DEVELOPMENT OF TUNNEL VENTILATION SYSTEM (TVS) MAINTENANCE MANUAL FOR MRT PUTRAJAYA LINE UNDERGROUND SECTION

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DEDICATION

To my beloved mother and father,

Mr. Abdul Jalil & Mdm. Zainun

For being the backbone of my life by supporting me from the very beginning

To my supervisor and mentor,

Dr. Mimi Faisyalini Binti Ramli

Dr. Aimi Syamimi Ab Ghafar

Dr. Reventheran A/L Ganasan

Mr. Kamarul Ehsan Bin Mohd Rashid

For their consistent encouragement, guidance and support throughout the research journey

To my beloved husband,

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Close family members & true friends

For their endless support, trust, cooperation, and motivation during this project

To supporting company/organisation

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For their direct and indirect support in completing various stages of this research

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ABSTRACT

A tunnel ventilation system (TVS) on railway lines has been installed for the primary purpose of providing safe evacuation conditions for people and contributes to the energy efficiency and sustainability of the system. In Malaysia, the Klang Valley Mass Rapid Transit (KVMRT) project which began operation in 2017, was designed with a comprehensive TVS. The ventilation system is typically tested and commissioned before the railway is opened to the public to ensure that it meets safety and performance standards. As part of the operation, TVS will be controlled remotely using the Integrated Control Supervisory System (ICSS), which provides retrieval of field inputs and remote control of field devices. Hence, Interface pre-test between TVS and ICSS is conducted to validate the approved interface design, monitoring and control functions whichever is applicable. For this study, the Interface Pre-test is conducted at one of the underground stations of the MRT Sungai Buloh Putrajaya line which is Chan Sow Lin Station. The pre-test includes tests for the Input/Output (I/O) List, a redundancy test, and a test for the Corrective Maintenance Work Order. After the completion of the pre-test, rectification works were conducted to rectify the findings from the pre-test before proceeding with the official Interface Test. To minimize the risk of errors and faults during the live operation of the rapid transit system, a maintenance manual is required to serve as a guide for the end-users, which are the rapid rail staff who operate the system. This manual provides detailed instructions for the maintenance and operation of the TVS, including troubleshooting procedures to identify and rectify any issues that may arise during operation. This maintenance manual was reviewed by the Design and Technical team from MMC – Gamuda KVMRT (T) Sdn Bhd, the project's main contractor, before been approved by MRT Corporation, the government agency responsible for the development and operation of the Mass Rapid Transit system. The review ensured the manual met project specs, technical standards, and safety criteria for the railway system's operation.

ABSTRAK

Sistem pengudaraan terowong (TVS) pada laluan kereta api telah dipasang untuk tujuan utama memberikan evakuasi yang selamat untuk orang ramai dan menyumbang kepada kecekapan tenaga dan kelestarian sistem. Di Malaysia, projek Klang Valley Mass Rapid Transit (KVMRT) yang memulakan operasi pada tahun 2017, direka dengan sistem pengudaraan terowong yang komprehensif. Sistem pengudaraan biasanya diuji dan disahkan sebelum kereta api dibuka untuk penggunaan awam bagi memastikan ia memenuhi piawaian keselamatan dan prestasi yang diperlukan. Sebagai sebahagian daripada operasi, TVS akan dikawal dari jarak jauh menggunakan Sistem Kawalan Penyeliaan Bersepadu (ICSS), yang menyediakan pengambilan input lapangan dan kawalan jarak jauh peranti lapangan. Oleh itu, Ujian 'Interface' antara TVS dan ICSS dijalankan untuk mengesahkan reka bentuk antara muka yang diluluskan, pemantauan dan fungsi kawalan yang sesuai. Bagi kajian ini, Pra-Uji dijalankan di salah satu stesen bawah tanah laluan MRT Sungai Buloh-Putrajaya iaitu Stesen Chan Sow Lin. Pra-uji mencakupi ujian untuk Senarai I/O, ujian kerelipan dan ujian Pesanan Kerja Penyelenggaraan Pembetulan. Selepas penyelesaian Pra-Ujian, kerja-kerja pembetulan dilakukan untuk membetulkan temuan dari Pra-Ujian sebelum melanjutkan dengan Ujian rasmi 'Interface' ini. Untuk mengurangkan risiko kesilapan dan kerosakan semasa operasi, sebuah manual penyelenggaraan diperlukan sebagai panduan kepada pengguna akhir, iaitu kakitangan rel. Manual ini memberikan arahan terperinci bagi penyelenggaraan dan operasi TVS, termasuk prosedur pembaikan untuk mengenal pasti dan memperbetulkan sebarang masalah yang mungkin timbul semasa operasi. Manual penyelenggaraan ini diulas semula oleh pasukan Reka Bentuk dan Teknik dari MMC - Gamuda KVMRT (T) Sdn Bhd, kontraktor utama projek, sebelum diluluskan oleh MRT Corporation, agensi kerajaan yang bertanggungjawab untuk pembangunan dan operasi sistem Mass Rapid Transit. Semakan memastikan manual memenuhi spesifikasi projek, standard teknikal, dan kriteria keselamatan untuk operasi sistem kereta api.

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LIST OF SYMBOLS AND ABBREVIATIONS

ACK	-	Acknowledge
AI	-	Analog Input
AO	-	Analog Output
AFC	-	Automatic Fare Collection
APG	-	Automatic Platform Gate
BCC	-	Backup Control Centre
BMS	-	Building Management System
BTN	-	Backbone Transmission Network
CCTV	-	Closed-circuit Television
CSLS	-	Chan Sow Lin Station
COM	-	Telecommunication Systems
CMMS	-	Computerised Maintenance Management System
CPU	-	Central Processing Unit
CRA	-	Remote I/O Adapter
DBMS	-	Database Management System
DE	-	Depot Equipment
DI	-	Digital Input
DO	-	Digital Output
DPS	-	Differential Pressure Sensor
ET	-	Electric Trains
EAC	-	Electronic Access Control
ECS	-	Environmental Control System
FAT	-	Factory Acceptance Test
FCR	-	Fire Control Room
FDPS	-	Fire Detection and Protection System
FEP	-	Front-End Processor
FWD	-	Forward

GS	-	General Specification
GIM	-	General Information Manual
HMI	-	Human-Machine Interface
HTTPS	-	Hypertext Transfer Protocol Secure
HW	-	Hardware
ICE	-	Independent Consultant Engineer
I/O	-	Input / Output
ICD	-	Interface Control Document
ICSS	-	Integrated Control Supervisory System
IFT	-	Interface Test
IP	-	Internet Protocol
ITS	-	Information Technology System
JSON	-	JavaScript Object Notation
KVMRT	-	Klang Valley Mass Rapid Transit
LAN	-	Local Area Network
MCC	-	Motor Control Center
MCS	-	Master Clock System
MFD	-	Motorized Fire Damper
MFT	-	Multi-Functional Terminal
MRTC	-	Mass Rapid Transit Corporation
NAS	-	Network Attached Storage
NB	-	North Bound
NEJV	-	NAJCOM – EVD Joint-Venture
NTVS	-	North-End Tunnel Ventilation System
OCC	-	Operations Control Centre
OIL	-	Open Item List
OSIT	-	Off-Site Integration Test
OWPC	-	Other Work Package Contractor
OTE	-	On-Target Earnings
PAC	-	Programmable Automation Controller
PAS	-	Public-Address System
PAT	-	Partial Acceptance Test
PDP	-	Project Delivery Partner
PIDS	-	Passenger Information Display System

PLC	-	Programmable Logic Controller
PPE	-	Personal Protective Equipment
PPS	-	Pre-actuator Power Supply
PS	-	Particular Specification
PS&DS	-	Power Supply & Distribution System
PSD	-	Platform Screen Door
REV	-	Reverse
RFI	-	Request for Inspection
RS	-	Radio System
RTD	-	Resistance Temperature Detector
RTN	-	Return / Normalize
SAT	-	System Acceptance Test
SB	-	South Bound
SCR	-	Station Control Room
SIT	-	System Integration Test
S&TCS	-	Signalling & Train Control System
SW	-	Software
SPS	-	Sensor Power Supply
STVS	-	South-End Tunnel Ventilation System
T&C	-	Testing & Commissioning
TCP	-	Transmission Control Protocol
TECS	-	Tunnel Environmental Control System
TEF	-	Trackway Exhaust Fan
TES	-	Trackway Exhaust System
TVS	-	Tunnel Ventilation System
WPC	-	Work Package Contractor

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CHAPTER 1

INTRODUCTION

The Mass Rapid Transit (MRT) Sungai Buloh-Kajang (SBK) Line is a modern rapid transit system that connects the northern and southern regions of the Klang Valley and becomes the second underground railway in Malaysia after the Light Rail Transit Kelana Jaya Line that begin operation in 1999. This project is a part of Kuala Lumpur's Klang Valley Integrated Transit System, which is a larger rail transport system encompassing all of city's rail transport systems (Faris, 2022).

One of the critical components of the SBK Line is the Tunnel Ventilation System (TVS), which plays a crucial role in ensuring the safety and comfort of passengers and staff who use the train system. Therefore, the success of the TVS in the SBK Line has led to its continuation in the Sungai Buloh Putrajaya (SSP) Line which to utilize the same transverse ventilation system that was first implemented in the SBK Line (Ir. Paul, 2018).

As part of the testing and commissioning process, the interface test between the TVS and the Integrated Control Supervisory System (ICSS) is a critical process in ensuring the safe and efficient operation of the MRT system. The TVS is responsible for managing air quality, temperature, and humidity within the tunnel, while the ICSS oversees the overall operation of the system, including the power supply, train control, and communication systems (Bin Ning *et al*., 2006).

In this study, the interface test was conducted at the Chan Sow Lin underground station of MRT SSP Line, and the focus was on the pre-test phase, which is aimed at identifying any faults or errors in the communication protocols between the two systems. During the pre-test phase, the TVS and the ICSS were installed, and their communication protocols were tested using simulation scenarios. These simulations were designed to mimic various environmental conditions and emergency scenarios, such as smoke and toxic gases.

The aim was to verify that the ventilation system could respond appropriately to changes in the environment, and that the ICSS could monitor and adjust the ventilation system as needed. The pre-test phase revealed several findings in terms of errors or faults in the communication protocols between the TVS and the ICSS. These findings highlight the importance of conducting a thorough pre-test phase before proceeding with the official Interface Test and most importantly before TVS and ICSS are put into service.

After the pre-test phase, the findings were carefully analysed, and corrective actions were taken to rectify the errors and faults identified. These actions were necessary to ensure that the system operated efficiently and safely during the official interface test with MRT Corporation. Once the railway is operational, the TVS is operated and maintained by trained staff to perform regular inspections, maintenance and respond to emergencies such as fires or other incidents that may affect the system. Therefore, a maintenance manual was developed as a guide for the end user which is Rapid Rail to understand the whole systems during live operation.

1.1 Problem Statement

In 2017, the operation of Klang Valley Mass Rapid Transit (KVMRT) project has introduced an advanced Tunnel Ventilation System (TVS) that has greatly improved the safety and efficiency of underground transportation in Malaysia. Compared to older systems such as jet fans used in the LRT Kelana Jaya Line that begin operation back in 1999, the new system in MRT project provides more accurate and precise monitoring of environmental conditions in the tunnels, allowing for faster and more effective response to emergencies.

During the testing and commissioning phase, interface pre-test must be conducted to identify any faults or errors before the system could be put into service. The interface pre-test is necessary because the TVS and Integrated Control Supervisory System (ICSS) are complex systems that rely on precise communication and interaction between various subsystems.

To minimize the risk of errors and faults during the live operation of the rapid transit system, a maintenance manual is required to serve as a guide for the end-users, which are the rapid rail staff who operate the system. This manual provides detailed instructions for the maintenance and operation of the TVS, including troubleshooting procedures to identify and rectify any issues that may arise during operation.

1.2 Objective

In order to ensure the smooth and reliable functioning of the Tunnel Ventilation System (TVS) during live operation, this thesis aims:

i. To identify the errors and faults during the live operation of the Tunnel Ventilation System (TVS) by performing pre-test of the Interface Test with Integrated Control & Supervisory System (ICSS).
ii. To analyse and rectify the findings from the completed Pre-test.
iii. To develop and validate the Maintenance Manual for Tunnel Ventilation System (TVS) as a guide to end user during actual operations.

1.3 Scope

These are the scopes that this project is focusing on:

i. The pre-test is conducted at Chan Sow Lin Station of the MRT Putrajaya Line specifically along a 1.9km tunnel leading towards Bandar Malaysia North MRT Station. The tunnel has a diameter of 5.8m.
ii. Only I/O List test and Redundancy Test are required for Chan Sow Lin station.
iii. The maintenance manual is developed as a guide for the end-users, which are the rapid rail staff who operate the system.
iv. The maintenance manual is tailored to the specific MRTC's requirements and specifications of the transverse type of Tunnel Ventilation System (TVS) installed in the SSP Line and is not intended for use in other rapid transit projects.

1.4 The Importance of Project

The interface test and development of the maintenance manual for the Tunnel Ventilation System (TVS) in MRT SSP Line are critical to ensuring the safe and efficient operation of the rapid transit system. By identifying and rectifying potential faults before the system is put into service, and by providing comprehensive guidance on maintenance and operation, the TVS can be operated safely, efficiently, and reliably, benefiting both commuters and the environment.

CHAPTER 2

REVIEW ON CURRENT PRACTICES

In Malaysia, the Mass Rapid Transit (MRT) project represents one of the projects identified by the Economic Transformation Programme as one of the economic entry points into the Greater Kuala Lumpur/Klang Valley National Key Economic Area. For MRT Putrajaya Line, the tunnel system of this railway project consists of 11 underground stations with 13.5km length. Compared to MRT Kajang Line, the line runs underground for 9.5km beneath the centre of Kuala Lumpur with 7 stations (Imran *et al.*, 2021). The brand used for Tunnel Ventilation System (TVS) for these 2 projects also different which is Kruger as a supplier for MRT Kajang Line, and Systemair for MRT Putrajaya Line. Therefore, there would be a difference in the operation procedure and the instructions provided to the end user.

This chapter focuses on the background of the Tunnel Ventilation System (TVS) used in the underground railways of Malaysia, specifically the LRT Kelana Jaya Line, MRT Kajang Line, and MRT Putrajaya Line. These three underground railway systems in Malaysia are currently the only ones utilizing TVS. This chapter further delves into the Integrated Control Supervisory System (ICSS) used for the MRT Putrajaya Line which this system helps in the monitoring and controlling of various components of the railway system, including TVS.

This chapter then proceeds to discuss the Interface Test between the Tunnel Ventilation System (TVS) and Integrated Control Supervisory System (ICSS) for MRT Putrajaya Line. This test is essential to ensure that TVS and ICSS are working together seamlessly and effectively, allowing for a smooth and safe operation of the railway system. Finally, this chapter concludes with a discussion on the Maintenance Manual for Tunnel Ventilation System for MRT Putrajaya Line. This manual provides a comprehensive guide for maintaining and servicing TVS to ensure its optimal functioning, which is critical for the safety of passengers and the efficient operation of the railway system.

2.1 Tunnel Ventilation System for Underground Railway in Malaysia

Tunnel ventilation systems are an essential component of any rail system to ensure passenger safety and operational efficiency. In recent years, there has been a significant amount of literature published on tunnel ventilation systems in railways, covering a wide range of topics from design and performance to maintenance and energy efficiency (Chi-Ji Lin *et al*., 2007). Several studies have focused on the design and performance of tunnel ventilation systems in railways. These studies have explored different types of ventilation systems including longitudinal, transverse, jet and hybrid ventilation systems.

In a longitudinal ventilation system, fresh air is supplied to the tunnel through air inlets located at one end of the tunnel, and the air is extracted through exhaust vents at the other end. This type of system is suitable for tunnels with a low gradient. For a transverse ventilation system, air is supplied to the tunnel through ducts located along the length of the tunnel. The air is then extracted through exhaust vents located on the tunnel ceiling. This type of system is suitable for tunnels with a high gradient. Meanwhile for a jet ventilation system, high-velocity air is supplied through jet fans located at regular intervals along the tunnel. The air flow is directed towards the ceiling, creating a flow pattern that draws smoke and other pollutants away from the passengers. This type of system is particularly effective in case of fire (Mohammad *et al*., 2004).

Lastly, a hybrid ventilation system combines elements of longitudinal and transverse ventilation systems. Fresh air is supplied through air inlets located at the tunnel entrances, and the air is then distributed along the length of the tunnel through ducts. The air is then extracted through exhaust vents located at regular intervals along the tunnel (Mohammad et al., 2004). The choice of ventilation system depends on several factors, including tunnel length, gradient, and the type of train running through the tunnel. A well-designed ventilation system is essential to ensure passenger safety and comfort in railway tunnels.

The LRT Kelana Jaya line and the MRT system in Malaysia both utilize tunnel ventilation systems to provide a continuous supply of fresh air, remove pollutants, and control the airflow within the tunnel environment. It achieves this through a combination of intake and exhaust systems strategically positioned along the tunnel's length. These systems facilitate the circulation of air, preventing the accumulation of harmful gases, heat, and smoke.

The LRT Kelana Jaya line uses a longitudinal ventilation system, which supplies fresh air through air inlets located at one end of the tunnel and extracts the air through exhaust vents located at the other end. The system also incorporates jet fans located at regular intervals along the tunnel to ensure proper air circulation and smoke extraction in case of a fire. The ventilation system is designed to maintain a comfortable temperature and air quality level for passengers throughout the entire length of the tunnel.

On the other hand, the MRT system in Malaysia utilizes a transverse ventilation system that delivers fresh air along one side of the tunnel and extracts contaminated air along the other side. The airflow moves across the tunnel's cross-section. The fresh air supply and exhaust air removal are achieved through plenums that run longitudinally along the tunnel, which can be situated either below the road surface or above a false ceiling. The mechanical fans that power the ventilation system are in external ventilation facilities, not within the tunnel.

MRT system started to improvise the TVS by using axial fans compared to LRT Kelana Jaya Line that using jet fan to ensure proper smoke extraction in case of a fire. The ventilation system for MRT system is designed to maintain a comfortable temperature and air quality level for passengers throughout the entire length of the tunnel.

2.1.1 Tunnel Ventilation System for MRT Putrajaya Line

Unlike buildings with multiple floors, rail tunnels can have various ventilation method, which are longitudinal, semi-transverse ventilation and transverse ventilation. It can be provided by either large, reversible fans that extract/supply air from the centre of a tunnel, or by jet fans that are placed at the vicinity of the tunnel's walls (WTW Bill Cory, 2005).

In tunnels, if air cannot be extracted or supplied from the centre, then the air will enter or leave the tunnel via the easiest path, generally through the empty tunnel and not through the section containing the train. As such, when calculating the flow past a train, it is necessary to consider the relative system resistances that exist within the system. Generally, TVS for MRT Sungai Buloh Putrajaya Line underground section consists of the following system:

i. Tunnel Environmental Control System (TECS)
ii. Tunnel Ventilation Fan (TVF)
iii. Trackway Exhaust Fan (TEF)
iv. Motorised Fire Damper
v. Actuator
vi. Limit Switch
vii. Thermal Jacket
viii. Silencer
ix. ICSS Control (By Najcom-EVD Joint Venture)

2.1.1.1 Tunnel Environmental Control System (TECS)

The entire tunnel ventilation system is controlled by the Tunnel Environmental Control System (TECS) located within the station under initiation control from the Operation Control Centre (OCC) via Integrated Control Supervisory System (ICSS). Two Programmable Logic Control (PLC) are provided within the station. Each PLC is programmed with all TECS modes of operation relevant to the fans and dampers within the station to provide 100% redundancy should one PLC fail. Each PLC is provided with connections to ICSS via Backbone Transmission Network (BTN) which will initiate control as dictated by the OCC. As shown in Figure 2.1, the TECS system consists of the following equipment:

i. Magelis HMI
ii. Ethernet switches
iii. Fibre optic converters
iv. Redundant PLC CPU racks
v. I/O racks

The operation of the TECS is primarily controlled from the OCC. A master mode table has been developed to account for all identified modes of operation including normal, congested and emergency operation. The operator at OCC will select the required mode of operation and send this command via the ICSS network to the TECS PLC. Upon receive of the master mode, the PLC will configure the TECS for the required operation. In the event of ICSS failure, operator at station can operate the TECS PLC at ancillary building from the TECS Human Main Interface (HMI) at relative station Station Control Room (SCR) or Fire Control Room (FCR).

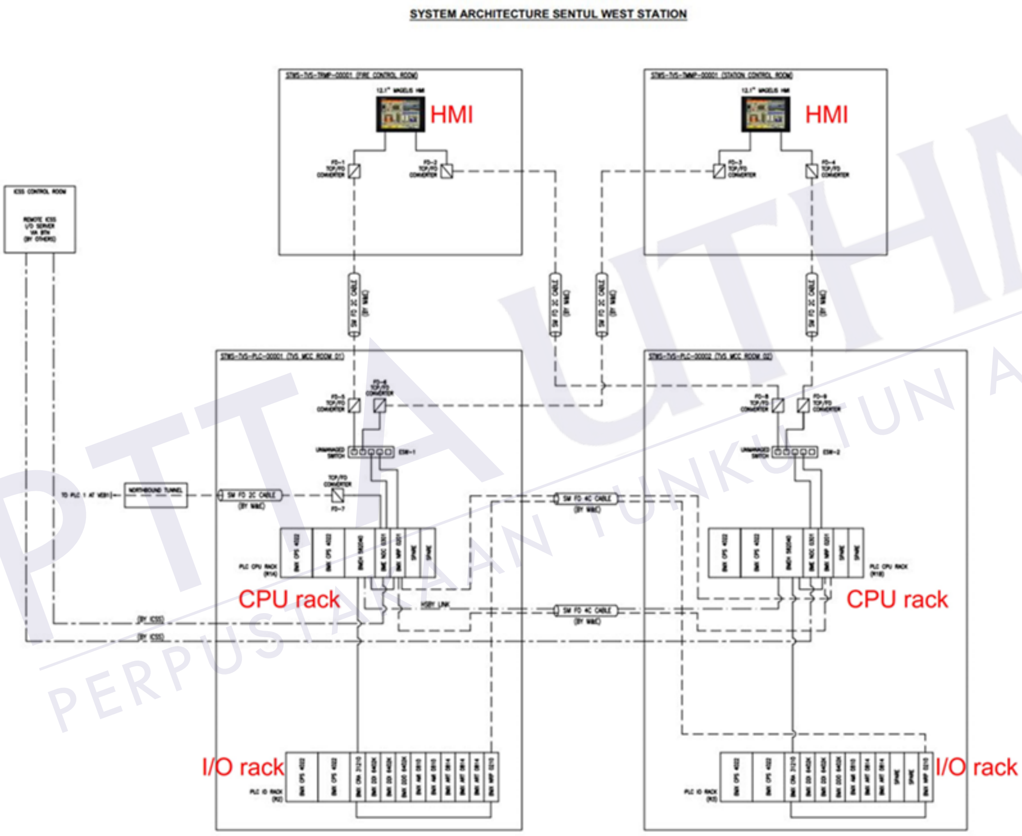

Figure 2.1: Typical TECS System Architecture of Station (MMC-Gamuda KVMRT (T) Sdn Bhd, 2022)

2.1.1.2 Tunnel Ventilation Fan (TVF)

The Tunnel Ventilation Fan (TVF) is supplied by SYSTEMAIR. It has an internal diameter of 2000mm, and its casing was constructed by using mild steel and coated with hot dipped-galvanized. The blades are made from LM13 aluminium-alloy forging

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VITA

The author is a professional technologist and was born on April 28th, 1992, in Kuala Lumpur. She went to Sekolah Kebangsaan Seri Cheras Kuala Lumpur, Sekolah Menengah Kebangsaan (SMK) Agama Kuala Lumpur and Sekolah Menengah Teknik Tuanku Jaffar, Seremban for her primary and secondary schools respectively. She first obtained her Matriculation Certificate in Physical Science in 2011, at Kolej Matrikulasi Melaka located in Masjid Tanah, Melaka. She further pursued her bachelor's degree at Universiti Teknologi Malaysia (UTM), Skudai, Johor, and graduated with the B.Eng. (Hons) in Mechanical Engineering (Industrial) in 2015. In 2017, she started her first professional career in South Korea as a Quality Control Inspector. She returned to Malaysia after a year and worked at Legoland Malaysia as a Health and Safety Executive for one year. In 2018, she switched fields and worked with Gamuda Berhad as a Mechanical and Electrical Engineer and was directly involved in the MRT Sungai Buloh Putrajaya Line (Underground) project. It was here that she developed an interest and a passion for the field of railways, which she decided to pursue further. During this time, she decided to further her studies at UTHM in Master of Engineering Technology which UTHM is the only university in Malaysia to offer Railway Courses with Industrial Based style. After four years been involved with MRT SSP Line Underground project, she has gradually developed her career and is now working with Sapura Rail System as a Senior Engineer for LRT3 Bandar Utama Johan Setia Line project.