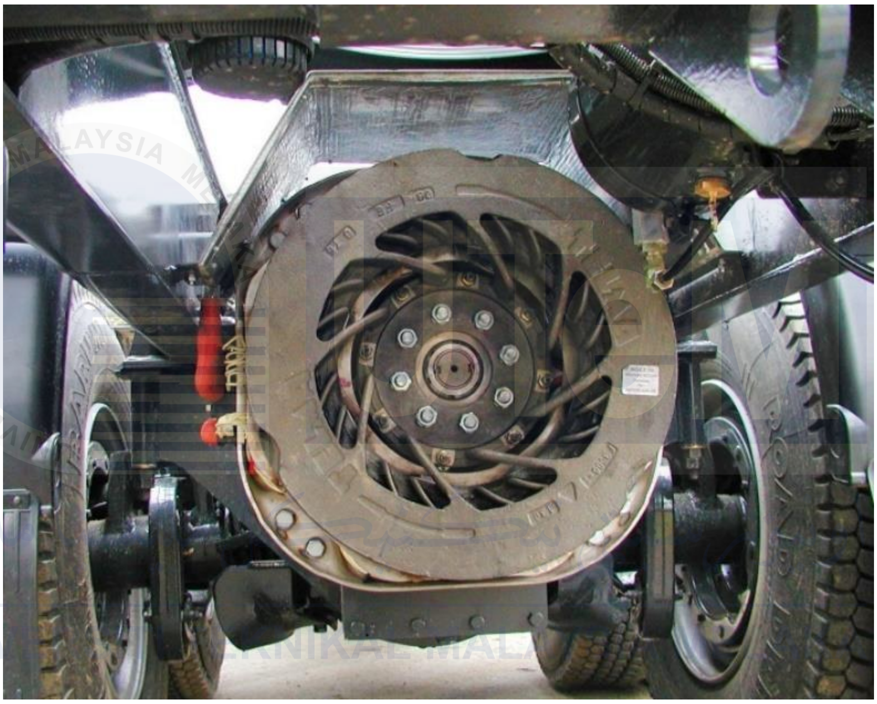


Figure 2.19 Electromagnetic Retarder on a Truck (Porgest, 2021)

PROS	CONS
• Silent functioning • Able to apply brakes when the engine is not running or the gearbox is in neutral; no special upkeep is needed • Compared to hydraulic retarders, electromagnetic retarders offer a quicker reaction time. • Increasing braking in response to pedal position • There is no need to replace worn components or fluid. • Able to be combined with ABS systems	• Operator education is required for both general use and while used in slick conditions. • Uses power to run the car; a bigger alternator could be needed.

Table 2.4 Pros and Cons of Electromagnetic Retarders (Avinash Patel, 2015)

2.5.4 Compression Release Engine Brakes

Compression-release engine brakes: Engine brakes that dump some of the compressed air in the engine cylinders when the piston cannot move back to the top of its stroke. This action helps to cool down the engine and acts as an effective brake by releasing heat from the engine out through the exhaust system. To control the power production, these brakes release the compressed air and prevent it from being added to the engine by retiming the exhaust valves to open during the compression stroke (Jia, 2018). This type of brake has immense stopping power which is needed when very large vehicles are on steep descents. It lessens the possibility of brake fade from overheating by enabling drivers to maintain greater control and stability (Martin Macánek, 2019) . **Table 2.5** below shows the pros and cons of compression brakes.

PROS	CONS
• Not as costly as other retarder systems. • Far more braking power compared to conventional exhaust brakes. • Adjustable braking level for the user. • Able to be integrated for automated applications with cruise control. • Automatic gearbox controls that allow downshifting for increased braking.	• May cause increased exhaust noise, which is not allowed in certain places. • Operator education is required for both general use and complex situations. • Braking force at low rpms are limited.

Table 2.5 Pros and Cons of Compression Brake (Motor Vehicle, 2016)

2.5.5 Regenerative Braking System

During braking, regenerative braking systems, which are frequently seen in electric and hybrid cars, absorb kinetic energy and transform it into electrical energy, which is then stored in the battery of the car (Aravind Samba, 2013). By repurposing the energy it has gathered, this device not only slows down the car but also improves energy efficiency overall (Murthy, 2013). The electric motor that ordinarily propels the car goes into reverse when the driver uses the brakes, generating power from kinetic energy (Singh, n.d.). By storing this energy in the battery for later use, the range of the car is essentially increased. In stop-and-go traffic, where repeated braking can greatly recharge the battery, regenerative braking systems are very helpful (Murthy, 2013). **Table 2.6** below summarizes the pros and cons of the regenerative braking system.

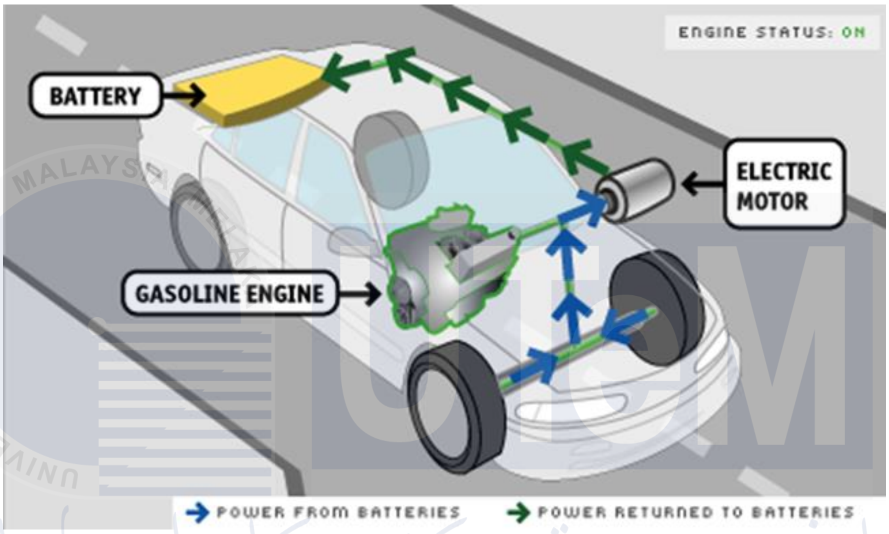


Figure 2.20 Regenerative Braking System (Motor Vehicle, 2020)

PROS	CONS
• Energy recovery • Less mechanical strain • Lower maintenance cost • Energy conservation	• Higher initial costs • Increased system complexity • Inconsistent Braking • Efficiency drop in stop-and-go traffic • Reduced effectiveness with degraded batteries • Added weight from extra components

Table 2.6 Pros and Cons of Regenerative Braking System (Akshay Thakur, 2021)

2.5.6 Transmission Brakes

Transmission brakes, sometimes called gearbox brakes, are an essential part of a car's braking system, particularly a heavy-duty one. These brakes, which are mounted directly on the gearbox of the car, apply hydraulic pressure or friction to slow down the driveline and, in turn, the car (Wandera Mourice, 2010). Usually installed on the gearbox's output shaft, they provide more stopping force without overworking the wheel brakes.

This braking force distribution is very useful while making long descents when control is crucial. Driveline brakes help to manage the braking load, which keeps the primary brakes from overheating and guarantees that they will continue to work even in an emergency (Wandera Mourice, 2010). As a result, they are a top option for heavy-duty vehicles that operate in difficult terrain or severe conditions since they significantly improve performance and safety. **Table 2.7** summarizes the pros and cons of transmission brakes.

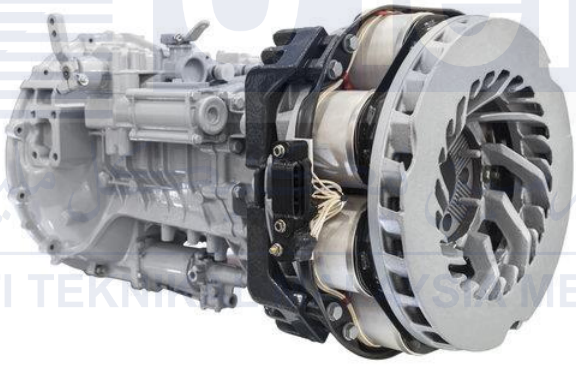


Figure 2.21 Transmission Brakes (Philipus, 2023)

PROS	CONS
• Function without regard to engine speed or gearbox ratio. • Strong retardation force even at slow-moving speeds. • Coordinated by the gearbox controller and integrated within the gearbox	• Produce heat that the car's cooling system needs to remove. • More expensive than engine compression or exhaust brakes

Table 2.7 Pros and Cons of Transmission Retarder (Olivia Wilson, 2024)

2.6 Comparisons of Common Auxiliary Brakes

Exhaust brakes, engine brakes, driveline retarders, and gearbox retarders are the most popular kinds of auxiliary brakes. Depending on the application and particular vehicle requirements, each type has distinct advantages and disadvantages and functions in a different way. It is crucial to understand these variations in order to select the proper braking system for a given set of driving circumstances and vehicle models. **Table 2.8** below shows the differences in terms of braking power, noise, weight, cost, heat generation, and maintenance between these auxiliary brake types.

	Exhaust Brake	Engine Brake	Driveline Retarder	Trans Retarder
Braking Power	Low	Medium	Highest	High
Noise	Low	Medium	Low	Low
Weight	Low	Low	Highest	Medium
Option Cost	Low/Medium*	Medium	Highest	Highest
Heat Generation	Low	Low	High	Highest
Maintenance	Low	Low	Medium	Medium

Table 2.8 Differences between the most common Auxiliary Brakes (FAMA, 2021)

2.7 Integration of Auxiliary Braking System with Emergency Brake Systems in Commercial Vehicle

Modern electronic control units (ECUs) as shown in **Figure 2.22** that are capable of managing and coordinating the operations of both emergency and auxiliary brake systems enable the integration of these systems. ECU Coordination is one of this integration's main features (Gunjate & Khot, 2023). Advanced algorithms installed in modern ECUs process data from multiple sensors in real-time. This makes it possible to handle emergency and auxiliary braking systems with ease. For example, the ECU can immediately engage the auxiliary brakes to aid in deceleration if it senses that the primary brakes are overheating (Shital Suresh, 2023).

Figure 2.22 Modern Electronic Control Unit(ECU) (Karim Nice, 2021)

Moreover, in certain critical conditions (with a brake failure already detected by the ECU, or about to occur) emergency braking is simply automatically activated, and automatically combined with controlled auxiliary braking, which is guaranteed an essential safety element (Vigna, 2018). The integration of ECU as shown in Figure 2.23 minimizes the occurrence of accidents, skidding, and loss of control by making sure the vehicle can be controlled stopped even when primary brakes are disabled. The ECU will bring the auxiliary brakes online and fire the emergency braking system when it detects potential failure. It then tailors the power of the auxiliary brakes so the vehicle can make a slow, controlled drop (Vigna, 2018).

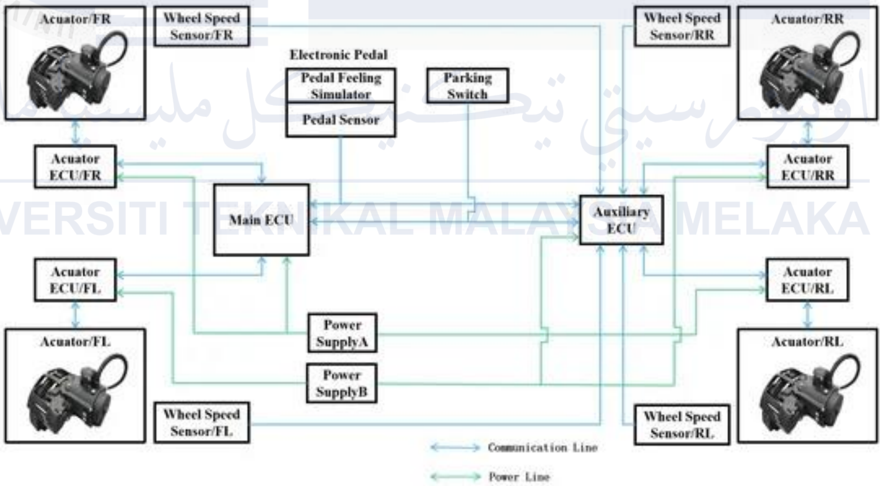


Figure 2.23 Circuit connection of ECU to Auxiliary Brake System (MDPI, 2023)

The technology optimises the vehicle's braking performance by dynamically distributing brake force to each wheel, using real-time data from the sensors that monitors the speed of the vehicle, the load of the weight and the condition of the road. This keeps the vehicle stable and secure throughout the whole stop Sastiki D, 2019). This coordinated effort reinforces the importance of the role of the integrated braking system in vehicle safety and reliability, a role that is even more critical in emergency conditions which require split seconds for effective decision-making (De Novellis, 2014).

Sensors are the eyes and ears of the integrated brake system, and carry important data that the ECU uses to help distribute braking force intelligently. As presented in Fig. 2.24 the vehicle speed sensor provides the ECU with up-to-date speed information with which it can calculate the appropriate braking force to induce the desired deceleration rate (Heydrich et al., 2021). The brake temperature sensor (fig 2.25) monitor the temperature of the front and rear main brakes and alerts the ECU of a potential overheating issue that might reduce the car's stopping power. Load weight sensors measure the load the car is carrying which in turn effects how much braking power is necessary, taking into account the different dynamics with large loads (Heydrich et al., 2021).

Figure 2.24 Vehicle Speed Sensor (CarParts, 2024)

Figure 2.25 Brake Temperature Sensor (FAMA Engineering, 2023)

Furthermore, there are also sensors for monitoring road conditions and pressure sensors for detecting wet or icy surfaces and infrared sensors for sensing presence of obstacles etc., which provide informative data about the surroundings of vehicles which make it possible for the ECU to dynamically adjust its braking strategies for safety and traction demands (Ma et al., 2022). Through analysis of all this data, the ECU can dynamically distribute the braking force on the primary, auxiliary and emergency systems to best adapt to a variety of driving conditions, thereby enhancing the safety and stability of the vehicle brake function.

2.8 Challenges in Implementing Auxiliary Braking Systems in Commercial Vehicles.

When it comes to auxiliary braking systems in commercial vehicles there are many different challenges and considerations to ensure the deployment is effective, safe, and reliable.

One big hurdle that comes with implementing auxiliary braking systems for commercial vehicles is compatibility and integration with existing vehicle systems. It is neither obvious nor trivial how to enable this smooth integration from today's commercial vehicle braking systems - with a lot of complexity - to an embedded system that is able to execute the given algorithms (Hu et al., 2023). Integrative: To maintain the validity of the vehicle brake system, each new part or technology must integrate with the current setup (FAMA, 2021). That involves ensuring not only the physical compatibility of the control systems, sensors and software interfaces, but that they also connect without a glitch. Interfere any in vehicle with rolling brakes system accuracy, is the safety dangerous behavior, can be make cars out of control or even cause accidents.

It is mandatory to assure without fail that the auxiliary braking systems (ABS) of commercial vehicles are made durable and reliable to handle extreme operating conditions. These system must withstand high temperature, frequent usage, and possible wear and tear and without any compromising on account of their efficacy and safety (Hu et al., 2023). Manufacturers have to make use of quality materials, apply sound design and engineering principles, and then thoroughly test to evaluate the performance of the system in real-world conditions (Strategic Market Visionaries, 2024). You still need to have proactive maintenance done to prevent premature wear, and to catch any potential issues before they get out of hand. Durability and reliability are key to boosting fleet performance-and customer satisfaction-for manufacturers and operators alike.

Since auxiliary braking systems for commercial vehicles frequently need a sizable investment from network operators, cost considerations are crucial when implementing these systems. Therefore, a thorough analysis of the return on investment is required to support the implementation of such systems (NHTSA. 2009). In this analysis, the initial expenditures are compared to the possible advantages—such as enhanced safety standards, lower maintenance costs, and better vehicle performance. Transport companies need to carefully consider things like increased fuel efficiency, longer vehicle lifespans since fewer key brake components are worn out, and possible insurance savings from better safety measures (NHTSA, 2009).

Transport companies are better equipped to decide whether to install auxiliary braking systems by performing a detailed cost-benefit analysis.

Auxiliary braking systems for commercial vehicles must be implemented with careful regard for regulations and compliance requirements. In order to maintain legal compliance and reduce any liability concerns, these systems need to be in accordance with all applicable safety standards and laws (Wabco, 2011). Complying with these regulations necessitates extensive certification and testing procedures to confirm that the auxiliary braking system satisfies or beyond recognised safety standards. Commitment to regulations not only protects against legal consequences but also creates confidence among consumers, such as vehicle operators, drivers, and government agencies, regarding the dependability and efficiency of the auxiliary braking system (Wabco, 2011). Therefore, the effective integration of auxiliary braking systems into fleets of commercial vehicles depends on managing regulatory environments and guaranteeing compliance (UN Regulations, 2023).

2.9 Implementation and Testing

In order to create a complete system that incorporates both hardware and software, a number of processes and tests are necessary. This is to get everything ready for the calculation and optimisation of the parameters and schema. It is possible to conduct simulation experiments on almost all components while they are operating. Simulation experiments are among the most crucial research and development methods. This is because of the method's safety concerns, which include fewer injuries, speed, repeatability, and relative economy. The experiment's requirement for more parameters and a sophisticated schema is a disadvantage, though. Additionally, it is difficult to learn the exact experimental technique. Having said that, a sophisticated concurrent simulation testing method using hardware and mathematics simulation was needed.

Therefore, researchers use a sophisticated co-simulation method called Model-in-the-Loop (MIL) simulation. The automotive sector makes extensive use of this testing system. This is because there is a good chance that this approach will increase convenience and lower costs. Currently, one of the most important validation techniques is the MIL approach. This is because it can validate mathematical models (virtual) as well as hardware (actual). MIL can be broken down into several techniques, the most significant of which were hardware-in-the-loop (HIL) and software-in-the-loop (SIL) simulation.

2.9.1 Software-in-the Loop Simulation

Software validation that is based on simulation is known as software-in-the-loop (SIL) simulation. When it comes to model validation for today's intricate large-scale networks, SIL simulation can overcome the low quality and slowness of traditional simulations. Additionally, it may be applied to both the project's design and testing phases and is able to solve the traditional simulation issues with model validity. SIL blends hardware accuracy with the simulator's affordability and flexibility. It is simple to use in both the design and testing stages, and by maximising code reuse and reducing software development coding effort, it may result in significant cost savings.

In SIL simulation, testing takes place in the virtual realm rather than on hardware. However, SIL simulation can be run under a variety of simulated input situations during software analysis. Investigating the software system's functionality under various input situations is the primary goal of the evaluation. Multibody dynamics, a 3D virtual model, or a mathematical model are used to build the plant model. The 3D virtual model closely matches the plant model's real setup.

Furthermore, any faults that occurred in a system prior to its implementation into HIL and Vehicle-In-the-Loop (VIL) simulation methodologies are referred to using the SIL simulation approach. The actuator and real vehicle involvement in the simulation analysis are referred to as HIL and VIL approaches. This lessens significant mistakes that could harm the actual hardware system or endanger the people doing the testing directly. Additionally, during testing, SIL is used to find any undesired failing conditions that might arise inside the controller design.

2.9.2 Hardware-in-the Loop Simulation

The mathematical model is swapped out for the hardware-in-the-loop (HIL) simulation technique. More genuine hardware system testing is used. As of right now, one of the most frequently accepted recognised approaches for creating different automotive control systems is HIL. Automotive researchers and designers now use HIL testing as one of their resource tools. The intended input is simulated in order to evaluate the device. Additionally, it is checked for disturbances that could arise in actual circumstances.

This will notify the researchers in the event that the suggested hardware makes a mistake that could harm the device or endanger human life. The researchers can also test the hardware's capabilities up to its maximum limit in the interim. Additionally, Deng et al. noted that testing an actuator on a real system necessitates a combination of both approaches. This will assist in determining the hardware's performance prior to its application to the real automobile system. Additionally, the method can maximise the system's robustness while drastically cutting down on the amount of time required to analyse it.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Regarding the exhaust brake, but in a more general outlook, integral stages of the design and prototyping phases for an emergency brake system for a commercial vehicle using an auxiliary braking system can be noted. Literature survey and requirement specificationsFirst step is to perform a detailed literature survey and demand analysis to understand the current emergency and auxiliary braking system. This means that the consortium will identify the specific needs and performance targets for commercial vehicles and analyze the limitations of traditional braking systems.

Then the design phase involves sharing the exhaust brake into the emergency brake system. That could mean, for example, using computer-aided design (CAD) tools to create intricate schematics and models that correspond with various designs commercial vehicle available. Each step in the process will be scrutinized to accomplish the purpose of the project Figure 3.1 - Entire Work Flow Chart of Project Methodology

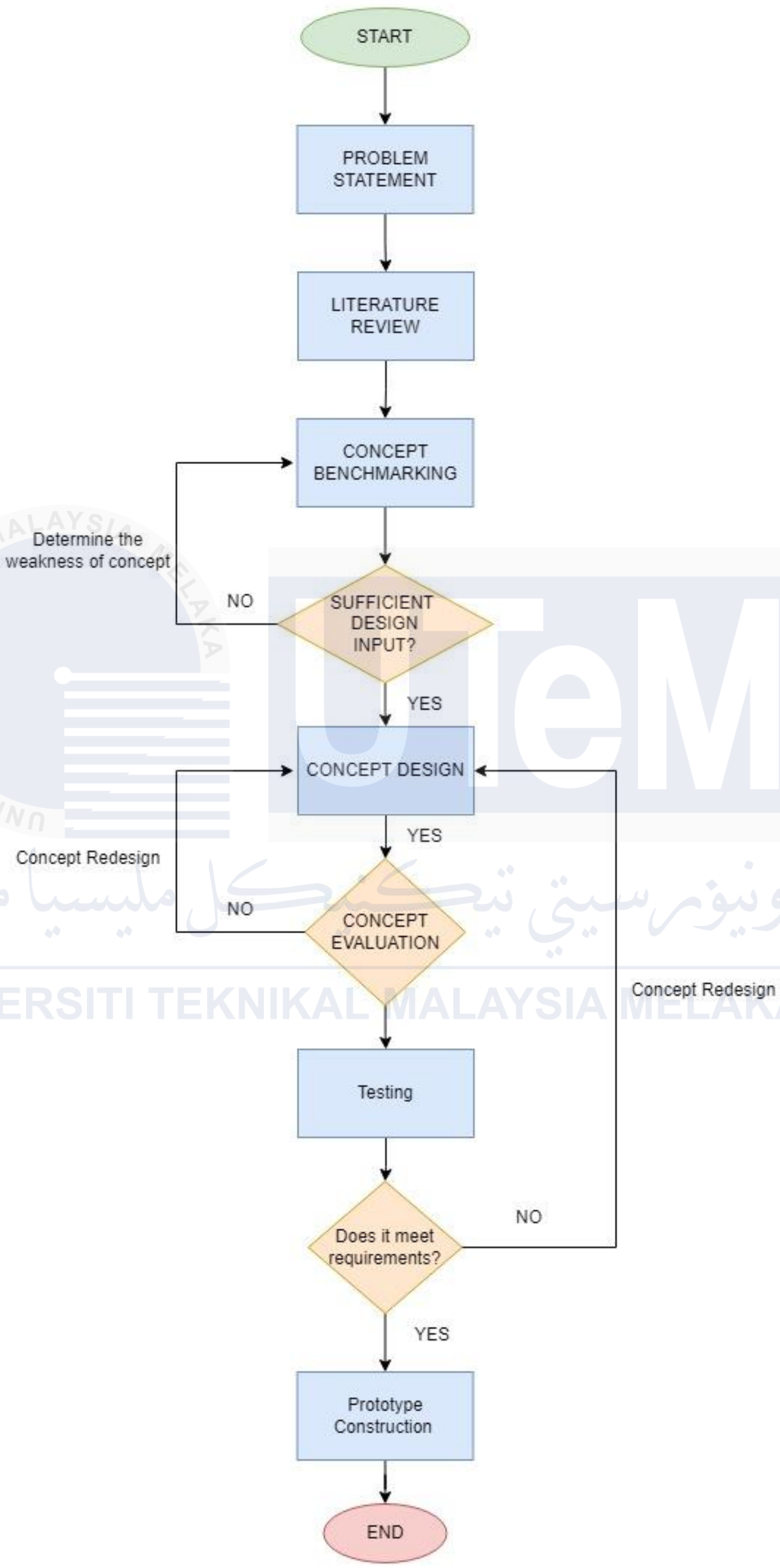


Figure 3.1: Overall flow chart for the methodology of the project

3.1.2 Research Background

Researches, which have been developed across a vast number of topics in the world of commercial vehicle braking systems, can tackle issues that range from brake force distribution and characteristics of different brake devices to the role played by electronic control systems to increase the efficiency of stabilization. Nevertheless, there remains a void in research and development activity in the specific area of the exhaust brake-dependent emergency braking. This project aims to design and build a prototype exhaust brake based emergency braking system to overcome this gap thereby increasing the safety of the vehicles as a whole.

Recent development in Computer Aided Design (CAD) and simulation tools have brought a revolution in how the complex systems can be accurately modelled and tested. The deployment of these tools allows researchers to more accurately predict the behavior of new braking systems in various situations, resulting in the development of more reliable and effective prototypes. By employing these advances in technology the objective of this study will be to develop, fabricate and test a proof-of-concept exhaust brake emergency braking system. The objective of the project is to demonstrate the usage and advantages of such a system in commercial vehicles via comprehensive simulations. With vehicle technology advances such as this, commercial vehicle operation will be much safer and this work is a supported contribution to allow technology to advance toward that goal by the researchers from IFW Dresden and TU Dresden (possibly a mouthful)... so far, the whole collaborative project prove to be on the right way with a strong and reliable prototype to seamlessly integrate in present car architectures.

3.2 Concept Benchmarking

The concept of the system was a benchmark in the literature of the early stages of this project. Being able to find prototype designs made by other researchers was another responsibility, but in this case the challenge also required comparing the concept with available products and ultimately creating a refined prototype that could allow the project to achieve its goals. New prototype concepts to be considered and tested later in this project were inspired by various concept prototype designs, component designs, and concept designs evaluated in the concept design stage.

Also we looked more into the right coding algorithm. Based on these strategies, they also then served as inspiration to create new algorithm which would, in the case of testability, the movements of the prototype. We were able to select the most suitable prototype for the system under development in this project with the assistance of all the data gathered from literature reviews. Many of the concepts from earlier research have been reimagined and included in the product.

3.3 Concept Design

The primary goal of the design of the system is to minimise vehicle modifications and associated expenses by utilising a product development approach that is integrated into the vehicle. The primary idea behind this device's design is to keep things simple and practical while utilising modern innovations to make it easier to fit into any type of vehicle. The adaptable design concept suggests that any car can have this innovative system installed, meaning that premium cars aren't the only ones that could. In order to minimize the impact on the vehicle's price when this system is installed, the design aims to create a high-quality, dependable system at a cheap cost.

3.4 Product Design Development

The design and fabrication of the emergency brake system for commercial vehicles using an auxiliary braking system was developed and advanced in this section. The criterion entails carrying out crucial market research before beginning actual production in order to guarantee the greatest possible outcome of the final product that minimises the limitations and defects of the product. Utilising every component that comes together to form a system in the most effective way is essential to achieving this goal. The design development process must be split into three parts in order to do this: component design, product development, and concept generation and evaluation. This part is coordinated and reciprocal with each other.

Table 3.1: Types of Arduino Board.

Specification	Arduino UNO	Arduino Mega	Arduino Leonardo	Arduino Due
Processor	16MHz Atmega 328	16 MHz Atmega 2560	16MHz Atmega 32u4	84MHz AT91SAM3X8E
Operating Voltage	5 V	5 V	5 V	3.3 V
Input Voltage	7-12 V	7-12 V	7-12 V	7-12 V
Input Voltage	6-20 V	6-20 V	6-20 V	6-16 V
Digital I/O Pins	14 (6 PWM output)	54 (15 PWM output)	20 (7 PWM output)	54 (12 PWM output)
Analogue Input Pins	6	16	12	12
Flash Memory	32 kb	256 kb	32 kb	512 kb
SRAM	2 kb	8 kb	2.5 kb	2 banks: 64KB and 32KB
EEPROM	1 kb	4 kb	1 kb	-
DC current per I/O pin	40 mA	20 Ma	40 mA	130 mA
Price	RM 80-100	RM 160-175	RM 80-105	RM 180-220

3.4.2 Concept Generation and Evaluation

3.4.2.1 Morphological Chart

Table 3.2: Morphological Chart

Function	Solution 1	Solution 2	Solution 3	Solution 4
Pressure Sensor	Digital Barometer pressure sensor BMP280 	Absolute Pressure sensor MPX5700AP 	Gauge Pressure sensor MPX 5010 	Pressure Transducer 
Microcontroller Board	Arduino UNO	Arduino Mega	Arduino Leonardo	Arduino Due
Warning Sound	Small speaker 	Piezoelectric buzzer 	Alarm Siren 	N/A
Motor Actuator	SG 90 servo motor 	MG 995 servo motor 	MG 996 servo motor 	N/A
LED	Red/Green			
DC Motor	1.5V	3V	6V	12V above

The first and last concepts are the only two that are being considered for idea evaluation, despite the fact that the Morphological Chart results indicate that there are five possible optimal settings in the concept. The Digital Barometer Sensor, Arduino Leonardo, Small Speaker, RED/GREEN Led, SG 90 servo motor, and 1.5V DC motor are used in the first one (blue line).

The advantage of this setup is that it costs far less overall than others because the Arduino Leonardo, SG 90 servo motor, and 1.5V DC motor are all reasonably priced and produce excellent results. Nevertheless, a digital barometer sensor's inability to measure exhaust pressure and merely ambient pressure is a drawback. To activate the little speaker, an additional modification or media player is required, which complicates the software construction process. As a result, the project does not take into account or utilise the initial concept setting.

The pressure transducer, Arduino Mega, piezoelectric buzzer, MG 995 servo motor, GREEN/RED LED, and DC motor 6V above make up the final setup (black line). The advantages of this configuration include its low cost, excellent accuracy, and quick response time. This is a result of industrial engineering's widespread usage of pressure transducers. Because the board has enough I/O pins for this project, the Arduino Mega can handle a system well. Because the piezoelectric buzzer allows the user to fine-tune the sound, we may change the loudness and frequency of the sound to suit our system settings. One drawback of this configuration is that the MG 995 servo motor requires a greater working voltage than the MG 90 servo motor, therefore it replaces the MG 90 servo motor.

3.4.2.2 Pugh's Evaluation Method

Table 3.3: Concept Screening of the 5 concepts

Selection Criteria	CONCEPT				
		1 (Blue)	2 (Orange)	3 (Black)	4 (Purple)
Respond Time	Datum	0	+1	+1	+1
Cost		+1	-1	+1	-1
Reliability		-1	+1	+1	+1
Accuracy		+1	+1	+1	-1
Prototype Authenticity		-1	+1	+1	-1
Warning Effect		-1	0	+1	+1
Simplicity of Indication		+1	+1	+1	-1
Conveniences		0	-1	-1	-1
Easy to construct		+1	-1	-1	-1
Σ (+ 1)		4	5	7	3
Σ (- 1)		3	3	2	6
Σ (0)		2	1	0	0
Σ		4	5	7	6
Rank		2	5	1	4
Continue		NO	NO	YES	NO

From the concept screening result above, the concept 3 has receive the highest rate. Based on the screening process, concept 3 will have better respond time because Of pressure Transducer and Arduino Mega board, lower cost due to inexpensive of components, good reliability, better accuracy, good warning effect due to adjustable piezoelectric buzzer, good indication due to the red and green LED, conveniences and easy to construct because does not have any external power source and extra processing.

3.4.3 Component Design

The first step is to figure out which components, as well as the system's flow, are required for pressure input and detection from exhaust. **Figure 3.2** depicts the new system's operation, whereas **Figure 3.3** depicts the system block diagram.

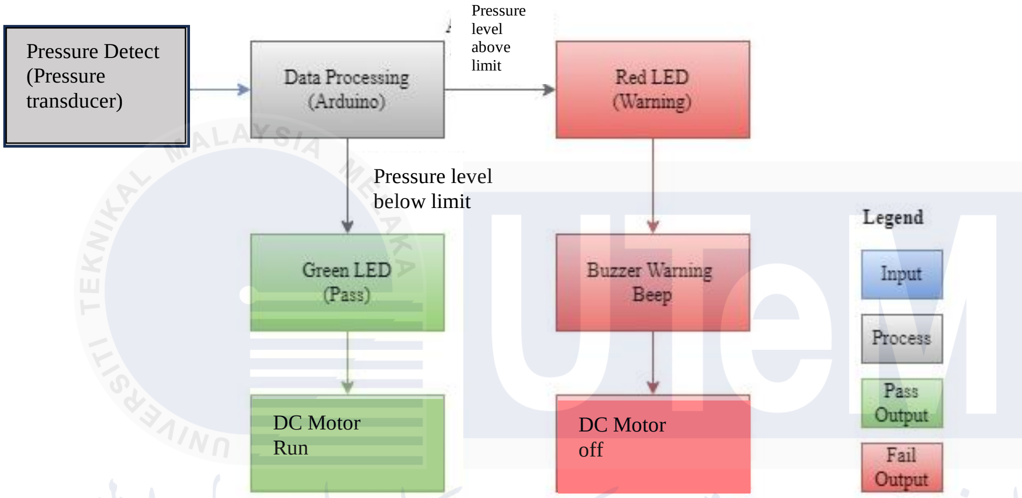


Figure 3.2: Work Flow Of Exhaust Brake System

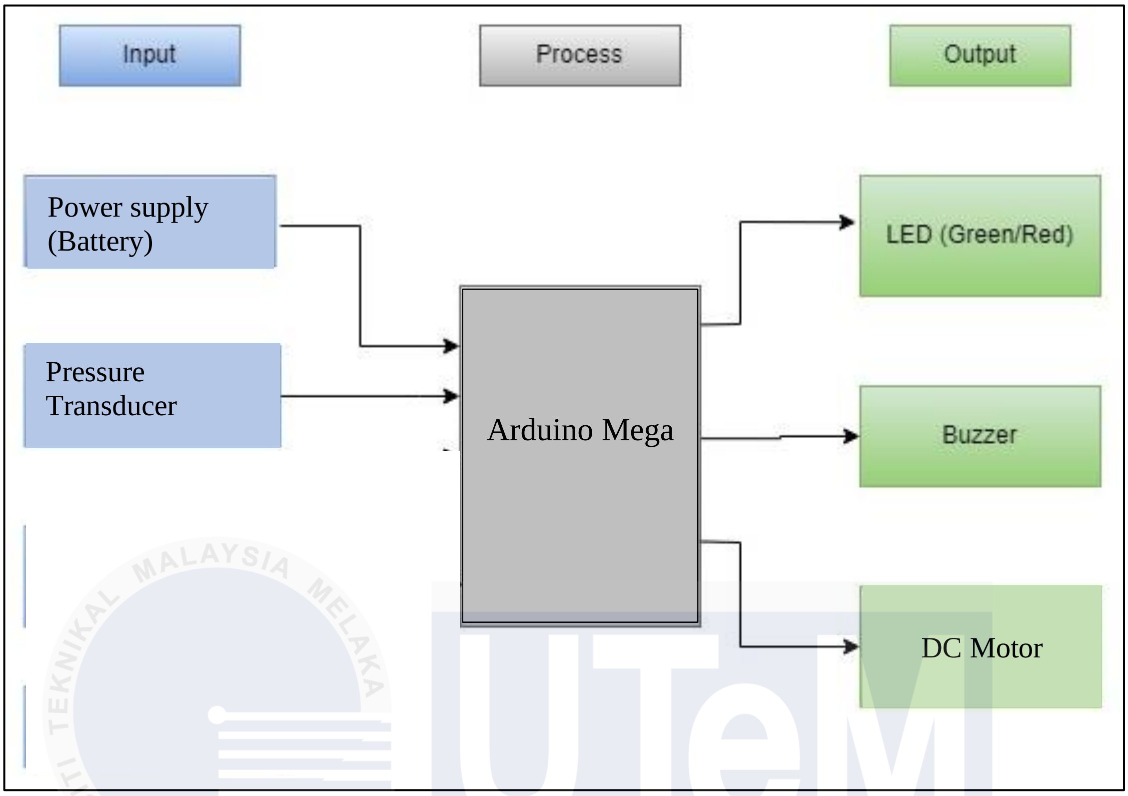


Figure 3.3: Exhaust Brake System Block Diagram

3.4.3.1 Arduino Mega

The Arduino Mega 2560 microcontroller board, which has a 16 MHz crystal oscillator, 4 UARTs (hardware serial ports), 16 analogue inputs, a reset button, a power jack, an ICSP header, and a USB connection, is centred around the ATmega2560 microprocessor. Arduino Mega 2560: As seen in Figure 3.7, the open-source microcontroller Arduino Mega 2560, which has more I/O pins and memory capacity, is recommended for projects that are more complex. Its compatibility with many sensors and actuators and electronics components makes it ideal for advanced embedded systems and inter-electronics.

It is easily programmable and communicate with/instructed from a computer via USB to turn off/on high power (0-1000 watts) lines which have been connected to the AC supply, THE board uses AC to DC using an on-board plug pack to power itself. The ATmega2560 acts as the system's brain, analyzing data and responding according to the code it holds in its memory. This enables the Rpi to control and interact with a plethora of devices, providing a durable& robust platform for engineers and developers to build incredibly intricate electronic projects on top of.

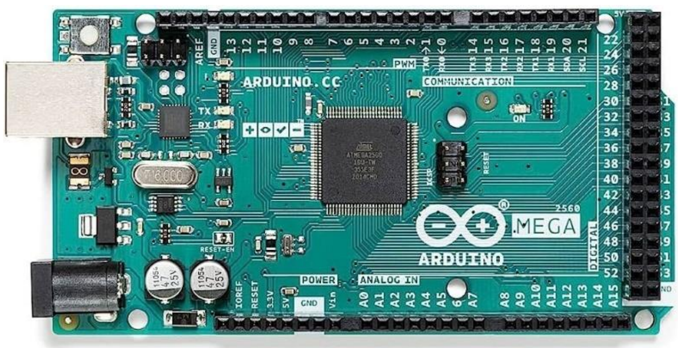


Figure 3.4: Arduino Mega board

We worked out a type of an exhaust brake system, connected to the power supply through an Arduino Mega board. The semiconductor sensor sends a signal to this control unit, which is designed to do so, which then processes the data. It is operated by applications of computer code preloaded on the board that when certain criteria are met, will turn on an LED, activate a buzzer, and finally control the servo motor. The Arduino Mega uses Peripheral Interface Controller (PIC) able to manage up to 12V, so it's OK. Table 3.4. Characteristics of the Arduino UNO

Table 3.4: Specifications of Arduino Mega

Specification	Details
Microcontroller	ATmega2560
USB Type	USB-B
Build-in LED Pin	13
Digital I/O Pins	54
Analog Input Pins	16
PWM Pins	15
I/O Voltage	5V
Input Voltage	7-12V
DC Current per I/O Pin	20mA
Flash Memory	256KB
SRAM	8KB
Clock Speed	16MHz

Program Size: Given the small code, the program size of this Arduino Mega makes it perfect for a system that utilizes a pressure transducer, two LEDs, a buzzer, a DC motor, a servo motor, and some other input. Primarily, that makes the board completely free to use and the system is able to make accurate measurements of the data with a very high level of precision that results in a fast responding and very accurate pressure sensing device. It can be used in line with the project's concept design since it is a compatible microcontroller with a lot of personalisation capability.

3.4.3.2 Pressure Transducer

Because of its accuracy and dependability, the pressure transducer is one of the most often used sensors in a variety of industrial and scientific applications. It is now a standard component of equipment that needs accurate pressure measurement. This transducer's sensing unit usually uses a piezoelectric sensor or strain gauge. When put under pressure, these sensors pick up changes in voltage or electrical resistance. It is possible to determine pressure levels precisely by integrating the transducer into a Wheatstone bridge circuit. A common pressure transducer is depicted in Figure 3.8. It uses electricity in accordance with its operating voltage, which is typically 5 volts DC.

Pressure transducers are useful for a variety of applications because they can measure a wide range of pressures, from very low (a few millibars) to extremely high (thousands of psi). Additionally, these gadgets have unique features including sensitivity adjustments. Through the adjustment mechanism, users can fine-tune the transducer's sensitivity to suit various environments, situations, and objectives. By spinning clockwise to enhance sensitivity, users can decrease it. The transducer can be adjusted to give accurate readings that are customised to meet particular requirements.

Figure 3.5: Pressure Transducer

3.4.3.3 Light Emitting Diode (LED)

The LED bulb is a device that, when activated, emits a strong beam of light. In this project, red and green LED will be used. This red LED will illuminate when the detected pressure exceeds the limits, alerting the driver. The green LED, which signifies that the pressure level is normal in the system. **Figure 3.6** depicts the LED that will be used in the system.

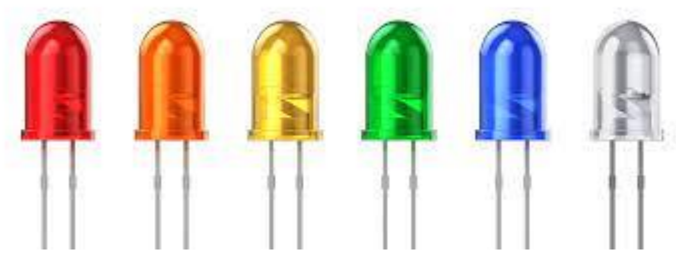


Figure 3.6: LED Bulb

3.4.3.4 Buzzer

Figure 3.7 illustrates the piezoelectric buzzer, one of the system's crucial warning elements. Depending on the configuration, this gadget will either beep or buzz when it detects a voltage or signal. There are three common varieties of buzzers: piezoelectric, passive, and active. Essentially, a piezo-electric material with two electrodes is used to create the piezo-electronic buzzer. This buzzer is the most basic and easiest to use. Its goal is to make someone focus on themselves, because of the pressure detection mechanism. This buzzer needs an oscillator, like a microcontroller, to function properly. The buzzer is reasonably priced and uses little power to generate a loud, clear sound. **Table 3.5** lists all of the specifications for the piezo buzzer that will be utilised in this project.

Figure 3.7: Piezoelectric Buzzer

Table 3.5: Details of the piezo buzzer used in the system

Details	UNIT	Large Piezo Buzzer
Min. Sound Output at10cm	dB	95
Rated Voltage	V DC	12
Operating Voltage	V DC	3~24
Resonant Frequency	Hz	3900±500
Max. Current Consumption	mA	10
Tone Nature	-	Continuous
Alarm Diameter	mm	22
Alarm Height	mm	10
Price per piece	RM	2.94

This piezo buzzer is used by the project system to give the essential sound for the system. When the level of pressure measured by the pressure transducer and gauge exceeds a predetermined threshold level, it will turn on. The buzzer is also inexpensive and simple to use with all of the Arduino boards, which can be found in stock at a local electronics store or on an online shopping platform.

3.4.3.5 Direct Current (DC) Motor

An electrical motor that rotates and converts electrical energy from direct current to mechanical energy is called a direct current (DC) motor. It is one of many varieties of electric motors that rotate. There are two groups into which magnetic field forces and different kinds of magnetic field forces fall. An internal mechanism in the majority of direct current motors alternates the direction of current in a motor component on a regular basis. This device may be electronic or electromechanical.. A direct current motor can have its speed adjusted across a broad range by altering the supply voltage or increasing the current intensity in the primary winding. The universal motor, pictured in **Figure 3.8**, is a small, light, direct-current brushed motor that is used in conjunction with other parts. **Table 3.6** offers further details about DC motors.

Figure 3.8: Small DC Motor

Table 3.6: DC motor specifications

ITEM	SPECIFICATION
Rated Voltage	6V
No. load speed	9100 ± 1800 rotation per minute
No. load current	70 mA
Operating voltage	1.5 V to 12 V
Starting Torque	20 gcm (depends on blade used)
Starting current	500mA
Insulation Resistance	> 10 Ω
Rotation Direction	Clockwise at positive terminal
Axis Diameter	2 mm

3.4.3.6 Servo Motor

A servo motor is a type of rotary actuator that combines a position feedback sensor and a motor to provide exact control over acceleration, velocity, and angular position. The motor's control circuitry continuously modifies its movement to align with the target position, which is dictated by a servo signal. This ensures high precision and accuracy.

One of those important functions, the project's exhaust brake systems feature an exhaust valve controlled by a servo motor; By controlling where the valve sits, it can restrict the escape of exhaust gases, creating back pressure in the engine and thus assisting with slowing the car down. Braking is effective, as the servo motor reacts quickly enough to maintain valve adjustment in response to braking commands. It is particularly important in emergencies (especially sudden deceleration.) The integrated feedback system, which constantly verifies the valve position against the desired setting, further increases the system's accuracy and reliability. Better still, the precision control provided by the servo motor means exhaust brake, which is able to tailor braking force based on vehicle speed and load (by manipulating valve position) **Figure 3.9** shows the type of servo motor used in this project and its specifications stated in **Table 3.7**

Figure 3.9: MG996 Servo Motor

Table 3.7: Specification of MG996 Servo Motor

Rotation	180deg
Weight	55g
Sizes	40.7 x 19.7 x 42.9 mm
Working voltage	4.8V-6.6V
Stop Torque and Current	11kgf/cm(2.5A) at 6V
Current Drawn	500mA – 900mA
Dead Bandwidth	5us
Temperature Range	0 – 55 deg celsius

3.4.5 Conceptual Prototype Development

TinkerCAD software was utilised in the early stages of conceptual prototype development to produce design concepts based on the several projects cited in the literature review. The circuit was constructed using software, and it is possible to write program code to test the circuit. A pressure transducer and a few other new parts were added to the prototype design from the (International Journal for Multidisciplinary Research, 2023) as seen in **Figure 3.10**. The ultrasonic sensor and LCD display were removed from the circuit to make it simpler, and they are not needed for this project. While the system's flow has been totally changed and there has also been a significant adjustment to meet the project's goal, some system components have remained unchanged. The optimal design is illustrated using the TinkerCAD software, as shown in **Figure 3.11**.

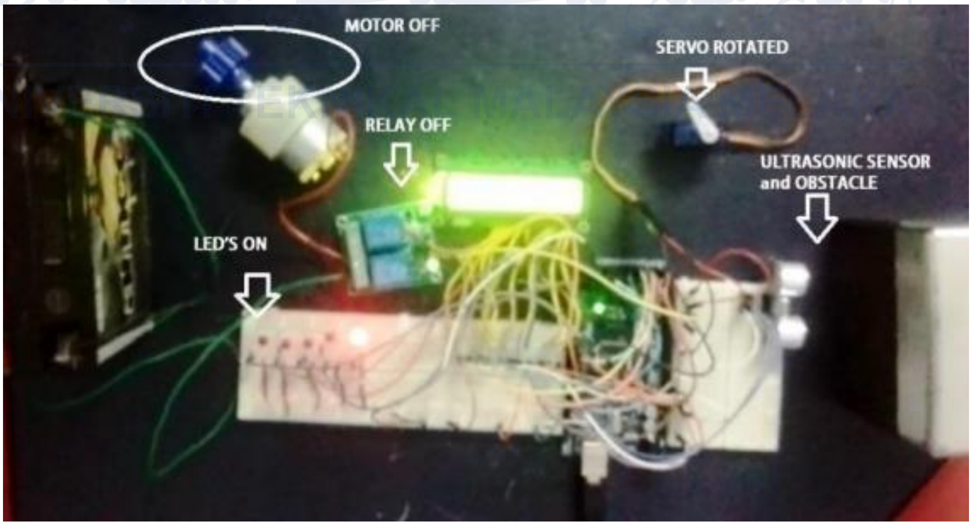


Figure 3.10: Design and Fabrication of Emergency Braking System (IJFMR, 2023)

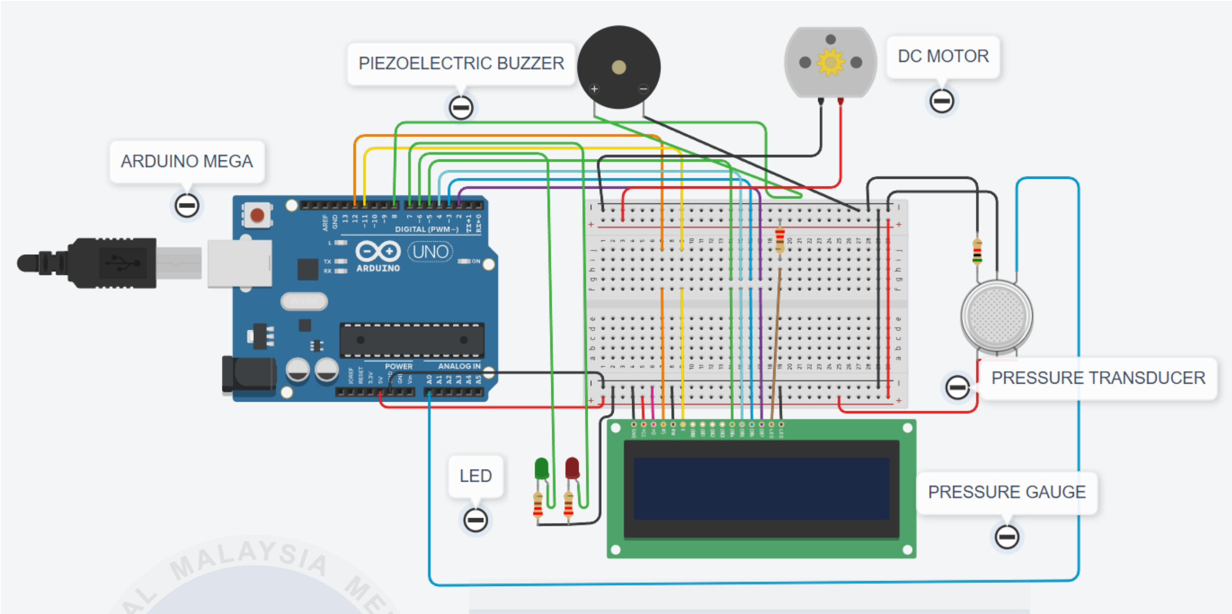


Figure 3.11: Emergency Braking System Concept Design

3.4.5.1 Simulink Block Diagram

It is mandatory to write any new microcontroller-based devices, like Arduinos, in C++ or another programming language. In this project, the microcontroller was programmed using MATLAB Simulink software. To operate the sensor and other parts in line with the system's parameters, it is essential and crucial. Programming is crucial to this project since each component's functionality depends on the Simulink model being uploaded in accordance with the system's requirements. An already pre-programmed block diagram model will serve as the foundation for the new system. When the programme is launched, it will be made to respond extremely quickly and accurately.

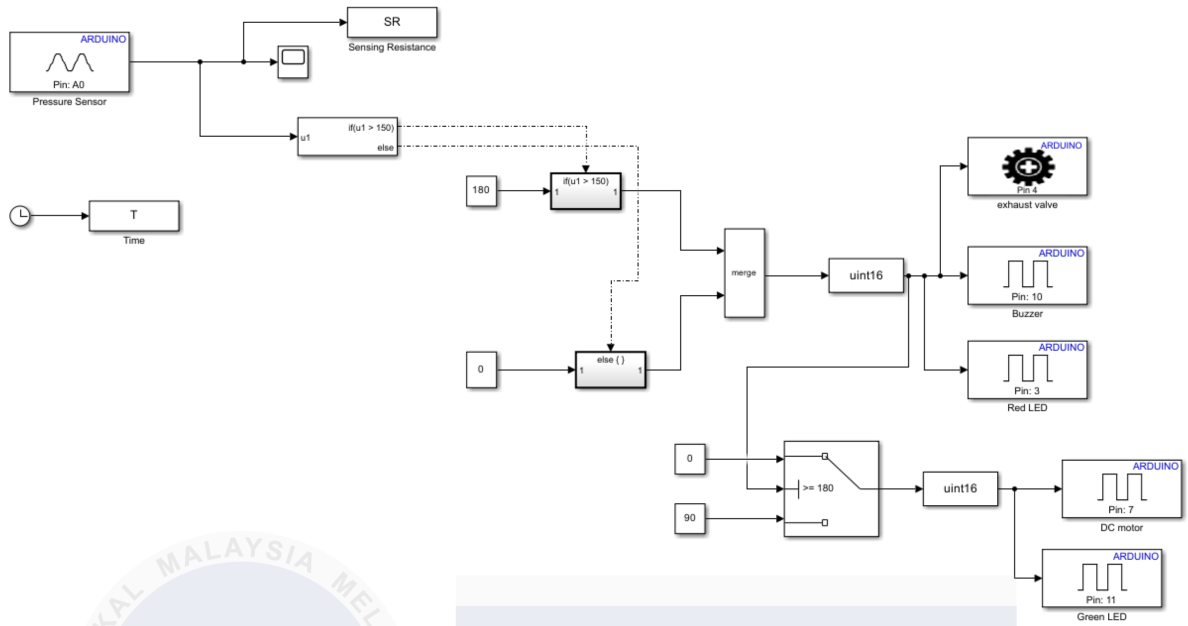
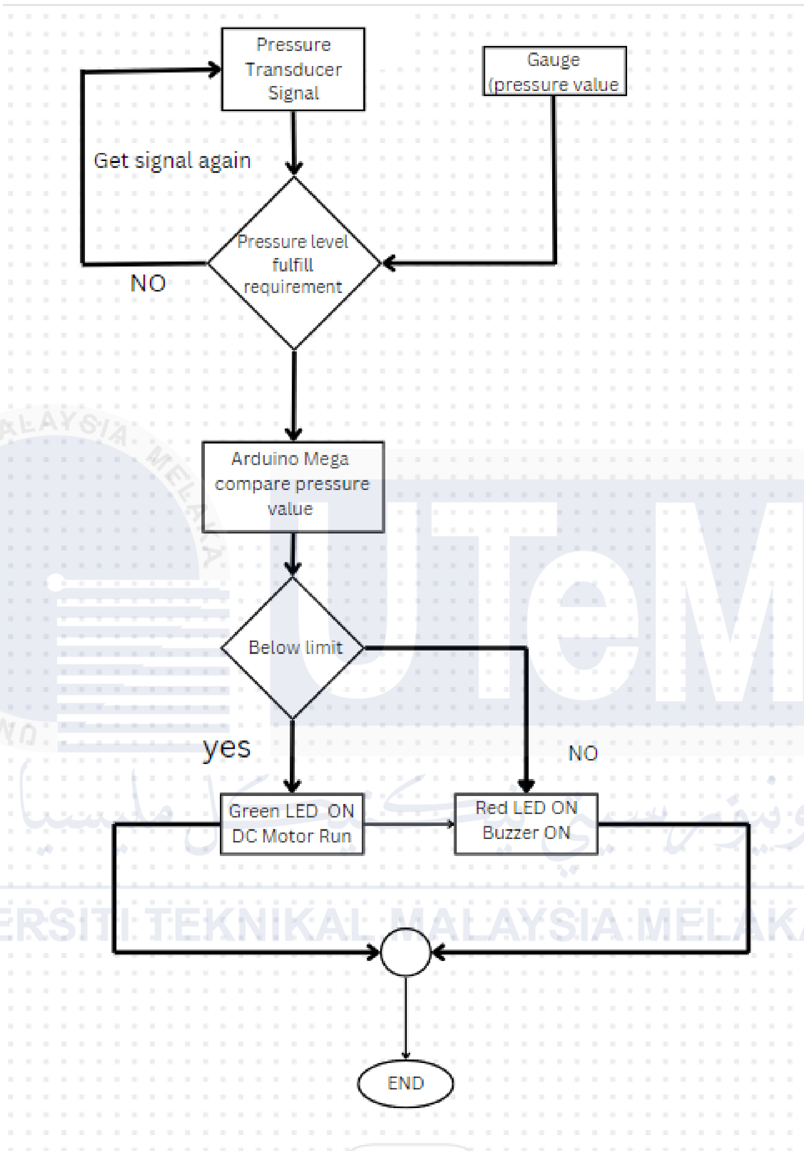


Figure 3.12 Simulink Block Diagram

This Simulink block diagram represents a pressure-based control system using an Arduino microcontroller, designed to manage an exhaust valve, buzzer, red LED, DC motor, and green LED based on pressure readings. A pressure sensor connected to pin A0 of the Arduino measures the pressure and sends the signal for processing. The signal is compared against a threshold value of 150 psi. If the pressure exceeds 150 psi, a value of 180 is passed forward, activating the exhaust valve (pin 4), buzzer (pin 10), and red LED (pin 3). If the pressure is below this threshold, a value of 0 is sent, keeping these components off. Simultaneously, another condition checks if the signal reaches 180. If true, both the DC motor (pin 7) and the green LED (pin 11) are activated; otherwise, they remain off. A sensing resistance (SR) block processes the input for better signal accuracy, while a time block (T) is present but not actively connected in this specific setup. This system efficiently monitors and responds to varying pressure levels by controlling multiple actuators and indicators for automation tasks.

To create the system's programme code and send it to the microcontroller, the MATLAB Simulink software and the Arduino simulation add-on packages need to be installed. The block diagram model of this system was created to determine the response of each component to pressure input, as well as to measure characteristics including pressure level, light indication, sound warning signal, and DC motor functioning. This part of the data processing process is when the choice is made on whether to turn on the motor, buzzer, and LED light indicator. The system flow is as shown in **Figure 3.13** overall.

Figure 3.13: System Flow Chart



3.4.5.2 Conceptual Prototype Construction

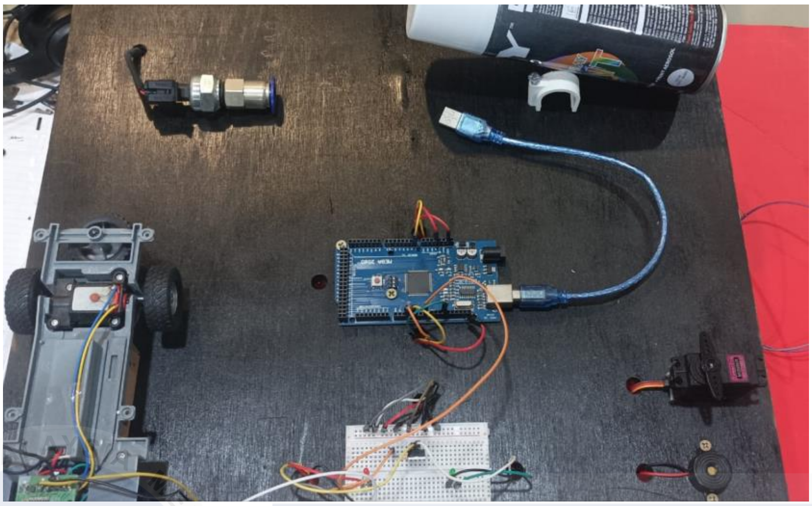


Figure 3.14 System Prototype Fabrication

Table 3.8: List of Software and Hardware Components

No.	Type of Component	Component Name
1	Software	MATLAB Simulink
2	Hardware	Pressure Transducer
3		Buzzer
4		LED
5		DC motor
6		Arduino Mega
7		Servo motor

All of the software and hardware parts mentioned in Table 3.8 were combined to build the prototype. The pressure transducer, buzzer, LED, servo motor, and DC motor are all connected to the Arduino Mega.

3.4.5.3 Trucksim

TruckSim is an advanced vehicle dynamics simulation package frequently employed for simulating and studying the behaviour of heavy-duty trucks subjected to different operational scenarios. It can be used in designing trucks, analysing safety, and training of the drivers, giving a broader picture of the parameters like load, speed, breaking, and time that dictate the way a truck behaves. Below shows the figure of truck choice for commercial vehicle auxiliary brake testing and the input of load data:

Figure 3.15 Conventional LCF Truck (Box Truck)

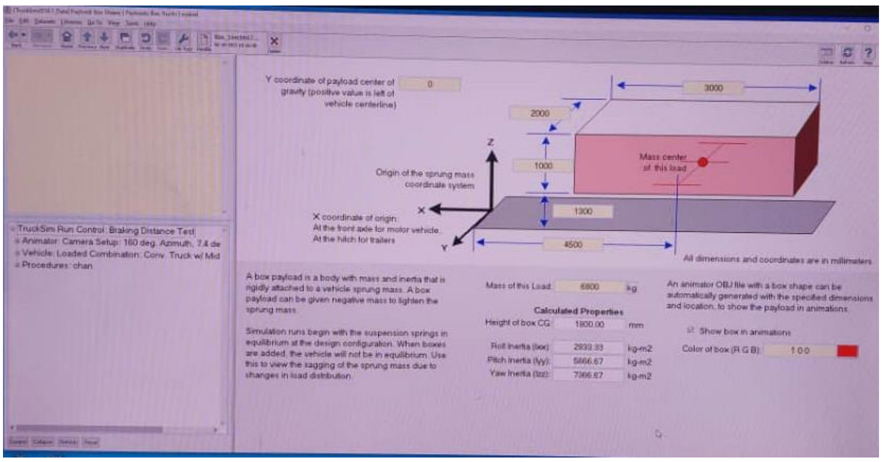


Figure 3.16 Load Input in Trucksim

3.4.5.4 Braking Distance

Stopping distance is a safety parameter of commercial vehicles and is part of the design process and operation. It is the sum of the distance driven from the moment the driver decides to leave the gas pedal to the moment the vehicle stop. The distance will depend on factors like speed of the vehicle, type of braking system available, type of road surface, and weight of the vehicle. In most cases, stopping distance is made up of both the perception reaction distance and the brake distance.

The distance is the perception reaction distance, the distance or distance covered from the moment that the vehicle detection of the stimulus with the acceleration due to the reaction to brake. It is computed utilizing the following formula:

$$\boldsymbol{PRD = v.t}$$

Where,

- v is the initial velocity of the vehicle
- t is the reaction time of the driver

This component of stopping distance depends on the driver's alertness, fatigue and environmental distractions. The braking distance refers to the distance the vehicle travels under the influence of braking force until it comes to a complete stop. This is determined by the equation below:

$$\mathbf{BD} = \frac{\boldsymbol{v}^2}{\mathbf{2}.\,\mu.\,\boldsymbol{g}}$$

Where,

- v is the initial velocity
- μ is the coefficient of friction between the tires and the road surface
- g is the acceleration due to gravity

The braking distance is influenced by factors such as the road surface condition, efficiency of the braking system and the vehicle's weight. Combining these two components, the total stopping distance of a vehicle can be expressed:

$$\boldsymbol{Sd} = \boldsymbol{v}.\,\boldsymbol{t} + \frac{\boldsymbol{v}^2}{\mathbf{2}.\,\mu.\,\boldsymbol{g}}$$

For commercial vehicles, additional considerations must be taken into account. These include the performance of the braking system, which may exhibit lag time in exhaust brake systems, and the effect of load conditions, as fully loaded vehicles exhibit greater inertia and require more braking force.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

In this chapter, we will take a closer look at the acceleration and braking characteristics of a commercial vehicle under various conditions. We will primarily focus on its colour of dynamic behaviour both during speed increases and emergency braking situations. We will then understand how good its auxiliary braking system was by looking into how fast the vehicle is able to reach certain speed limits, and how effectively it can decelerate. Just in those critical moments where rapid deceleration is required, these results are vital for overall safety and vehicle control.

This analysis focuses primarily on determining the acceleration potential and braking performance of the vehicle to serve as a base for performance assessment under various scenarios. The other aspect of the project is to analyse the deceleration rates and stopping distances at various speeds to verify that the system complies with safety requirements. Moreover, the obtained results provide a wealth of information on the relationship between speed, braking response, and stopping distances, providing useful data that may aid in potential design optimizations of the auxiliary braking system.

This discussion aims to support the development of safer and more reliable braking solutions for commercial vehicles, emphasizing improved vehicle control during critical braking situations.

4.2 Simulation Results

This section discusses the experiment procedure carried out in this study in order to evaluate the performance of the modified exhaust brake index. The experiment procedure involves the TruckSim driving simulator, commercial truck model, and modified exhaust brake algorithm, which is integrated the buzzer and red light-emitting diode (LED) threshold to establish the overall pressure warning system. In this experiment, a Driver-Hardware-in-the-Loop (DHIL) real-time simulation platform in the TruckSim driving simulator is designed to evaluate the performance of the exhaust brake system. The data parameter is taken from TruckSim software as shown in Figure 4.1 below:

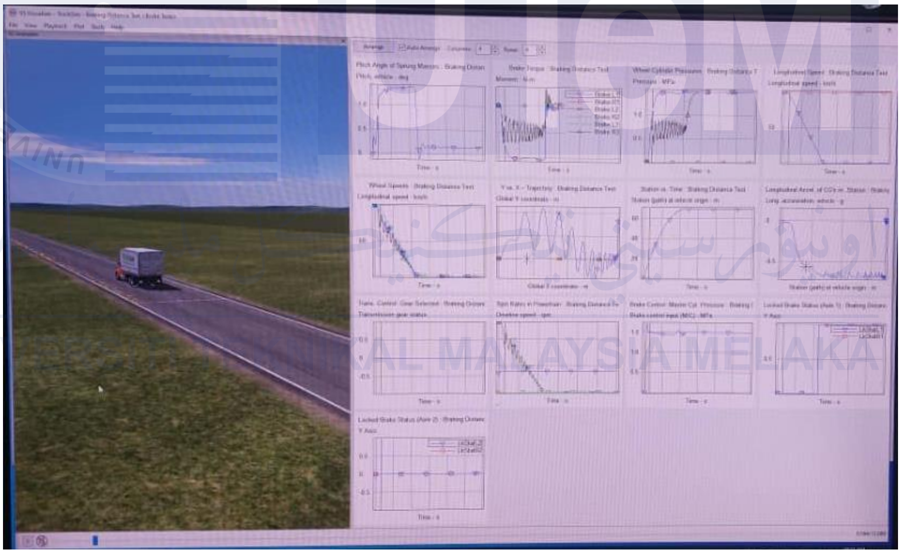


Figure 4.1 Data Collection for Parameter

In this study, the performance of the modified exhaust brake index is obtained from the experiment conducted using TruckSim driving simulator and MATLAB/Simulink with a speed of 60 km/h, 80 km/h and 100 km/h. The box truck used in this experiment is loaded with laden (8,800 kg), half-laden (6800 kg) and unladen conditions (4500 kg). The weight parameters used in this experiment are established based on the TruckersReport, 2011. The exhaust brake system module configuration on the TruckSim driving simulator is shown in Figure 4.1. Three axles box truck is selected for the experiment procedure.

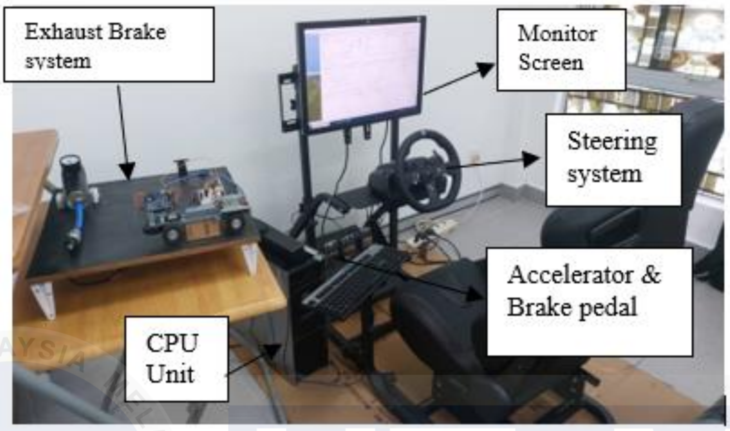


Figure 4.2 Exhaust brake system module configuration on the TruckSim driving simulator

4.2.1 Graph Depicting Accelerative and Braking Performance of a Commercial Vehicle (Unladen Condition)

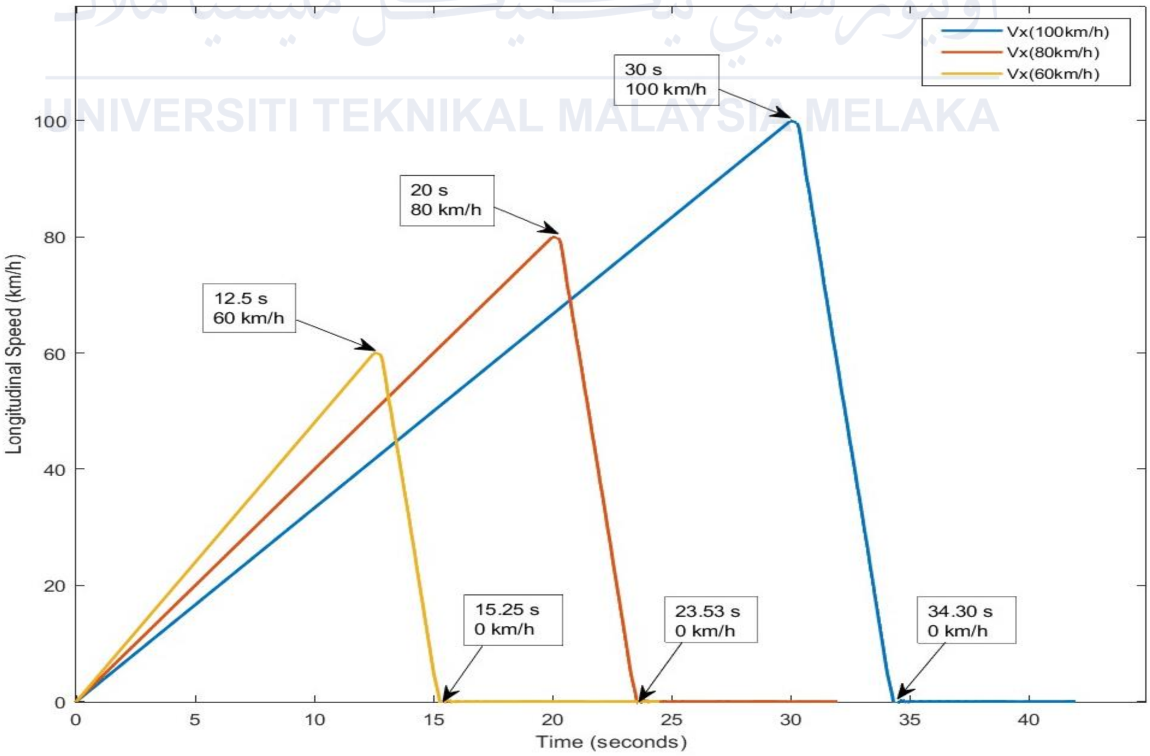


Figure 4.3 Unladen Condition Graph

The graph shows the longitudinal speed graph of a commercial vehicle in unladen condition, highlighting both accelerative and braking phases based on the maximum speed conditions (60 km/h, 80 km/h, 100 km/h). On the x-axis is time in seconds and on the y-axis is the longitudinal speed in kilometers per hour (km/h).

In the acceleration phase, the speed of the vehicle increases linearly, which reflects a constant acceleration. The times taken to achieve peak speeds of 60 km/h, 80 km/h, and 100 km/h are about 12.5 s, 20 s, and 30 s respectively, showcasing linear acceleration performance.

During the braking phase, the phase is represented by a rapid drop in speed, which indicates a sharp deceleration. The time taken to reach a complete stop from the moment braking is applied is recorded as 15.25 s, 23.53 s, and 34.30 s for the respective maximum speed conditions. Then there is the overall steepness of the deceleration curves, hinting at the efficiency of the braking process — which may benefit from the use of the auxiliary braking system.

4.2.2 Graph Depicting Accelerative and Braking Performance of a Commercial Vehicle (Half - Laden Condition)

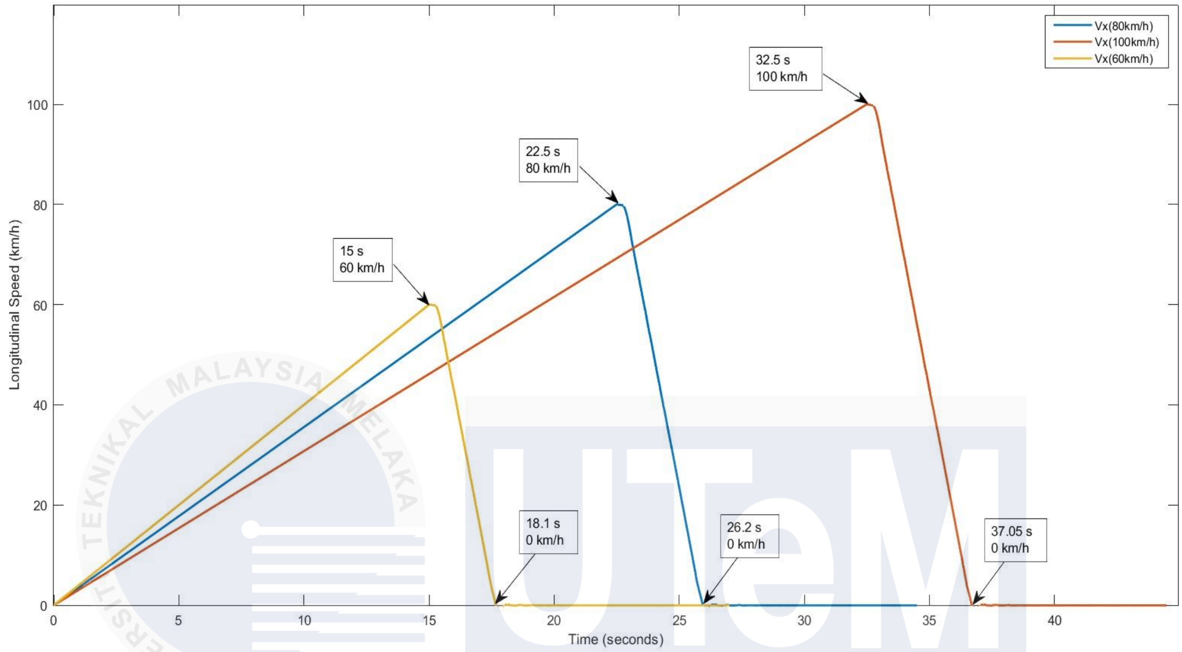


Figure 4.4 Half Laden Condition Graph

Figure 24 shows the longitudinal speed capture test result in a half-laden condition of a commercial vehicle for the accelerative and braking phases toward the 60 km/h, 80 km/h, and 100 km/h targets. The x-axis of the figure shows time in seconds, and the y-axis represents longitudinal speed [km/h].

In the acceleration sub-phase, the speed of the vehicle linearly increased toward all target speeds, indicating a gradual and controlled acceleration. It goes from 0 to 60 km/h in around 15 seconds, 0 to 80 km/h in 22.5 seconds and 0 to 100 km/h in 32.5 seconds. The time is a little longer than the unladen condition, showing how the load affects acceleration performance

In the braking phase, there is a rapid decrease in speed, which means the car is decelerating rapidly. From target speeds of 18.1, 26.2 and 37.05 seconds, the car comes to a halt. With half the load, more distance is required to stop just as you need less room with no load

This analysis highlights the direct impact of vehicle load on both acceleration and braking performance. The half-laden condition results in longer acceleration times and stopping distances compared to the unladen scenario. The findings emphasize the importance of considering load conditions when designing and evaluating braking systems, particularly in commercial vehicles where varying cargo weights influence dynamic performance. This data further supports the need for optimized auxiliary braking systems capable of maintaining safety and control across different loading scenarios.

4.2.3 Graph Depicting Accelerative and Braking Performance of a Commercial Vehicle (Full Laden Condition)

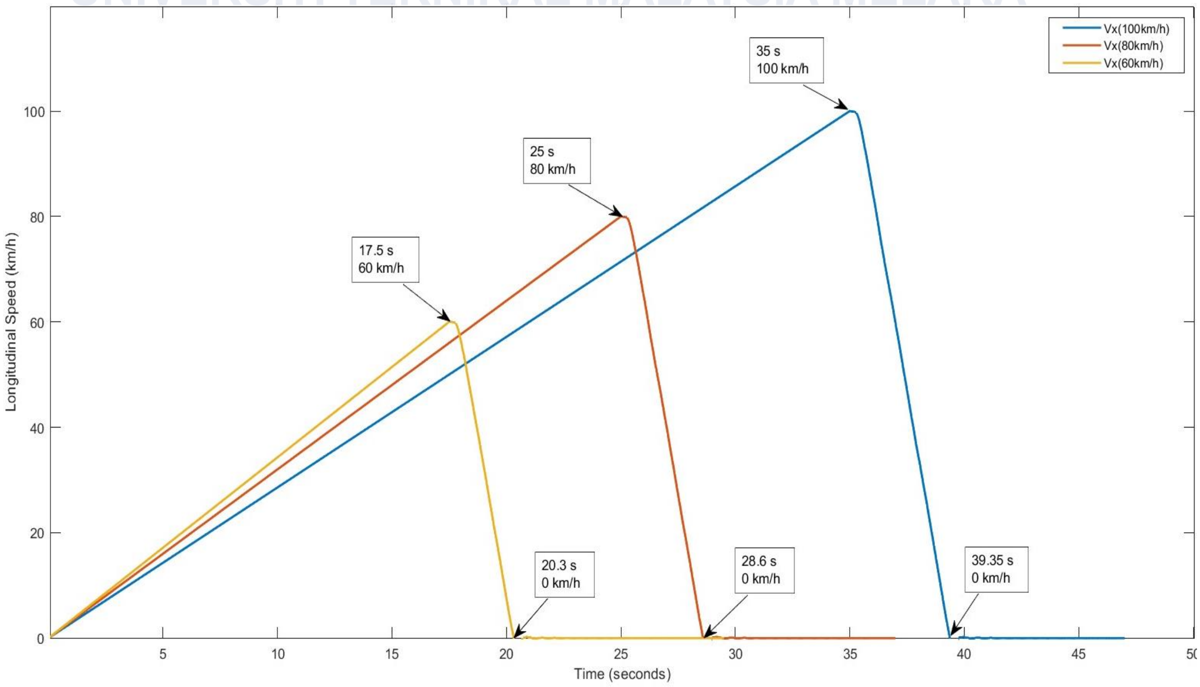


Figure 4.5 Full Laden Condition Graph

The graph above illustrates the longitudinal speed of a commercial vehicle with a full laden, where target speeds of 60 km/h, 80 km/h, and 100 km/h are represented, and the acceleration and braking stages are recorded. The x-axis is marked in seconds, and the y-axis marks km/h.

During this acceleration process, the vehicle differs from the unladen as well as half-laden case in the sense that it consumes more time to achieve all speed targets across the range of the model. 0-60 km/h takes around 17.5 seconds, 0-80 km/h takes 25 seconds, and 0-100 km/h takes an approximately 35 seconds. Due to the inertia of the more massive fully charged vehicle, it will take more energy, and time, to reach the same speeds.

On the other hand, braking results in a higher deceleration, but this is also softer and longer than the lighter load situation. The round the vehicle comes to a stop after approximately 20.3 seconds, 28.6 seconds, and before 39.35 seconds for the corresponding speed goals. The longer stopping distances are due to the additional momentum of the fully loaded vehicle, which means it takes a greater distance and time to stop safely.

This study illustrates the impact of vehicle load on its dynamic performance in allowing for a full-laden state which affects both the acceleration and braking times resulting in a longer performance times for both acceleration and braking compared to half-laden and unladen condition. This data is crucial to subjective safety measurements and performance optimization, highlighting the importance of advanced braking systems and control methods for laden commercial vehicles to further enhance operational safety and efficiency.

4.2.4 Braking Distance Analysis for Unladen, Half Laden and Full Laden Condition

Braking distance analysis is an important aspect of vehicle safety assessment, as it helps to understand the stopping performance of a vehicle under different loading conditions. The objective of this study is to experimentally measure and compare the braking distance of a vehicle of varying loads when it is unladen, half-laden, and full laden, for 60 km/h, 80 km/h, and 100 km/h respectively. Knowing how the load effects the distance of stopping for different speeds is important in understanding the standards in safety and design of a vehicle. Using the formula stated in subtopic **3.4.5.4.**

The study shows that speed increases braking distance momentum in kinetic energy. On the other hand, heavier vehicle loading generally results in longer brake distance, as expected, showing the effect of added mass on stopping power. The braking distance for every condition is in **Table 4.1** below.

CONDITION	SPEED (km/h)	TIME (s)	BRAKING DISTANCE (m)
Unladen	60	2.75	45.83
	80	3.53	78.44
	100	4.30	119.44
Half-laden	60	2.80	46.67
	80	3.60	80.00
	100	4.35	120.83
Full-laden	60	3.00	50.00
	80	3.70	82.22
	100	4.56	126.67

Table 4.1 Braking Distance Data for All Condition

The results provide valuable data for vehicle safety evaluations and can be used to recommend braking system enhancements or speed regulations for various load conditions. This analysis also highlights the importance of considering load dynamics when designing braking systems, ensuring optimal performance and passenger safety.

4.3 Discussion

4.3.1 Analysis of Braking Performance

For all loading conditions (unladen, half-laden, full-laden) and speeds (60 km/h, 80 km/h, 100 km/h), the braking performance was determined in term of braking distance and braking time by adopting the common kinematic relation as given in Figure 4.4. This relation gives the correlation between speed, braking time and deceleration for other different loads.

The unladen brake time was longer at increasing speeds, 2.75 seconds at 60 km/h and 4.3 seconds 100 km/h, with the shorter braking times corresponding with less inertia and less momentum in the unladen form, allowing it to decelerate faster. Braking took a touch longer than in the bare state, with figures measuring 2.8 seconds (60 km/h) to 4.35 seconds (100 km/h). There was moderate resistance to deceleration with the added mass, which makes sense, as more weight means more braking force is needed to stop. Under these conditions, full laden stopping times were longest at all speeds scaling up from 3.0 seconds (60 km/h) to 4.56 seconds (100 km/h). The full load greatly increased the momentum of the vehicle, requiring longer braking distances to come to a stop.

4.3.2 Effectiveness of Auxiliary Braking System

The auxiliary braking system's effectiveness is particularly evident in its ability to maintain control across all load conditions. Despite the increase in load, the variations in braking times remained relatively small, demonstrating the system’s capacity to distribute braking forces effectively. The pressure transducer and servo motor's coordinated response help in maintaining consistent deceleration rates, preventing excessive reliance on the primary braking system. This is crucial for avoiding brake fade, especially during continuous braking events like steep descents.

Then there's emergency braking situations that really show how valuable the auxiliary braking system is. At higher speeds (100 km/h) and when fully loaded, the braking time increased to 4.56 seconds, however the auxiliary braking system kept the braking distance from excessive growth, giving safe and controlled braking stops. Likewise, in steep downgrades, the exhaust brake valve and servo motor apply braking acceleration to reduce thermal loading on the primary brakes.

The graphs of braking performance data support the importance of the auxiliary braking system in enhancing vehicle safety and efficiency. Under varying loads, it distributes the braking force to maintain a controlled deceleration and limit the occurrence of brake fade. It highlights the necessity of a well-integrated auxiliary braking system under certain conditions, for example, operating vehicles under various loads and speed situations, and for both regular and emergency braking.

4.3.3 Limitations of the Study

Despite the analysis of the auxiliary braking performance under several loading conditions being able to provide useful insights into the effectiveness of the auxiliary braking system, there were a number of limitations which may reduce the applicability of the results. These limitations arise from the controlled simulation setup, prototype constraints, and certain assumptions in the data analysis.

Firstly, the braking tests were performed under idealized conditions with uniform road surfaces and a constant distribution of braking forces. Study authors did not account for real-world variables like differences in road friction, surface irregularities or environment (wet or snow-covered roads). These considerations can greatly affect braking distances as well as general vehicle stability during deceleration, thus rendering the controlled results somewhat optimistic when compared to real-world performance.

Second, it assumes brakes are actuated as soon as they should be, ignoring any delay from the driver taking action (reaction time) or lag through the system itself. In real-life cases, human response time could also introduce a large delay before brake force is exerted though, particularly for emergency situations. In addition, the working time of the auxiliary braking system is influenced by the performance parameters of the servo motor and the exhaust brake valve that operate under dynamic loads, which did not fully simulate in the work.

Prototype limitations also contributed to the restrictions on this analysis. Which specified speed intervals and loading conditions for the braking tests that may not entirely capture the continuous variation of these variables while driving on the road. The effect of brake wear and thermal effects such as the efficiency of braking over long braking periods like (long downhill descents) was not modelled in detail. Brake fade, a big consideration for heavy load brakers, will need long-term testing for a full assessment.

Additionally, the calibration of the braking system was derived from theoretical assumptions regarding the even distribution of brake forces among all of the wheels. The effectiveness of brake components can also lead to an imbalance in braking pressure distribution, which is a real-world experience not adequately covered in the simulated data.

To sum up, although the analysis of braking performance provides insights into how effective the auxiliary braking system is, it should be understood that the results should be analysed in the light of the limitations of the study. These limitations need future work with variable road conditions, while modelling driver behaviour and long-term data for brake performance to quantify are safe and efficient.

4.4 Summary

These results from the brake performance analysis are promising steps towards the development of higher safety standards for commercial vehicles. It also highlights the significance of efficient braking systems in minimizing stopping distances under various levels of load (unloaded, half-loaded and fully loaded). The capacity of the auxiliary braking system to regulate speed effectively under various loading conditions enhances its function in brake failure prevention and controlled deceleration, especially in emergency situations.

One of the most important implications for commercial vehicle safety is the demonstrated necessity of load-specific braking strategies. The increased braking time with a heavier load proves the need for an advanced braking technique, in addition to the standard emergency brake. This practice reduces the chances of overheating brake components a phenomenon called brake fade from extended braking situations (steep downhill runs, repeated stop-and-go traffic), where mechanical braking systems alone may overheat or become ineffective.

The results also support the inclusion of auxiliary braking systems as a standard safety feature in heavy-duty vehicles. These types of systems improve vehicle control in emergency braking situations, as they reduce the chances of jack-knifing or loss of control from uneven braking forces. This safety enhancement is significant for industries that depend on heavy weight transportation, where the vehicle stability and consistent braking performance of such vehicles can be the difference between averting accidents and merely reducing damage to the transported goods.

The findings also have implications for real-world applications, potentially favouring advanced braking systems in the context of driving on highways where speeds may increase and less abrupt braking may be ill-advised and during periods of frequent stopping in dense urban environments. Auxiliary braking systems are particularly beneficial for vehicles in mountainous terrains or places where steep gradients prevail. They help reduce the risk of runaway by better controlling deceleration.

Finally, this study strengthens the imposition of stricter regulatory standards regarding braking performance in commercial vehicles, with particular consideration for forced and auxiliary brake performance over the entire load spectrum. Not only would the deployment of such safety technologies improve driver safety, but they would also help improve road safety as a whole by lowering accident rates involving heavy-duty vehicles and increasing the reliability of commercial transport operations.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

In this thesis, an auxiliary braking system model for commercial vehicles was successfully developed and analyzed, focusing on enhancing vehicle safety and control during braking scenarios. The developed model was designed to complement the primary braking system by providing additional braking force, especially in high-load and high-speed conditions. Through the simulation and testing phases, the model demonstrated improved braking efficiency, reduced stopping distances, and better vehicle stability under various operating conditions. The performance metrics highlighted the importance of auxiliary braking in ensuring safety during extended downhill descents and emergency braking situations, making it a critical addition for commercial vehicles.

Additionally, a functional prototype of the auxiliary braking system was fabricated to validate the theoretical model's effectiveness in a practical setting. The prototype underwent multiple tests, confirming its reliability and ability to assist the primary braking system effectively. The fabrication process also revealed the importance of material selection and design optimization to balance performance and durability. This research provides a solid foundation for further development of advanced braking technologies and could serve as a baseline for future enhancements in commercial vehicle braking systems, focusing on energy recovery and intelligent control mechanisms.

5.2 Recommendations

For future improvements, there are some recommendations could be proposed from this project study as follows:

i. Conduct tests with more load variations, including incremental steps between unladen and fully laden conditions, to better understand braking performance trends.

ii. Simulate a wider range of operating conditions, such as varying road surfaces (wet, dry, icy) and gradients, to assess the auxiliary braking system under diverse scenarios.

iii. Perform extended testing cycles to evaluate the system's durability and wear over prolonged use, which is essential for commercial vehicle applications.

iv. Add a fail-safe mechanism to ensure braking efficiency in case of electrical or sensor failure, such as a mechanical backup system.

5.3 Project Potential

This project demonstrates significant potential in enhancing commercial vehicle safety and braking performance. The auxiliary braking system effectively reduces braking distances across different loading conditions, improving vehicle control, especially in demanding scenarios like steep descents and emergency stops. These findings can contribute to safer road standards and inspire further advancements in auxiliary braking technologies, emphasizing both safety and innovation in commercial vehicles.

REFERENCES

. *01) (71) Applicant: SCANIA CV AB, Södertälje (SE)*. (2016).
2120-Department of Automotive, Combustion Engine and Railway Engineering Consequences of reducing truck losses for vehicle braking and deceleration systems. (n.d.).

af Wåhlberg, A. E., & Dorn, L. (2024). The effects of Electronic Stability Control (ESC) on fatal crash rates in the United States. *Journal of Safety Research*, *88*, 217–229. https://doi.org/10.1016/j.jsr.2023.11.008

Baba, S. N. N., Hamid, M. N. A., Soid, S. N. M., Zahelem, M. N., & Omar, M. S. (2018). Analysis of drum brake system for improvement of braking performance. In *Advanced Structured Materials* (Vol. 85, pp. 345–357). Springer Verlag. https://doi.org/10.1007/978-3-319-72697-7_28

Balasubramaniam, S., & Senthil Kumar, D. (2019). Numerical analysis of exhaust gas braking system to maximize the back pressure. *IOP Conference Series: Materials Science and Engineering*, *577*(1). https://doi.org/10.1088/1757-899X/577/1/012133

Basma, F., Assistant, R., & Refai, H. H. (2009). *Collision Avoidance System at Intersections*.

Burton, D., Delaney, A., Newstead, S. V. (Stuart V.), Logan, D., Fildes, B., & Royal Automobile Club of Victoria. (n.d.). *Evaluation of anti-lock braking systems effectiveness*.
Emergency braking systems. (n.d.). http://www.my-cardictionary.comhttps://www.my-cardictionary.com/cardictionary/products/emergency-
fin_ijprems1657461642. (n.d.).

Greenwood, P. M., Lenneman, J. K., & Baldwin, C. L. (2022). Advanced driver assistance systems (ADAS): Demographics, preferred sources of information, and accuracy of ADAS knowledge. *Transportation Research Part F: Traffic Psychology and Behaviour*, *86*, 131–150. https://doi.org/10.1016/j.trf.2021.08.006

Grover, C., Knight, I., Okoro, F., Simmons, I., Couper, G., Massie, P., & Ppr, S. (2008). *Automated Emergency Brake Systems: Technical requirements, costs and benefits*.

Gunjate, S. S., & Khot, S. A. (2023). A Systematic Review of Emergency Braking Assistant System to Avoid Accidents Using Pulse Width Modulation and Fuzzy Logic Control Integrated with Antilock Braking. In *International Journal of Automotive and Mechanical Engineering* (Vol. 20, Issue 2, pp. 10457–10479). Universiti Malaysia Pahang. https://doi.org/10.15282/ijame.20.2.2023.10.0808

Guo, J., Wang, Y., Yin, X., Liu, P., Hou, Z., & Zhao, D. (2022). Study on the Control Algorithm of Automatic Emergency Braking System (AEBS) for Commercial Vehicle Based on Identification of Driving Condition. *Machines*, *10*(10). https://doi.org/10.3390/machines10100895

Heydrich, M., Ricciardi, V., Ivanov, V., Mazzoni, M., Rossi, A., Buh, J., & Augsburg, K. (2021). Integrated Braking Control for Electric Vehicles with In-Wheel Propulsion and Fully Decoupled Brake-by-Wire System. *Vehicles*, *3*(2), 145–161. https://doi.org/10.3390/vehicles3020009

Hu, C., Pan, G., Kong, L., & Yu, J. (2023). Research of Brake by Wire System. *Journal of Physics: Conference Series*, *2479*(1). https://doi.org/10.1088/1742-6596/2479/1/012051

Jin, L., Ling, M., & Li, J. (2018). Development of a new traction control system using ant colony optimization. *Advances in Mechanical Engineering*, *10*(8). https://doi.org/10.1177/1687814018792152

Karthikeyan, M., Sathiamoorthy, S., & Vasudevan, M. (2020). Lane keep assist system for an autonomous vehicle using support vector machine learning algorithm. In *Lecture Notes on Data Engineering and Communications Technologies* (Vol. 46, pp. 101–108). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/978-3-030-38040-3_11

Khorasani-Zavareh, D., Shoar, S., & Saadat, S. (2013). *Antilock braking system effectiveness in prevention of road traffic crashes in Iran*. http://www.biomedcentral.com/1471-2458/13/439

Kui Yang Wang. (2014). *Research on Coordination Control Strategy of Hydraulic Retarder and Friction Brake of Coach*.

Ma, Y., Wang, M., Feng, Q., He, Z., & Tian, M. (2022). Current Non-Contact Road Surface Condition Detection Schemes and Technical Challenges. In *Sensors* (Vol. 22, Issue 24). MDPI. https://doi.org/10.3390/s22249583

Miller, J. I. (2010). *Advanced Braking Systems for Heavy Vehicles*.

Murthy, A. S. (2013). *ANALYSIS OF REGENERATIVE BRAKING IN ELECTRIC MACHINES*.

Palanisamy, R., Veeramani, M., Jaganathan, T., Vasanth, M., & Prakash, D. (2018). *Exhaust Braking System-Review Paper*. *4*.

Patent Application Publication US 2013/0304313 A1 Record Piston travel/pressure Decision Ratio. (2013).

r-76-18. (n.d.).

Raksincharoensak, P., Akamatsu, Y., Moro, K., & Nagai, M. (2013). Predictive braking assistance system for intersection safety based on risk potential. *IFAC Proceedings Volumes (IFAC-PapersOnline)*, *7*(PART 1), 335–340. https://doi.org/10.3182/20130904-4-JP-2042.00072

Shinde, S., Kangate, S., Shirole, V., Waybase, K., & Chavan, A. (2023). Brake Failure Detection and Application of Auxiliary Braking System. In *International Journal of Innovative Science and Research Technology* (Vol. 8, Issue 5). www.ijisrt.com

Singh, A. (n.d.). *Regenerative Braking*. https://doi.org/10.13140/RG.2.2.20379.80160

Tan, H., Zhao, F., Hao, H., Liu, Z., Amer, A. A., & Babiker, H. (2020). Automatic emergency braking (AEB) system impact on fatality and injury reduction in China.

International Journal of Environmental Research and Public Health, *17*(3). https://doi.org/10.3390/ijerph17030917

Toru Fujiwara, & Kazutaka Takechi. (2021). *Making the world safer: autonomous emergency braking systems enhance safety for senior drivers*.

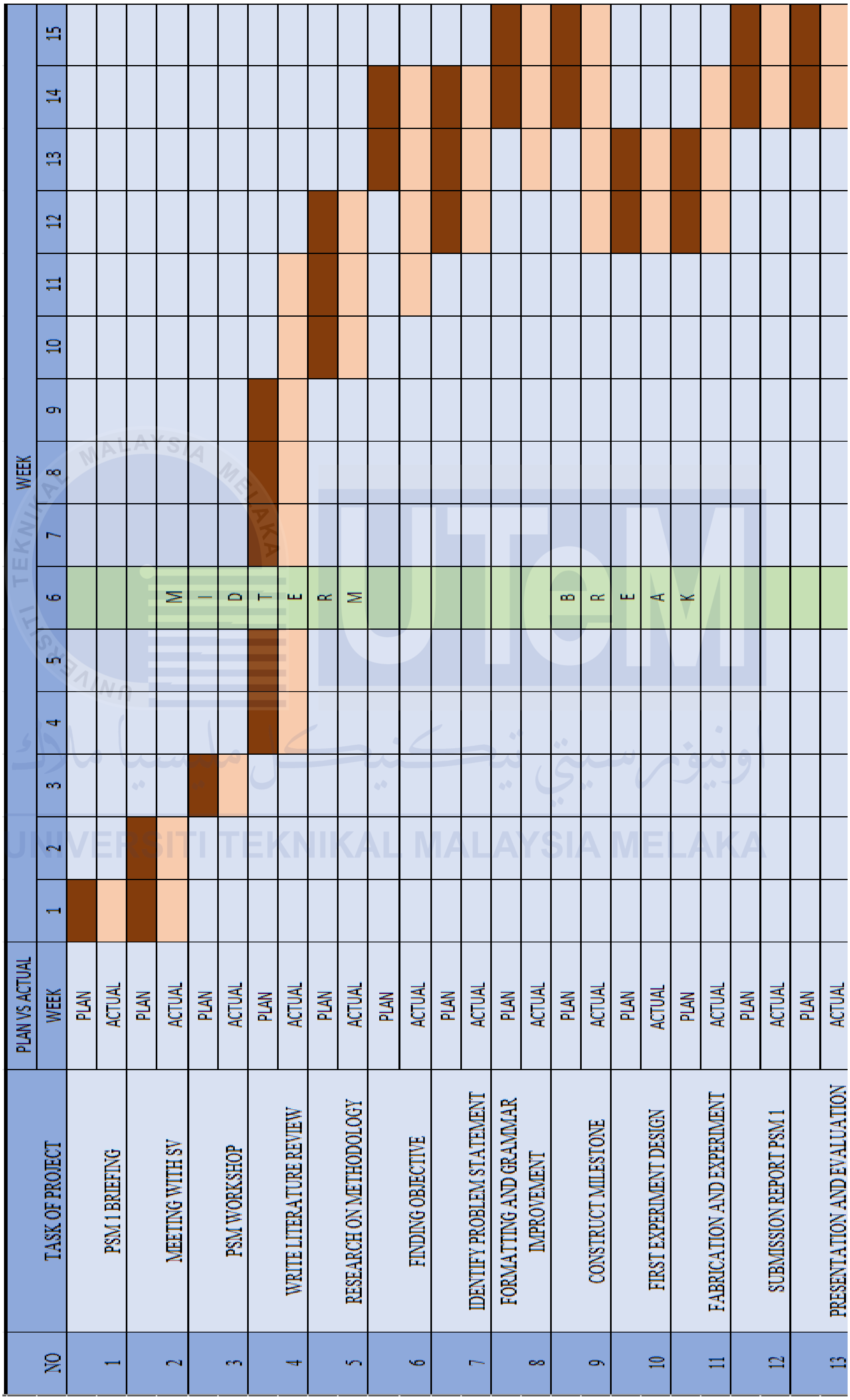
Vigna, L. (2018). *POLITECNICO DI TORINO Automotive Engineering*.

Wabco. (n.d.). *SYSTEMS AND COMPONENTS FOR COMMERCIAL VEHICLES PRODUCT CATALOGUE*. http://www.wabco.info/8150100033
WO2009003781A3. (n.d.).

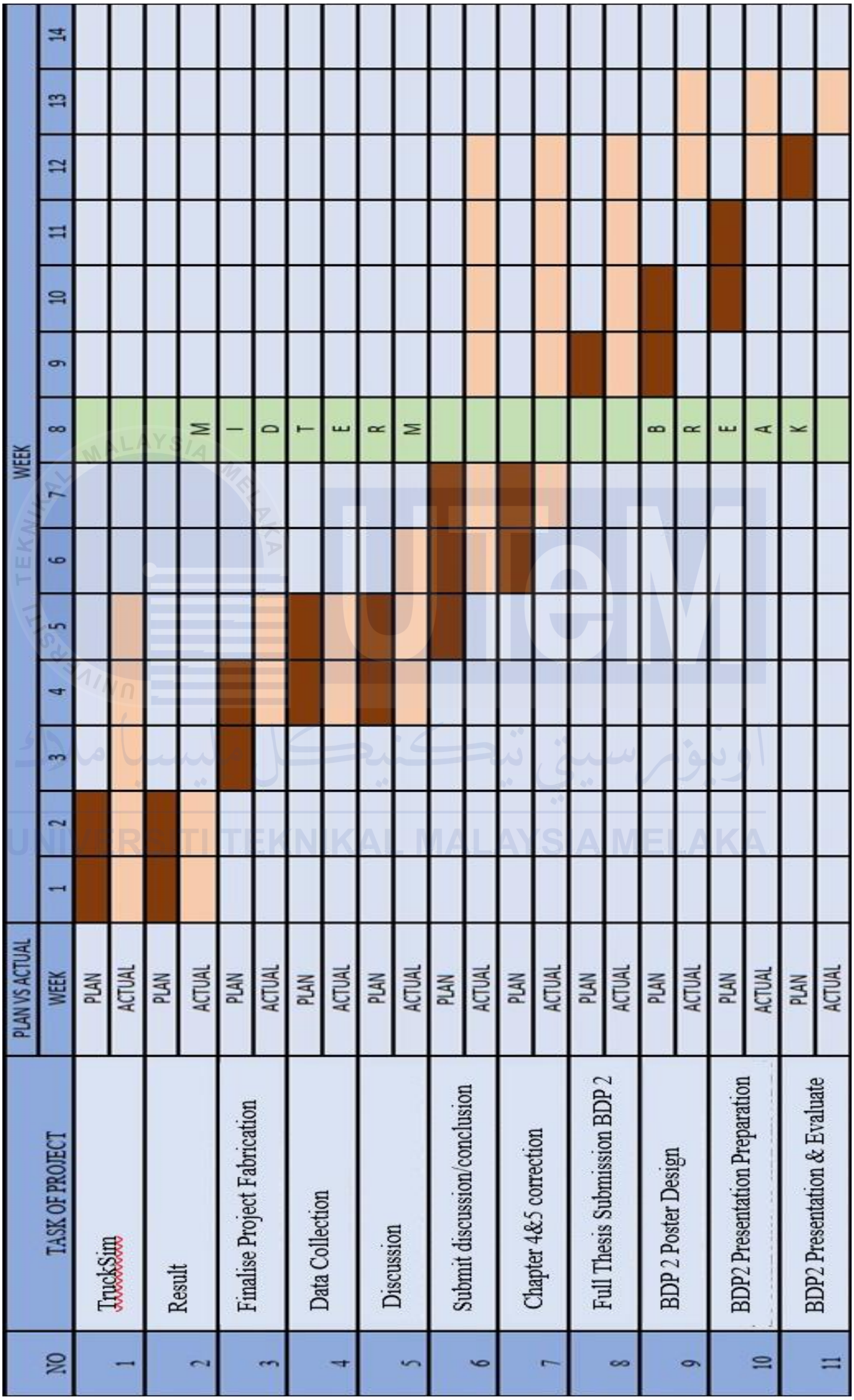
Xiao, F., Gong, X., Lu, Z., Qian, L., Zhang, Y., & Wang, L. (2021). Design and Control of New Brake-by-Wire Actuator for Vehicle Based on Linear Motor and Lever Mechanism. *IEEE Access*, *9*, 95832–95842. https://doi.org/10.1109/ACCESS.2021.3094030

Zhang, D. (2018). *Simulation and Experimental Research on Compression Release Engine Brake Performance*.

APPENDICES



Appendix A: Gantt Chart BDP 1



Appendix B: Gantt Chart BDP 2

Ezekiel Ernath

Design and Fabrication of Commercial Vehicle Emergengy Brake

PSM-2024-2025

PSM-2024-2025

Universiti Teknikal Malaysia Melaka - Library

Document Details

Submission ID

trn:oid:::1:3126401170

Submission Date

Jan 9, 2025, 3:56 PM GMT+8

Download Date

Jan 9, 2025, 4:01 PM GMT+8

File Name

Design_and_Fabrication_of_Commercial_Vehicle_Emergengy_Brake.docx

File Size

6.4 MB

97 Pages

15,577 Words

87,126 Characters

*% detected as AI

AI detection includes the possibility of false positives. Although some text in this submission is likely AI generated, scores below the 20% threshold are not surfaced because they have a higher likelihood of false positives.

Caution: Review required.

It is essential to understand the limitations of AI detection before making decisions about a student's work. We encourage you to learn more about Turnitin's AI detection capabilities before using the tool.

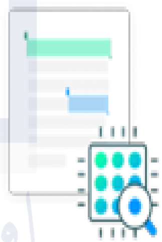
Disclaimer

Our AI writing assessment is designed to help educators identify text that might be prepared by a generative AI tool. Our AI writing assessment may not always be accurate (it may misidentify writing that is likely AI generated as AI generated and AI paraphrased or likely AI generated and AI paraphrased writing as only AI generated) so it should not be used as the sole basis for adverse actions against a student. It takes further scrutiny and human judgment in conjunction with an organization's application of its specific academic policies to determine whether any academic misconduct has occurred.

Frequently Asked Questions

How should I interpret Turnitin's AI writing percentage and false positives?

The percentage shown in the AI writing report is the amount of qualifying text within the submission that Turnitin's AI writing detection model determines was either likely AI-generated text from a large-language model or likely AI-generated text that was likely revised using an AI-paraphrase tool or word spinner.



False positives (incorrectly flagging human-written text as AI-generated) are a possibility in AI models.

AI detection scores under 20%, which we do not surface in new reports, have a higher likelihood of false positives. To reduce the likelihood of misinterpretation, no score or highlights are attributed and are indicated with an asterisk in the report (*%).

The AI writing percentage should not be the sole basis to determine whether misconduct has occurred. The reviewer/instructor should use the percentage as a means to start a formative conversation with their student and/or use it to examine the submitted assignment in accordance with their school's policies.

What does 'qualifying text' mean?

Our model only processes qualifying text in the form of long-form writing. Long-form writing means individual sentences contained in paragraphs that make up a longer piece of written work, such as an essay, a dissertation, or an article, etc. Qualifying text that has been determined to be likely AI-generated will be highlighted in cyan in the submission, and likely AI-generated and then likely AI-paraphrased will be highlighted purple.

Non-qualifying text, such as bullet points, annotated bibliographies, etc., will not be processed and can create disparity between the submission highlights and the percentage shown.

Appendix D: Turnitin AI Detection Report

UTeM
Universiti Teknikal Malaysia Melaka
Hang Tuah Jaya,
76100 Durian Tunggal,
Melaka, Malaysia.
+606 270 1000
+606 270 1022
www.utem.edu.my

FAKULTI TEKNOLOGI DAN KEJURUTERAAN MEKANIKAL
Tel : +606 270 1184 | Faks : +606 270 1064

Rujukan Kami (Our Ref):
Rujukan Tuan (Your Ref):
Tarikh (Date): 31 Januari 2021

Ketua Perpustakaan
Perpustakaan Laman Hikmah
Universiti Teknikal Malaysia Melaka

Melalui

Dekan
Fakulti Teknologi dan Kejuruteraan Mekanikal
Universiti Teknikal Malaysia Melaka

Tuan

PENGKELASAN TESIS SEBAGAI TERHAD BAGI TESIS PROJEK SARJANA MUDA

Dengan segala hormatnya merujuk kepada perkara di atas.

2. Dengan ini, dimaklumkan permohonan pengkelasan tesis yang dilampirkan sebagai TERHAD untuk tempoh **LIMA** tahun dari tarikh surat ini. Butiran lanjut laporan PSM tersebut adalah seperti berikut:

Nama pelajar: EZEKIEL ERNATH A/L ELLAPEN (B092110340)
Tajuk Tesis: DESIGN AND FABRICATION OF COMMERCIAL VEHICLE'S EMERGENCY BRAKE SYSTEM USING AUXILIARY BRAKING SYSTEM

3. Hal ini adalah kerana IANYA MERUPAKAN PROJEK YANG DITAJA OLEH SYARIKAT LUAR DAN HASIL KAJIANNYA ADALAH SULIT.

Sekian, terima kasih.

"BERKHIDMAT UNTUK NEGARA"
"KOMPETENSI TERAS KEGEMILANGAN"

Saya yang menjalankan amanah,

NAMA
Penyelia Utama/ Pensyarah Kanan
Fakulti Teknologi dan Kejuruteraan Mekanikal
Universiti Teknikal Malaysia Melaka

Appendix E: Library Form

FACULTY OF TECHNOLOGY AND MECHANICAL ENGINEERING
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BACHELOR DEGREE PROJECT
SUPERVISOR DECLARATION FORM

BACHELOR DEGREE PROJECT 1 [ ] BACHELOR DEGREE PROJECT 2 [/]

SEMESTER ...2.... SESSION ....2024 / 2025.....

A. DETAILS OF STUDENT *(to be completed by student)*

Name : EZEKIEL ERNATH A/L ELLAPEN

Program : BMKA Matric No. : B092110340 Phone No. :

Title : Design and Fabrication of Commercial Vehicle's Emergency Brake System using Auxiliary Braking System

B. CHECKLIST *(to be completed by student, choose only 1)*

BACHELOR DEGREE PROJECT 1 *(Please tick (/) if completed)*

Project Proposal [/] E-log book [/]

BACHELOR DEGREE PROJECT 2 *(Please tick (/) if completed)*

Full report [/] E-log book [/] Technical paper [/]

Student's Signature :

Date : 8 / 1 / 2025

C. CERTIFICATION BY SUPERVISOR *(to be completed by student, choose only 1)*

Comments: The student final year report is ready to be examined

[/] I hereby certified that the student is completed all the documents as stated in Part B and recommended for evaluation

[ ] Not recommended for evaluation

Supervisor's Signature : Date : 9/1/2025
And Stamp
IR. TS. DR. MOHAMAD HAFIZ BIN HARUN
Pensyarah Kanan
Fakulti Teknologi Dan Kejuruteraan Mekanikal
Universiti Teknikal Malaysia Melaka (UTeM)

REMINDER:
Kindly submit the completed form to the PSM (JTK) FTKM Committee

Appendix F: Supervisor Declaration Form