Addis Ababa University

Addis Ababa Institute of Technology (AAiT)

African Railway Center of Excellence (ARCE)

A Thesis in MSc. Railway Engineering (Traction & Train Control)

INVESTIGATION ON THE EFFECT OF THE INTERNET OF THINGS (IoT) TECHNOLOGY TO IMPROVE TRACTION SAFETY.

Case Study: Addis Ababa light rail transit (AALRT)

By

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June 21, 2020

A Thesis

Submitted In Partial Fulfilment of the Requirements for the Degree of Master of Science in Railway Engineering (Traction and Train Control).

DECLARATION

I, **John Kajubu**, do declare that this research is my work except where due acknowledgment is made in the text and that it has never to the best of my knowledge been submitted for any prior academic award or qualification.

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APPROVAL

The undersigned have examined the thesis report entitled **‘Investigation on the effect of the Internet of things (IoT) technology to improve traction safety’** presented by **John Kajubu** of registration number **GSR/5617/11**, a candidate for the degree of Master of Science in Railway Engineering (Traction and Train Control) and hereby certify that it is worthy of acceptance.

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ABSTRACT

Electric trains are made up of various safety-sensitive systems, these systems are safety-sensitive in that a simple loophole can compromise the train's safety and may lead to catastrophic incidents and accidents. These systems are usually maintained regularly at set schedules and frequencies to keep the train in good working conditions. This type of maintenance is called preventive maintenance. However, cases may occur where a system abnormality may occur or be altered before the pre-set preventive maintenance. This may or may not cause an immediate effect but can be a root cause of a major system failure and hence leading to equipment damage and accidents. What is currently being done in case of such a scenario is that the driver who may or may not technically upright make a call to the technical department to report any abnormality on the train. This method is time-consuming and it would require a detailed explanation to correctly diagnose the real cause of the problem.

Therefore this research investigates the effect of the Internet of Things (IoT) to improve the system's traction safety through real-time conditions monitoring over the LTE-R network and internet communication channel, meaning it advocates for predictive rather than preventive maintenance. Upon simulation of the IoT system, this research indicates an improvement in the time parameters of the average duration it would take for the technical team to get the information about a certain fault. The improvement was found out to be 97.4%, from approximately 1.5 hours to 0.02 hours. The other parameters of meantime to repair (MTTR) and meantime before failure (MTBF) are not affected by this idea of including IoT technology. This was achieved by constantly monitoring the system vital parameters in real-time and sending an instant e-mail and SMS notification in case of any fault or abnormality the system detects from the big data generated from the sensor nodes.

Keywords: IoT-Internet of things, safety, reliability, real-time.

ACKNOWLEDGMENTS

First and foremost, I would like to thank my advisors, Dr. Mengesha Mamo, and co-advisor Mr. Biniyam Ayalew for their valuable guidance and advice. They inspired me greatly to work on this thesis and their willingness to motivate me contributed tremendously to my progress.

I would like to also thank all my friends like Brian Watuwa, Lubaale Solomon Azaria, and Philomera Nakyanja who contributed to this thesis work by giving me supportive materials, information, advice, and helpful ideas. I would also like to thank God and the Ethiopian government and the World Bank for having sponsored this graduate study for without them it wouldn’t have been possible.

Finally, I would love to express my utmost gratitude towards my family back in Uganda for their great support and understanding while working on this thesis and through all my graduate studies away from home.

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List of Acronyms

Term	**Explanation / Meaning / Definition**
AALRT	Addis Ababa Light Rail Transit
API	Application Programming Interface
BDA	Big Data Analysis
EMU	Electrical Multiple Unit
GSM-R	Global Systems for Mobile networks Railways
FMECA	Failure Mode Effects and Criticality Analysis
CCTV	Closed Circuit Television
FTA	Fault Tree Analysis
MTTR	Meant-time to repair
MTBF	Meant-time before failure
MDBF	Mean distance before failure
LTE-R	Long Term Evolution for Railways
IoT	Internet of Things
WSN	Wireless Sensor Networks
RIoT	Rail Internet of Things
RFID	Radio Frequency Identification
LAN	Local Area Network
Wi-Fi	Wireless Fidelity
NTC	Negative Temperature Coefficient
IR	Infrared

1.0 CHAPTER ONE

1.1 INTRODUCTION

In general, the traction system(s) on an electric train is key and is composed of very critical components. It is known that the traction motor must be efficient and reliable as it is required to provide both speed and torque over a wide range while maintaining precise control of the motor drive safely[1]. To prevent the traction motor's abnormalities, the improved reliabilities and effective operation with an early warning with the instant notification are desirable. Research has it that vibration, current, and temperature are the three parameters that are well studied and widely accepted in detecting traction system failures since electrical and mechanical faults are being monitored[1]. This is because of the high complexity, usage and rating of the train traction systems, it is generally impracticable to avoid these electrical and mechanical faults, and the effects caused may become more significant at high service speeds[1],[2]. However, the faults related to pantographs, motor drives, traction motors, gears, etc. have been discussed in recent years, and some preventive measures have been proposed[2]. Nonetheless, real-time monitoring of the operating conditions of train traction systems remains a bottleneck that impedes an effective operation of modern railway networks in terms of safety, reliability, and availability[2]. Therefore it is very important to provide an instant or even an early notification to railway or train operators about any abnormalities.

With the emerging new technologies, sensors and innovative wireless sensor networks (WSN), a smarter and more reliable technology known as the internet of things (IoT) has been integrated into the transport sector especially in the railway industry. It is sometimes referred to as Rail Internet of things (RIoT). In the RIoT systems, tracks only interact with trains and the central rail control system. Different technologies are installed along the railway track such as GSM-Railway (GSM-R), RFIDs, and balises[3]. GSM-R is an adaptation of GSM telephony for railway applications. It is designed for information exchange between trains and control centers. It has the advantage of low cost and worldwide availability[4]. Radiofrequency identification (RFID) is a wireless communication technology that lets computer systems read the ID of modest electronic tags from a separation or distance without requiring a battery in the tag[5]. The balise is an electronic tag or device that is placed between the rails and can be able to communicate with an onboard system by feeding information through electromagnetic communication[6]. The balise can either be active or passive type depending on the purpose, active balise exchanges information with the onboard system and also receives information. The passive balise only serves one purpose of providing static information to the onboard system, this information includes the location of the train, speed limits, etc.[7].

Furthermore, the internet of things has the potential to play a vital role in the transport sector to efficiently contribute to transport management. To be specific in the railway sector, IoT could improve areas like cross-border transport, rail passenger, and real-time equipment management and tracking[8]. This technology can also improve inter-equipment communication that is alerting train drivers to take appropriate precautions, trains report delays or accidents. It can also help in predictive maintenance of the critical parts of the train, the trains transmit defect data directly to engineers on components in need of repairs[8].

In safety-conscious fields like railways, conditions monitoring of critical systems reduces human inspection requirements through automated monitoring, which helps to reduce maintenance through detecting faults before they escalate and also improves safety as well as systems' reliability. Real-time monitoring is also important and should be employed for systems whose degradation happens slowly over a relatively long period [4]. Big data is yet another enabler for investigation, data analytics, and real-time monitoring in fields like engineering, science, and management. Digital sensors can produce very large amounts of data, such as the internet, sensors, streaming, or mobile data[9]. The ambition in collecting big data of any critical system through effective IoT is to track and monitor assets or systems and be able to correct problems in real-time or call for immediate technical attention from the responsible technical teams[9].

IoT also offers many improvements to rail passengers' travel experience like internet services. Then also machine-to-machine communications can monitor and manage many of the services provided onboard the train. For example, intelligent systems can monitor the functioning of doors and air-conditioning and provide easy diagnostic tests and analysis by the technical and maintenance teams[10]. Real-time monitoring systems have the advantage to speed up the process of decision making during technical repairs and operations. This is because, from the big data analytics, it is easy to predict the possible cause of the failure, the system performance, and life span can also be predicted and determined. This is important in a way that complete system failure would not get the rail operators unaware which could have possibly led to catastrophic accidents or incidents[11].

A train is generally a large mass vehicle moving on steel on steel interaction contact surface with a low coefficient of friction, which unlike rubber tires makes it extremely difficult to come to a halt in a single instance. Therefore real-time monitoring and big data analysis of the traction systems including the brake system would make it possible to keep track of the status of the critical system to make sure that they are fully functional and wouldn't compromise safety in case of need for an emergency braking situation. Therefore real-time monitoring of train systems greatly improves on the safety levels of the systems and train movements in general[12].

1.2 BACKGROUND

Safety and reliability in railway systems are of huge importance, both technical and public safety especially when it comes to protecting the operator's image to the public[8]. The major issue in the railway industry is traction failure, this can lead to various concerns like derailment of trains, fire outbreaks on the train, and collisions. Traction systems are the heart of an electric train locomotive to be able to move and stop when required to do so. Traction systems are mainly comprised of the pantograph, traction motor drives, the motors, braking systems, the wheel axles, etc. Research has been conducted over recent years and it has been discovered that 44% of motor faults are from bearing and 24% are from the stator in motors and this is due to the electrical and mechanical abnormalities as the train moves and accelerates to higher speeds[1].

With the emerging technologies, IoT as new data-driven technology has made it possible to monitor systems in real-time to improve on the safety levels. Also in terms of safety of the train operation, the sensors play an important role in detecting the system state; in terms of intelligence of the rail transit, how to grasp more data for train operation to support the intelligent control of the train. Intelligent monitoring and diagnosis, intelligent maintenance, and other relevant functions are also inseparable from the advanced sensors for monitoring and controlling the train[13]. For example, the high-speed rail disaster prevention and safety monitoring system in Germany and France can achieve real-time monitoring of the environmental information of the train, snowstorm, and litter[11]. Since human error is a factor in most accidents on the railways, and the newer rail services are generally adopting using driverless trains that have remote monitoring of speed and braking, which all are to be controlled by automated signals. Therefore many of these IoT applications are likely to use wireless communication technology, sensors, live video, cloud-based technology, and machine to machine communications[10].

Generally, IoT is looked at as a network that achieves intelligent identifying, locating, tracking, monitoring, and managing through information sensing devices and big data analysis. It involves analysis and process mass data and information with a variety of smart computing technology to accomplish intelligent decision-making and control[11]. Using sensors provides continual monitoring of the conditions, it is also cost-effective and is ideal for covering locations that quite difficult for maintenance staff to reach[10],[2].

1.3 STATEMENT OF THE PROBLEM

Operator companies incur huge amounts of money to recover from the accidents, equipment damage and also to keep up a preventive maintenance schedule for electric trains to make sure that they are always healthy without any safety compromising concerns, yet it may happen so that a safety concern on a train system may arise before the scheduled preventive maintenance time of the locomotive[14], furthermore, time parameters of MTTR, MTBF and the average duration to know about a fault in the system could be improved with the inclusion of the IoT technology enabling real-time conditions monitoring. Therefore this research calls for a focus on predictive maintenance which involves algorithms like data mining, big data analysis and Artificial intelligence in general rather than preventive maintenance for electric trains.

1.4 OBJECTIVES

1.4.1 Main objective

To investigate the effect of the internet of things (IoT) technology on railway traction safety of electric trains through real-time conditions monitoring.

1.4.2 Specific objectives

i. Data collection from the industry, using interviews and existing data and technical specifications.
ii. To model and simulate a system showing potential IoT safety improvement techniques.
iii. To perform data analysis and draw to a conclusion on effect of IoT.

1.5 SCOPE

The scope of this research was limited to only the traction system which may include components like the electric motor and the converter, this is because the traction system fails most amongst the various systems on rolling stock.

1.6 ASSUMPTIONS

i) The basic assumption for this system operation to fully execute the functionalities is reliable internet connectivity. This is because the email and SMS notification functions require the internet to connect to the Twilio SMS API and the google mail servers as well.

2.0 CHAPTER TWO

2.1 LITERATURE REVIEW

There is a growing interest in the potential of the internet of things (IoT) technologies to support sustainable transport systems in Africa and the world in general[8]. With the advancement in technology, the idea of utilizing the internet of things (IoT) has made it possible to capture data and report vital parameters of systems with fast reliable data acquisitions, low power consumption in real-time[1]. Therefore this chapter explains the various terminologies used in the IoT industry, the various technicalities regarding the sensors used and the previous works done related to the topic of interest; investigation on the effect of the Internet of things (IoT) to improve traction safety and system reliability through real-time conditions monitoring.

2.2 IoT definition

The term internet of things generally refers to scenarios where network connectivity and computing capability extends to objects, sensors, and everyday items not normally considered computers, allowing these devices to generate, exchange and consume data with the minimal human intervention[15]. There is however no single or universal definition of IoT.

2.2.1 IoT Hierarchy Architecture in Railway Safety Monitoring

The IoT architecture in the railway safety monitoring from the sensor, transmission, service angle, vertically divided according to the function. It can be divided into the application layer, the network layer, and the sensing layer[11]. The sensing layer includes a variety of real-time data-aware acquisition equipment and the underlying sensor network which realizes transmission of putting these data into the LAN in the railway safety monitoring. The network layer in the IoT architecture is responsible for the railway internet of things network transmission of the real-time acquisition data. The application layer is the network layer real-time access to the information, applied to the field of railway safety monitoring system for the protection of railway safety[11]. Refer to the figure 2-1 for the typical layers of an IoT system in railways below;

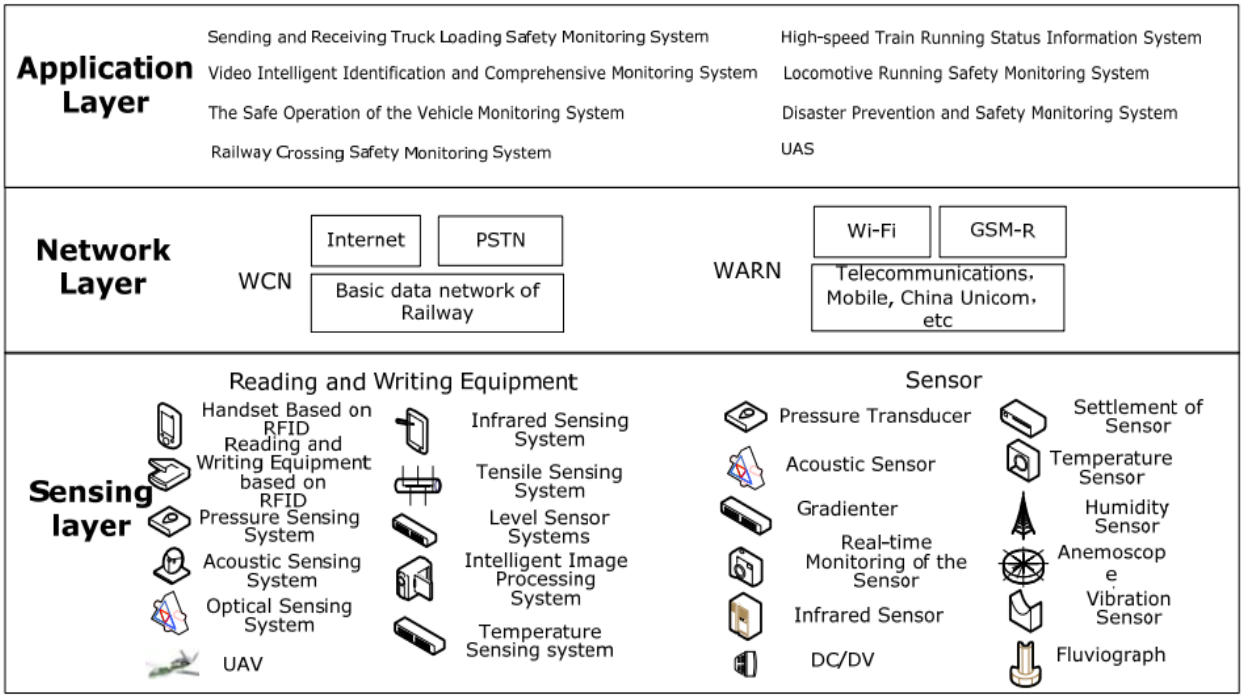


Figure 2-1: IoT Hierarchy Architecture in Railway Safety Monitoring, source: [11]

2.3 Railway safety

Trains are usually associated with low coefficients of friction because there is a wheel to rail interaction. This raises a safety concern since it increases the trains' braking distance except for the case of magnetically levitated trains. Also, trains possess a unique characteristic of always traveling on a guided track, this allows no opportunity to avoid collision by steering action. Therefore, high collision speeds and high kinetic energy makes it high for severity consequences[12].

2.3.1 How big data analysis is improving on railway safety

Big data analytics (BDA) age where mountains of data should enable us to understand how complex socio-technical systems work. This is the central idea for safety II unlike safety I that uses Failure Mode and Effects Analysis (FMEA) and fault tree analysis (FTA) to focus on the system failure rates[16]. However, a thorough understanding of the practitioner of past incidents is essential in all these processes. Without this knowledge, it will be impossible to understand errors, failures, and how hazards propagate into accidents[12]. In simple terms, technical teams usually focus on what goes wrong and not on how things go right. Below is an illustration showing the imbalance that occurs when the focus is on what goes wrong and not on how things go right.

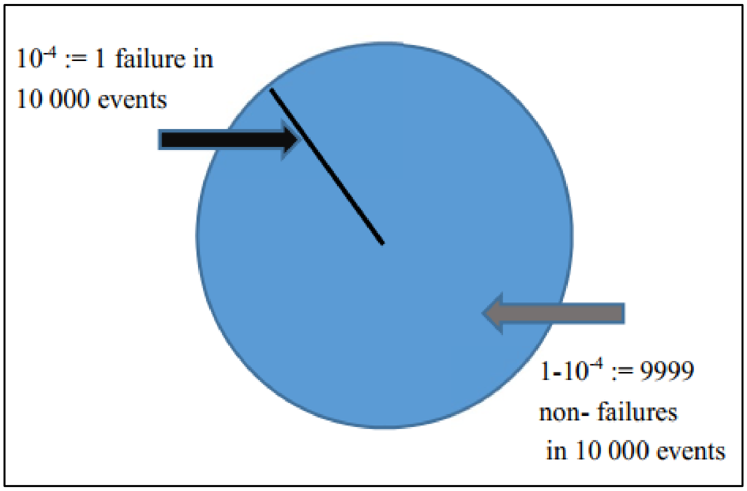


Figure 2-2: Illustration showing the imbalance that occurs when the focus is on what goes wrong and not on how things go right. Source: [12]

A big data analytics approach to learning from accidents which will enable the identification of heightened risk. The approach uses an accident causation model called an ELBowTie, this methodology is already well utilized in the safety engineering world[12]. The available sources of data that can be linked to railway operational risks may include condition-based monitoring information from sensors, either analog or digital, that would provide digital information, including vibration (accelerometers), machine vision, heat, displacement, strain, humidity, particle ingress, etc. this data is classified as real-time, remote monitoring data[12].

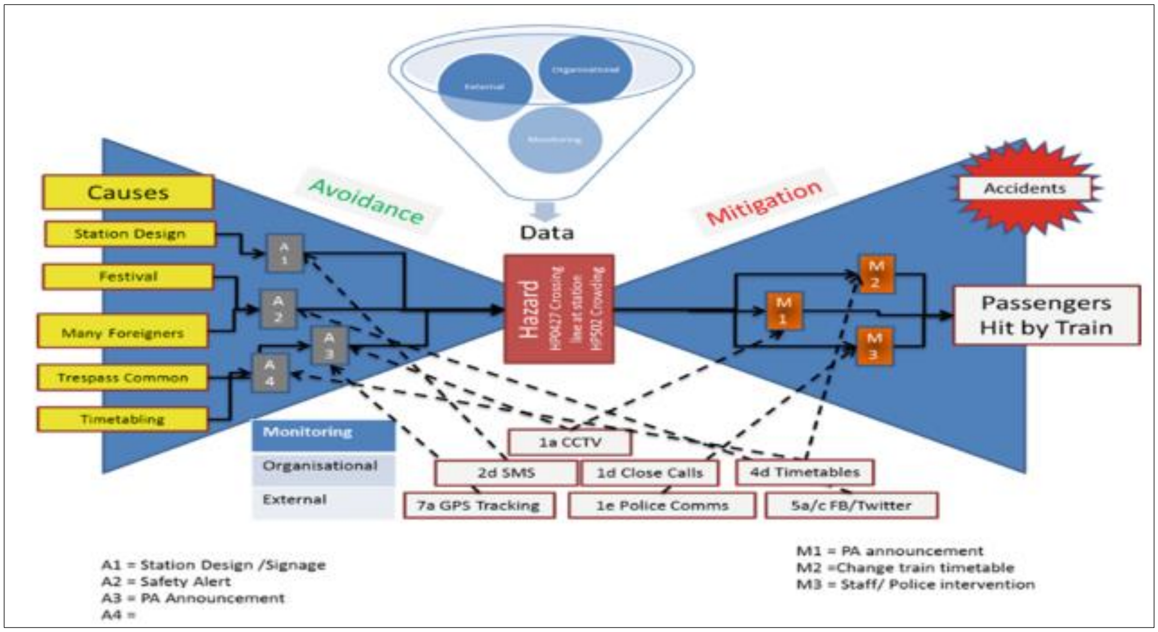


Figure 2-3: ELBowtie real-time data analysis example. Source: [12]

The railway is known to be one of the safest modes of land transport and any railway strategy should be aimed at maintaining that position. Therefore the railway will actively move towards being the safest mode of all transport sectors and thereby be even more attractive to the customers. However the human factor is one of the weakest links still in place and due to research, most processes are being automated and IoT is one of the primary drivers[17]. This is the primary goal of any transport industry.

IoT is playing quite an important role in railway, through IoT applications and solutions for train management to furthermore enhance the safety of trains while they move by making it possible to detect the position of other trains and also onboard systems monitoring. This reduces the risk of collision by allowing trains to operate safely close to one another[18].

Other benefits from automation and the IoT include[18];

- Signaling.
- Interlocking.
- Level crossing control.

2.3.2 How to use IoT technology in railways

In general, IoT applications make use of sensors and other internet services like accessing APIs, HTTP/HTTPS protocol servers to exchange information with system blocks[19]. An internet connection is required to send sensor data to the cloud storage or databases and also retrieving that data in some cases may require an internet connection. IoT based applications also through intelligent terminals help to analyze data, assist in decision making, and other comprehensive system functions based on the big data collected and analyzed[20].

2.4 IoT network technologies

The leading types of wireless technologies for IoT include[21];

- LPWANs (Low Power Wide Area Networks), these are a new phenomenon in IoT.
- Cellular which includes, 3G/4G (LTE)/5G.
- ZigBee and other mesh protocols.
- Bluetooth.
- Wi-Fi and WiMAX.
- RFID[22].

2.5 IoT data protection and security

Since IoT connected devices are run on networks and internet connectivity in most cases, it raises concern to poorly secured IoT devices that could serve as entry points to cyberattack by allowing malicious individuals to re-program a device or use it to malfunction. This is because poorly designed or secured devices can expose user data to theft by leaving data streams inadequately protected[15].

However, some of the industrial solutions may include;

a) Security by design.

This may consider issues like the amount of technical data collection and mitigating costs of security vulnerabilities. The following key points have to be kept in mind for any companies employing IoT[23]:

- Perform security risk assessment during the design process.
- Test device security measures.
- Consider the protection of sensitive data while transmission or storage.

- Monitor IoT devices and install regular software updates.

b) Data minimization

Data minimization is the strategy that organizations can use to maintain the data repository within organizations by defining its duration. In other words, organizations should obtain the data required for a specific purpose and period only and should discard it after, this is because gathering and maintaining large data repository can induce a risk of data breach[23].

2.5.1 Cloud computing data protection and security

Cloud computing can be associated with various security issues and they may include data protection and network security[24], [25],[26]. This is important and needs to be taken care of or thought of as important data and system information could be exposed since the IoT systems require a public network to transfer data and execute main functionalities. Accountability, which is defined as the management of the availability, usability, integrity, and security of the data used, stored or processed within an organization it is also known as data governance[27]. Some key elements of accountability many include; transparency, assurance, user trust, responsibility, and policy compliance[27]. DDoS (distributed denial of service) and man in the middle attack are some of the commonest threats however they can be solved by using a security technique called the Secure Socket Layer (SSL)[24]. Data protection can also be solved by deploying symmetric encryption algorithms and a secret key, this key is encrypted with asymmetric encryption and this key is controlled and managed by clients or users[25]. Finally, data protection in cloud computing can be improved by deploying basic security measures like firewalls, DMZ (demilitarized zone), use of hashed passwords, and adding policies in the networks like the use of administrative privileges[26].

2.6 Maintenance of electric trains

Electric train maintenance is usually done in levels (I-V), schedules, and specified frequencies. This is as a result of improving the safety, reliability, and availability of the various train systems, the preventive maintenance most times is done after a certain distance traveled by train or the mileage[28],[29],[30].

Maintenance of electric trains or any electrical equipment can be subdivided into three categories, that is corrective, preventive, and predictive types of maintenance[29],[30]. The major aim of preventive and predictive is to reduce the chances of corrective maintenance as much as possible.

Predictive maintenance may be understood as an action on the system, equipment, or subsystem components based on the previous operating conditions or system performance that can be obtained by utilizing parameters that were previously determined[30]. This in return would in return increase the system safety, reliability, and availability of the system.

2.7 Previous research works done

Different researches have been done on the potential and effect of the Internet of things technology in various fields like heavy industrial plant industrial application[31], automobiles, and the transportation industry at large. These works focus on the reduction of MTTR (Mean time to restore/repair), MTBF (Mean time between failures) among other parameters, this eventually helps to improve systems' safety and reliability in general and this is made possible by remote monitoring and IoT data[31].

Jose A. Afonso and Ruben A. Sousa *et al*[32], prototyped an IoT system for any time/Anywhere Monitoring and Control of Vehicles' Parameters. In this research, WSN and Bluetooth technology are used to monitor different vehicle systems that are the engine system and the battery or power supply system. Different parameters that are to say; electric charge, current, temperature, voltage level, and last sync which is a value of the GPS location and the speed of the vehicle. This system intended to utilize IoT technology to allow users to monitor sensor data from the vehicle systems and to also control processes like EV(Electric Vehicle) battery charging, either manually or automatically, anytime anywhere. Despite the performance limitations presented by the system on BLE (Bluetooth Low Energy) platform, the results show that the wireless network can satisfy the requirements of the developed IVWSN(Intra-vehicular wireless sensor network), that is if its parameters are properly configured[32].

J. Kunthong *et al's*[1] research, IoT-Based traction motor drive condition monitoring in electric vehicles presents an implementation of a wireless IoT system applied to the traction motor drive condition monitoring in electric vehicles and the prototype is based on an ESP8266 microcontroller to acquire the sensor data of the motor's vibration, current, and temperature. The system was designed using open-source software called a node-red platform for fast, reliable data acquisitions, low power consumption, and also data gathered by the system to get reported to the cloud server in real-time. The experimental results show that the IoT system is capable of capturing and reporting vital motor parameters to the cloud server and an automatic notification is sent to the operators when an abnormality is detected in real-time. Therefore, analytical information provided by the system is a crucial part of effective predictive maintenance which translates into more effective maintenance services and much lower operational cost over the motor's lifetime. Lastly, the mechanical abnormality of the motor can be predicted at the early stages.

Mohd Helmy Abd Wahab *et al*[33], also prototyped an IoT-Based battery monitoring system for an electric vehicle and this research aims at the description of the application of the internet of things in monitoring the performance of electric vehicle batteries. In this research, the system does not only notify the driver in the car but also notifies the manufacturers and other users. It also sends a live GPS (Global Positioning System) location of the car. The system utilizes simple hardware comprising of a voltage sensor, an Arduino UNO and a SIM808 GSM/GPRS/GPS Shield. The system is monitored through a web interface and the location through google maps application. For a better connection, it is recommended to adopt Ethernet rather than GPRS. It is also possible to use other communication shields to carry out this task effectively like the Wi-Fi 210 EVB[34].

Electric motor condition monitoring for predictive maintenance[35]. In this document from data loggers, the conditions of an industrial motor are monitored in real-time, this is because to conduct preventive maintenance, the factory needed reliable condition monitoring before problems could get worse, and also required local alarm notification when for example the motor temperatures go above a preset threshold say 160^0F. Unlike other research works seen previously, this system in this paper entirely relies on a USB port for connection to retrieve the data from the motor for analysis to the PC, and there is an auxiliary serial port and 8-Megabytes of memory. An optional USB device server could be employed to allow multiple Accsense VersaLog loggers to be connected to a single Ethernet port allowing remote, network access. These devices can report alarm status to the host PC via USB, Modem, or Ethernet device server using Accsence SiteView software.

Huag *et al's*[36] fault monitoring and reporting system for trains were designed to monitor and report the status of different systems on the multi-car train. These systems include; the brakes, door, motor, and other important subsystems. In this system, a controller in each car sequentially and repetitively reviews the condition of each sensed function and evaluates the conditions to determine whether a fault condition exists. The system stores all the information and then later displays them to the motorman upon system interrogation sequentially to report any faults detected along the train. Also, the cars communicate through a multiplex data link system that connects the cars in series in a multiplex current loop. The number of times each fault occurs is counted and this information is available for the maintenance personnel.

The existing system as of today at AALRT, basically relies on the LTE-R network for train control purposes and data exchange about the train location, train speed profile commands, etc. However, train health status and performance are not tracked in real-time from time to time as the train is on the move. Also, the type of preventive maintenance employed at AALRT currently is a combination of preventive and corrective maintenance. This means that's the trains are maintained based on a certain maintenance schedule and in case the system health is found not to be healthy then corrective maintenance is performed, furthermore, the fault may occur as the train is already on the move on the line. This can result in equipment damage, destruction, and accidents. Therefore, this research entitled investigation on the effect of the internet of things (IoT) to improve traction safety majorly highlights how IoT technology would be employed in the railway industry to improve safety. The effect of this technology was realized on the impact of the various time parameters of MTTR, MTBF, and the duration it would take for the technical team to get notified on the fault on a train locomotive, this is the gap this research addresses or tries to bridge. Based on the case study, AALRT, the effect of IoT would be tremendous as it would monitor the systems' parameters in real-time with instant notification if any fault or abnormality arises hence causing a positive impact on the time parameters of MTTR, MTBF and the average duration to be notified about a fault on the train.

3.0 CHAPTER THREE

3.1 METHODOLOGY

To carry out this investigation, the following techniques and software were used;

3.1.1 Data collection methods and analysis

During data collection, tools like interviews and existing data from the industry to conduct a successful survey. During the data analysis, simple safety engineering techniques like FMECA (Failure Mode Effects and Criticality Analysis), FTA (Fault tree analysis), and also Bowtie analysis for real-time data analysis were used[37],[38]. FMECA is preferred because early identification of potential causes of failures may reduce their occurrence. Then it may also allow choosing the most suitable technological processing during the initial stages of the project of the manufacturing phase[39].

There are various safety strategies but during this research, referencing to technical specifications and data analysis were used. This is because several kinds of research and surveys have been conducted and deployed on wireless technologies to improve the railways engineering industry[9].

3.2 Software

Various software tools could be used to perform any computer simulations or data analytics to carry out this investigation but the most available and user-friendly software were used to optimally conduct the research;

i. Proteus 8 professional

It is used to design and simulate electrical and electronics circuits. It has an advantage of availability, simplicity, and user friendly. Most electronics sensors, microcontrollers, and hardware components can be easily simulated using Proteus to mimic real-world scenarios. Other software capable of doing this would include LabVIEW, Eagle, etc. but this software is usually only available for purchase and the libraries' integration with other software like Arduino sensor libraries are not available like how it is with Proteus 8 professional. Therefore, it becomes quite easy to work with proteus than with other software that is available out there and putting in consideration the experience with proteus.

ii. Arduino C++

An Arduino is a board that can be programmed using object-oriented programming like C++. This kind of programming has the advantage of being simple and can be used to run most hardware components. Arduino programming is linked and simulated with the circuit in proteus 8 professional. This can be done or made possible by incorporating in the Arduino UNO library together with the sensor and other hardware libraries into the proteus library path.

iii. Node-red

This software is one of the best for simulating and deploying IoT applications both during prototypes and in industrial applications. This research used this software to simulate the system functionality and data analytics or visualization to analyze faults as projected from the sensor data. The software is a web-based system that can be customized and used to build an IoT system functionality, it also uses JavaScript and nodes to perform any of its required functionalities. However, there is also an option to use MATLAB for IoT applications with Simulink, but the obstacle with this option is the limitation with integration with other systems like mail servers, database cloud systems, and other APIs like the Twilio API this research used for SMS notifications. This is not the case with NODE-RED, as it easily incorporates these APIs and functionalities in its available nodes as shown during this study.

iv. Bowtie XP

This software is a safety engineering software that this research intended to use for system modeling for analyzing real-time data or situations to identify, mitigate, and manage risk. The software is easy to use and interact with and it can be used to model any system. However due to some constraints like funds, this software was quite expensive, so a substitute Microsoft Visio was used. It was possible to install bowtiexp samplers into the Microsoft Visio and this way model the bowtie real-time safety system.

v. PhpMyadmin

This software is mainly used to store the sensor data in a database. Using a NODE-RED MySQL node and a combination of SQL and Js. Code, it was possible to link the NODE-RED software to a database. This is important for purposes of backtracking such that the fetched sensor data is stored into a database so in case the engineer of the technical team wants to view the previous data or train performance, they can log in to the system and look out for the exact time and they can be able to get the data at that very time.

Furthermore, this data saved in the database can be compiled and used to generate a report of all the stored data or to a specific time into different formats like PDF or CSV. A sample of such a report is shown in the appendix section.

Some software that PHPMyAdmin needs or requires to connect and run on the localhost includes software called **xampp.** Within xampp Apache software and MySQL services are enabled. Without these services running, the NODE-RED software can't be able to connect to the database.

SYSTEM BLOCK DIAGRAM

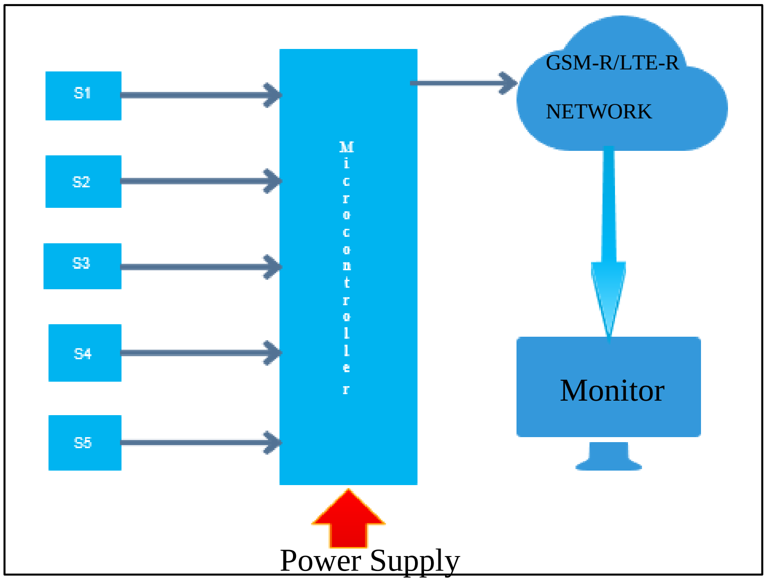


Figure 3-1: System Block Diagram

The sensors in the block diagram are labeled S1-S5;

S1-Temperature sensor

S2-Current sensor

S3-Voltage sensor

S4-Vibration sensor

S5-Accelerometer or Speed sensor

S6- Smoke sensor (MQ2-5)

DATA FLOW/ SYSTEM OPERATION

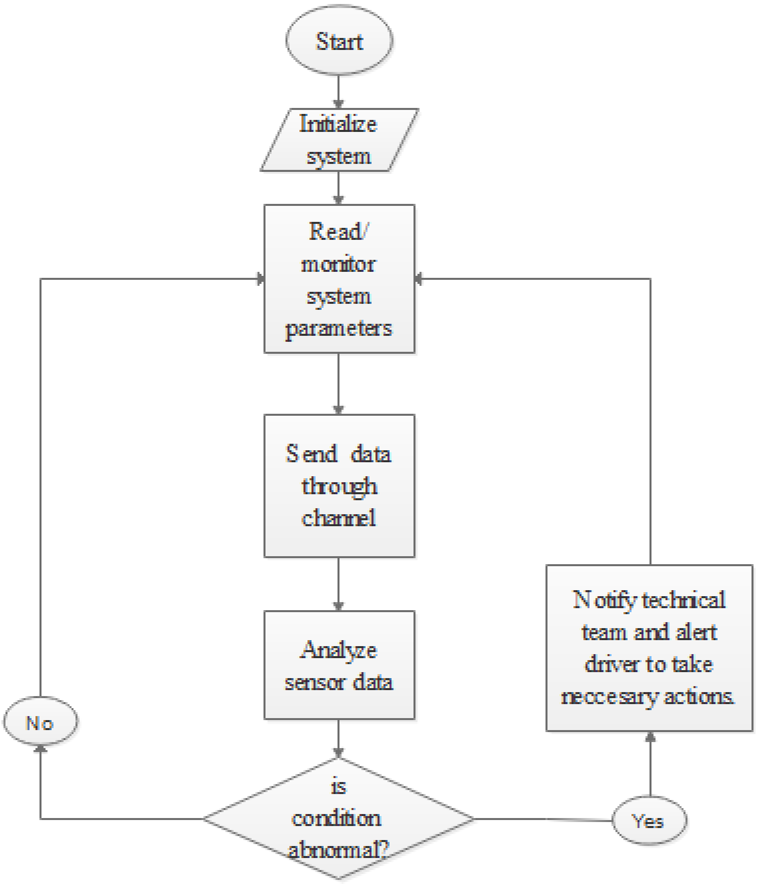
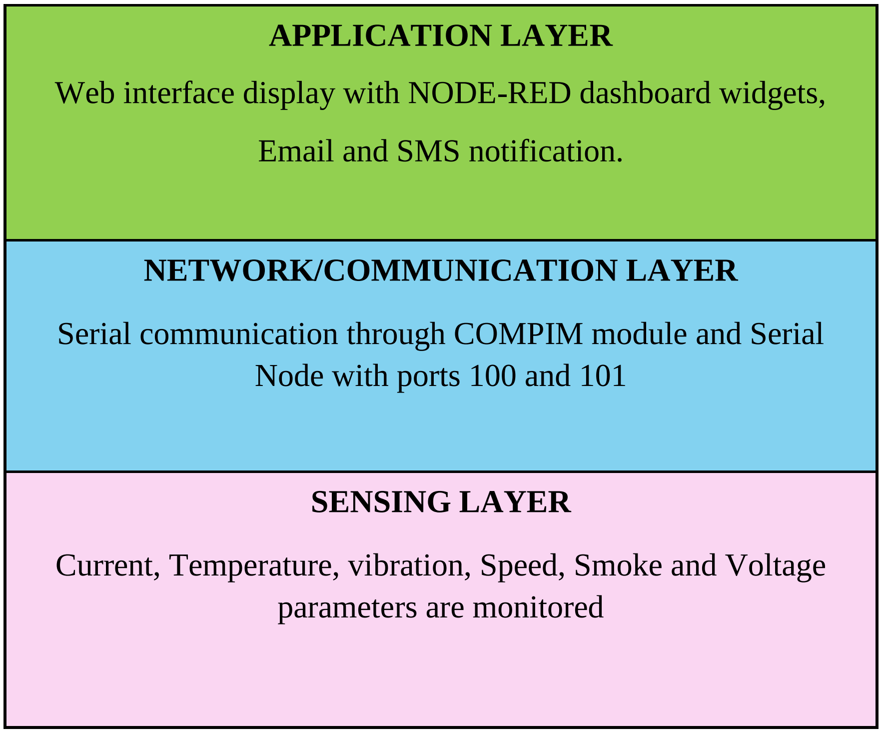


Figure 3-2: System Data Flow/System operation

The various sensors are programmed to monitor the conditions of voltage, current, temperature, speed, and vibration intensities while the train is in operation. The obtained data is sent via a GSM module or channel. This data through the GSM mobile network or an internet connection is sent to the cloud or system with a real-time data analysis tool. The results are displayed in real-time as well. Should the system detect an abnormality in any of the conditions being monitored, a notification is sent to the technical team and the driver alerted on what actions to take.

SYSTEM ARCHITECTURE



APPLICATION LAYER

Web interface display with NODE-RED dashboard widgets,

Email and SMS notification.

NETWORK/COMMUNICATION LAYER

Serial communication through COMPIM module and Serial Node with ports 100 and 101

SENSING LAYER

Current, Temperature, vibration, Speed, Smoke and Voltage parameters are monitored

Figure 3-3: System Architecture

The system adopts the above system architecture which is subdivided into three layers. The lowest layer which is the sensing layer is the layer that interfaces with the traction system, which is the system of interest to obtain the sensor data from the traction motors.

Then this data is sent through a data channel with an internet connection relying on the GSM-R/ LTE-R network along the railway line. This channel could be a Wi-Fi connection from access points installed along with the railway network. Then finally this data is sent to the application layer a web interface, or a mobile application for instance. This data is captured and analyzed from the application layer, should any abnormalities be detected then the system sends a notification to the engineer or the technical team for immediate action.

4.0 CHAPTER FOUR

4.1 SYSTEM SIMULATION, MODELING, and ANALYSIS

Upon simulation and modeling of the system, a couple of software and modeling techniques were used.

4.1.1 System Simulation

The IoT system was successfully simulated using software that includes Arduino, proteus 8 professional, Node-red/Node-js, PhpMyAdmin & Xampp, and Microsoft-Visio (with Bowtie Sampler). It should be noted that the research comprised of two parts; the communication part and the safety engineering part.

The communication part of the system was simulated in different steps, following a series of software executions since some software outputs were inputs to other software. This, therefore, called for the parallel running of this software to be able to visualize the results and necessary actions.

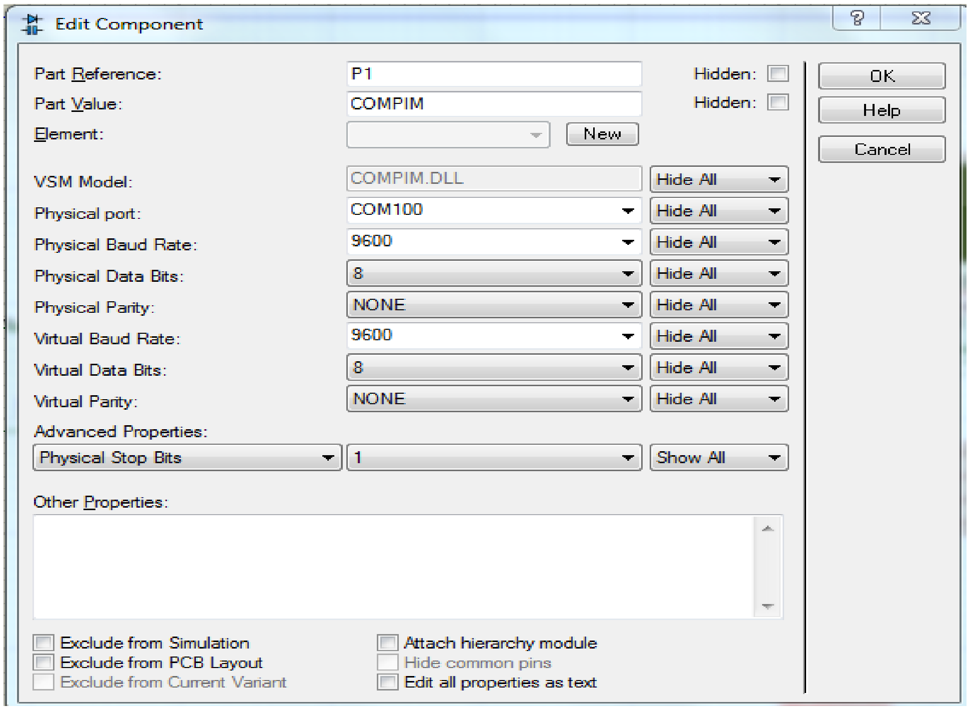
The steps of simulation are explained below and will be discussed in detail in the proceeding chapters together with the results;

i) The C++ code (sketch) written is run in the Arduino software environment. The program is written in a language called Arduino C++, this program is then compiled and debugged using an Arduino compiler. This compiler using the software creates a single file and it usually builds up into a .hex file. The extension .hex viewed as an .ino.hex file is the one that is containing the instructions to execute on the Arduino Uno board.

ii) This .hex file's path is now open onto the Arduino microcontroller (ATMEGA328pu) in the Proteus 8 professional environment. This code is written following the required functionality of the microcontroller together with the respective sensors.

iii) Then serial communication on a port at the virtual terminal of the microcontroller to mimic a wireless GSM/LTE internet connection is enabled. This is achieved by connecting two serial ports using a certain software called **com0com.** In our case, COM ports **100** and **101** were opened and connected. This kind of setup makes it possible to exchange data between two software applications or makes communication possible to send data from one computer program to another. In simple terms ports, 100 and 101 are virtually seen as a single pipe, and traffic that is loaded on port 100 can now be seen or received at port 101 and vice versa.

iv) Now sensor data that is generated in proteus from the sensor nodes is channeled through a module called **COMPIM**. This module is connected with the serial communication pins of the Arduino and it is configured with the following settings; physical port-Com100, Physical Baud rate-9600, Physical data Bits-8, Physical parity-NONE, virtual data bits-8 and virtual parity-NONE as shown in the figure 4-1 below.

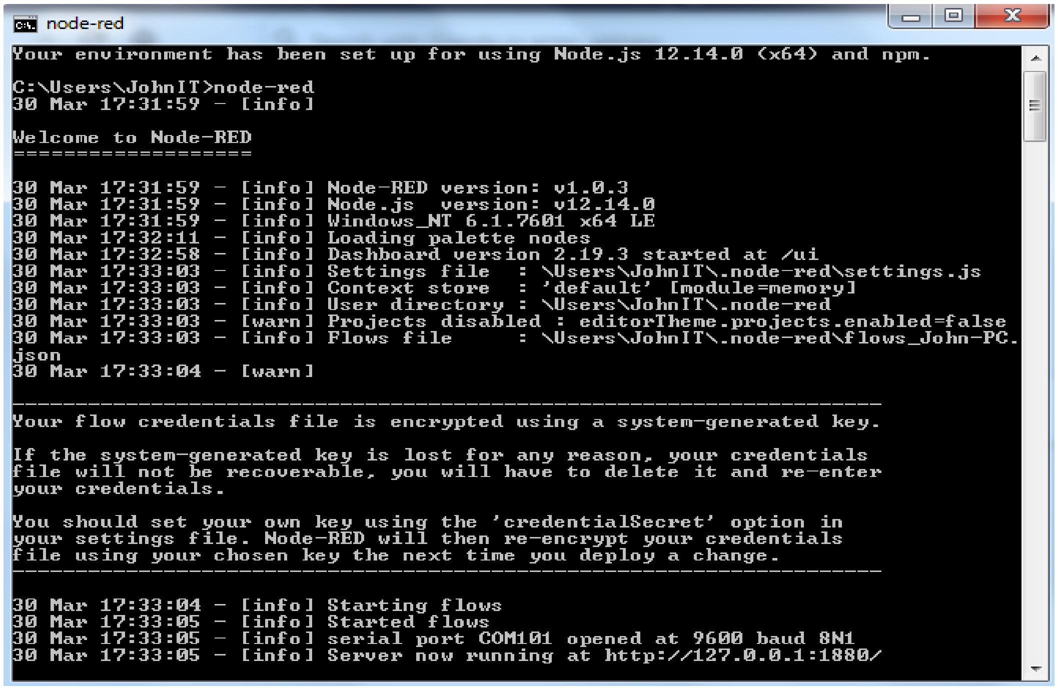


Part Reference: P1 Hidden: ☐
Part Value: COMPIM Hidden: ☐
Element:
VSM Model: COMPIM.DLL Hide All
Physical port: COM100 Hide All
Physical Baud Rate: 9600 Hide All
Physical Data Bits: 8 Hide All
Physical Parity: NONE Hide All
Virtual Baud Rate: 9600 Hide All
Virtual Data Bits: 8 Hide All
Virtual Parity: NONE Hide All
Advanced Properties:
Physical Stop Bits 1 Show All
Other Properties:
☐ Exclude from Simulation ☐ Attach hierarchy module
☐ Exclude from PCB Layout ☐ Hide common pins
☐ Exclude from Current Variant ☐ Edit all properties as text

Figure 4-1: Configuration settings for the COMPIM module in proteus 8 professional

The other com 101 port is configured and connected with NODE-RED software and it will receive data traffic from com 100 as in from proteus at the COMPIM module to now proceed with the communication and data analytics.

v) Upon pushing the data to NODE-RED, this means that the data is available for fault detection in the traction system. NODE-RED is capable of various things however in this study it required the system to be able to send an email or SMS notification to the responsible authority or the engineers so that faults can be known ahead of time before any serious accident or damage to expensive equipment is caused. NODE-RED also helps the responsible technical stuff to view the performance of the train's traction system in real-time in other words as the train is on the move, this software provides real-time data analytics from the sensor data being fetched. This is done through a web interface as it shall be seen in the proceeding chapters. Below is a figure showing how to start the NODE-RED software, it also shows that it's installed and running on the local-host server at port 1880 (http://127.0.0.1:1880). This address when typed in the web-browser at that port it leads us to access the software interface.

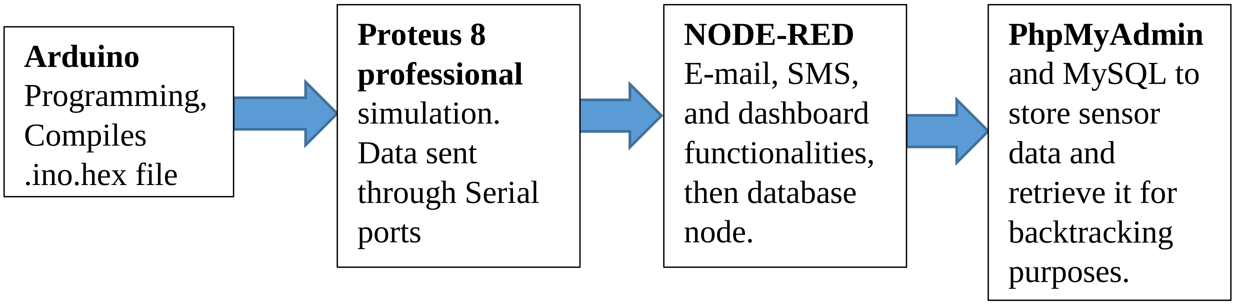


```
Your environment has been set up for using Node.js 12.14.0 (x64) and npm.

C:\Users\JohnIT>node-red
30 Mar 17:31:59 - [info]

Welcome to Node-RED
===================

30 Mar 17:31:59 - [info] Node-RED version: v1.0.3
30 Mar 17:31:59 - [info] Node.js  version: v12.14.0
30 Mar 17:31:59 - [info] Windows_NT 6.1.7601 x64 LE
30 Mar 17:32:11 - [info] Loading palette nodes
30 Mar 17:32:58 - [info] Dashboard version 2.19.3 started at /ui
30 Mar 17:33:03 - [info] Settings file  : \Users\JohnIT\.node-red\settings.js
30 Mar 17:33:03 - [info] Context store  : 'default' [module=memory]
30 Mar 17:33:03 - [info] User directory : \Users\JohnIT\.node-red
30 Mar 17:33:03 - [warn] Projects disabled : editorTheme.projects.enabled=false
30 Mar 17:33:03 - [info] Flows file     : \Users\JohnIT\.node-red\flows_John-PC.
json
30 Mar 17:33:04 - [warn]

---------------------------------------------------------------------
Your flow credentials file is encrypted using a system-generated key.

If the system-generated key is lost for any reason, your credentials
file will not be recoverable, you will have to delete it and re-enter
your credentials.

You should set your own key using the 'credentialSecret' option in
your settings file. Node-RED will then re-encrypt your credentials
file using your chosen key the next time you deploy a change.
---------------------------------------------------------------------

30 Mar 17:33:04 - [info] Starting flows
30 Mar 17:33:05 - [info] Started flows
30 Mar 17:33:05 - [info] serial port COM101 opened at 9600 baud 8N1
30 Mar 17:33:05 - [info] Server now running at http://127.0.0.1:1880/
```

Figure 4-2: Node-Red/Node.js command prompt showing the node-red startup

vi) For any backtracking purposes, the sensor data is stored in a database using an MYSQL node and PhpMyAdmin. This real-time data can be viewed at a later time together with the exact timestamp, the data report can also be exported in various formats like PDF, CSV for Excel, etc.

Block diagram showing the order of simulation using the various software tools is shown below;



4.1.1 System Modeling and analysis

As seen in the above sub-section, the system simulation for communication engineering involves a couple of software and configurations. However, during the safety engineering part, a single software called **Microsoft Visio** with a Bowtie sampler. The study opted to use this software as an alternative to **BOWTIEXP** which was quite expensive.

4.1.2 Bowtie Model structure basic explanation

The basic function of the BOWTIEXP software is to model safety systems and analyze their consequences, hazard causes, and the possibility of the real-time system.

This safety engineering modeling technique is usually used for real-time data systems and it usually uses bowtie diagrams[40]. The technique can be used to model complex systems in safety-conscious fields like aviation, railways, high-risk construction projects, and various equipment test environments. The basic bowtie model takes the following structure;

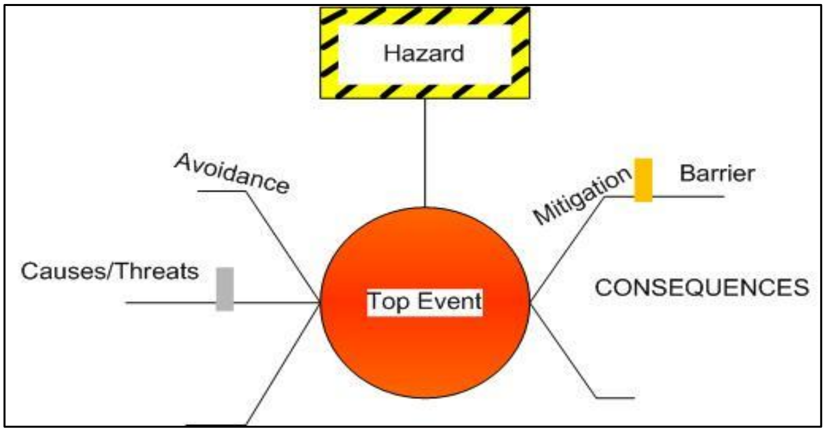


Figure 4-3: Basic structure of the Bowtie model

The top of the structure shows the threat at hand and it can be measured or seen from the sensor data that is feed into the model. It is from this data that we can easily detect a threat to safety. Then there is also the hazard or top event that is likely to happen to lead to the incident that is being shielded away from happening.

The Left side shows the causes of the hazard together with the barriers that should be put in place to avoid the causes of being pronounced. These barriers on the left side of the bowtie diagram are called **avoidances** and can be categorized according to the quality a company wishes or is capable of putting in place.

Then the right side of the model shows the consequences as a result of the causes on the left side breaches or breaking through the barriers. These consequences can be fatal depending on the incidence and also on the quality of the barriers put in place. These barriers on the right side are called **mitigation barriers or recovery measures**[40] and they are usually put in place to mitigate or limit the impact of the hazard as much as possible. Their quality also depends on the available funds a company is willing to invest in.

4.1.3 The Swiss cheese model

It should however be noted that the bowtie method/technique in a way is related to the famous Swiss cheese model. The Swiss cheese model bases on a principle that while putting in place barriers to a system to enhance safety[41], a hole or breach in one barrier can connect to another hole in another barrier connecting the holes can lead to the hazard occurrence or incidence[42]. Therefore the bowtie method tries to limit the holes in barriers as much as possible[40].

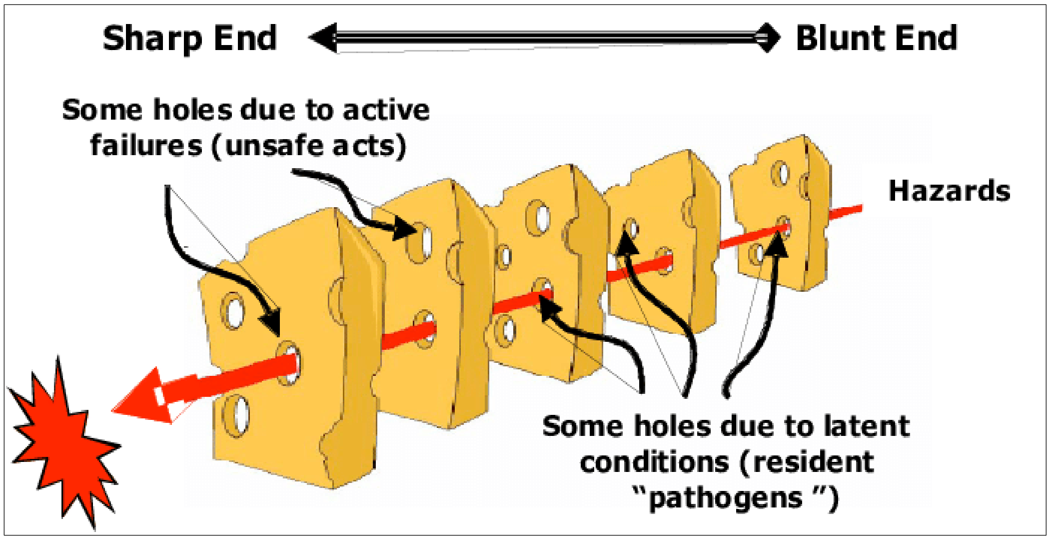


Figure 4-4: Swiss cheese model illustration. Source [36]

4.1.4 Failure Mode Effects and Criticality Analysis (FMECA)

FMECA is a basic methodology that is used for risk assessment and it involves studying the various failure modes that compromise the safety of a system, evaluating the effects and developing a risk priority number (RPN), or calculating an item's criticality number. Usually, in the automotive industry, research recommends developing the risk priority number (RPN) method[43].

While developing the RPN, the method uses linguistic terms to rank the probability of the failure-mode occurrence, the severity of its failure effect, and the probability of the failure itself being detected. This is done on a scale of 1 to 10. After, these rankings are then multiplied to finally give the RPN[43]. A risk matrix is then developed and the analysis is carried on by developing severity, occurrence definitions, and standards depending on the system of interest[28],[44].

5.0 CHAPTER FIVE

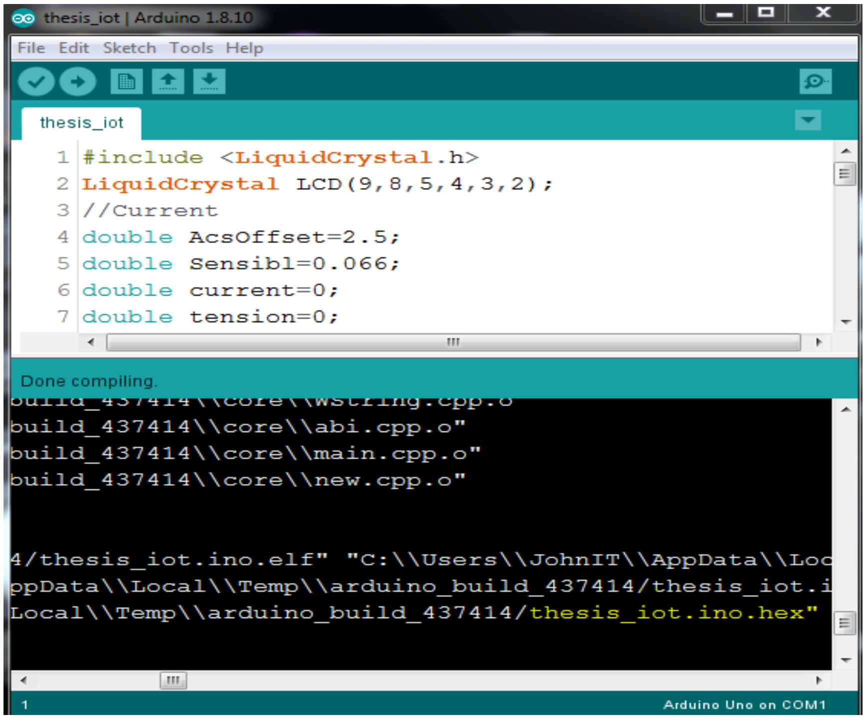
5.1 RESULTS and DISCUSSIONS

In this chapter, the results of this research are discussed, they include the simulation results showing the system functionalities to mimic the system in the real world. Safety engineering system models/techniques and analysis of the system are also discussed in this chapter.

5.1.1 IoT System Simulation and results

As seen in the previous chapter, the system simulation was done in a series of steps using a couple of software that was running parallel for some set. Proteus 8 professional and NODE-RED require to run in parallel as the data from the sensor nodes in Proteus 8 professional is sent through the COMPIM module (to mimic a GSM channel with an internet connection) to the NODE-RED that runs in a web interface. Below are the steps and results of the simulation;

i) Compilation of the Arduino C++ code to create the .hex file to be used by the microcontroller in Proteus 8 professional to make the microcontroller perform its required functionalities of sensing the various parameter from the sensor nodes.



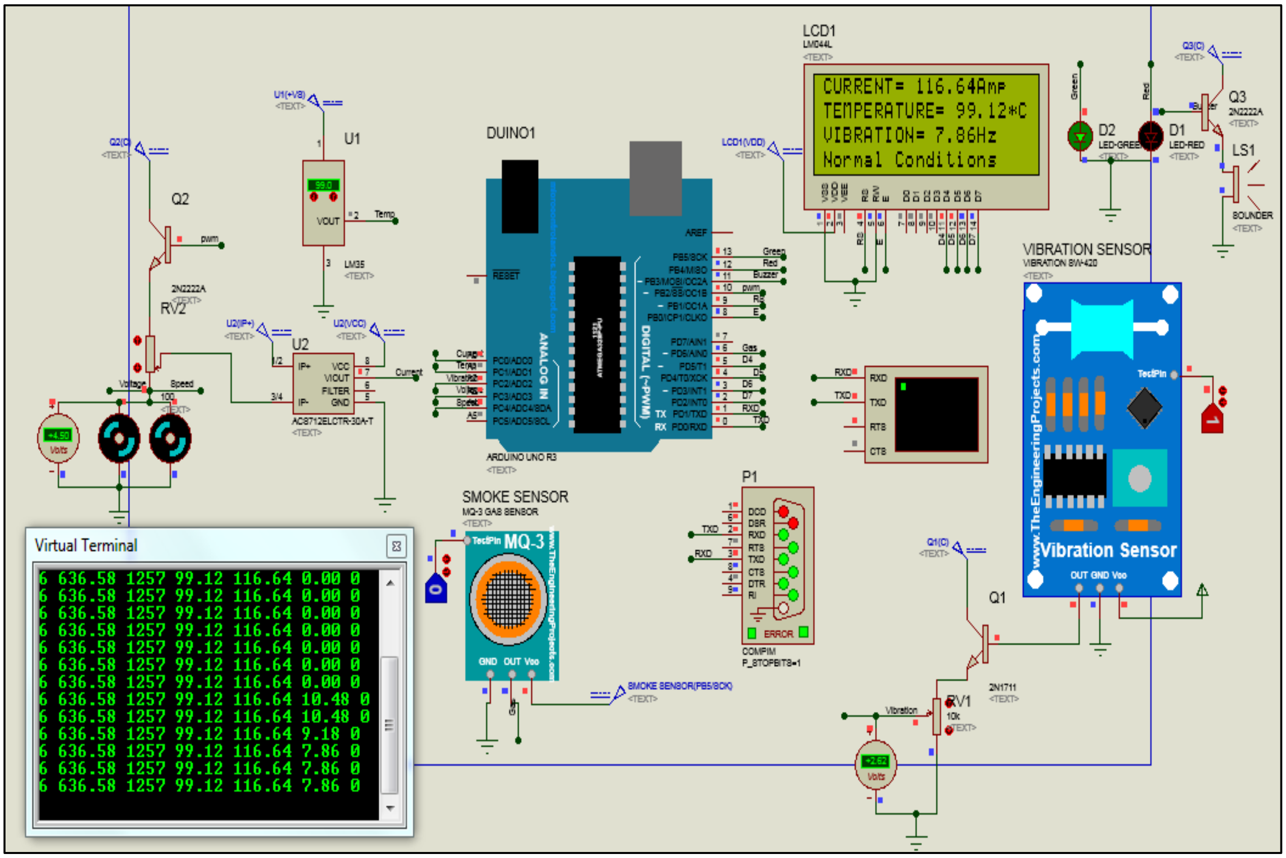
```
#include <LiquidCrystal.h>
LiquidCrystal LCD(9,8,5,4,3,2);
//Current
double AcsOffset=2.5;
double Sensibl=0.066;
double current=0;
double tension=0;
```

Done compiling.

```
build_437414\\core\\wstring.cpp.o
build_437414\\core\\abi.cpp.o"
build_437414\\core\\main.cpp.o"
build_437414\\core\\new.cpp.o"


4/thesis_iot.ino.elf" "C:\\Users\\JohnIT\\AppData\\Loc
ppData\\Local\\Temp\\arduino_build_437414/thesis_iot.i
Local\\Temp\\arduino_build_437414/thesis_iot.ino.hex"
```

Figure 5-1: Figure showing Arduino ino.hex file compilation of the sketch/code

The Hex file (in yellow highlight) path is then attached to the Arduino module in the Proteus 8 professional software environment to be able to simulate and enable the microcontroller's functionalities. Below is a figure showing the whole system circuitry in proteus 8 professional.



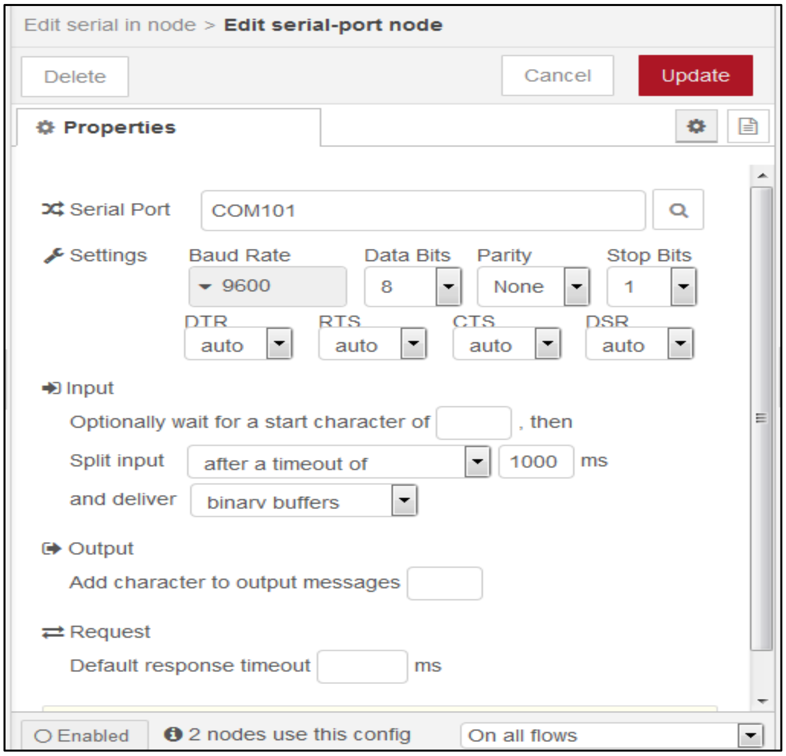
```
CURRENT= 116.64Amp
TEMPERATURE= 99.12*C
VIBRATION= 7.86Hz
Normal Conditions
```

Virtual Terminal

```
6 636.58 1257 99.12 116.64 0.00 0
6 636.58 1257 99.12 116.64 0.00 0
6 636.58 1257 99.12 116.64 0.00 0
6 636.58 1257 99.12 116.64 0.00 0
6 636.58 1257 99.12 116.64 0.00 0
6 636.58 1257 99.12 116.64 0.00 0
6 636.58 1257 99.12 116.64 0.00 0
6 636.58 1257 99.12 116.64 10.48 0
6 636.58 1257 99.12 116.64 10.48 0
6 636.58 1257 99.12 116.64 9.18 0
6 636.58 1257 99.12 116.64 7.86 0
6 636.58 1257 99.12 116.64 7.86 0
6 636.58 1257 99.12 116.64 7.86 0
```

Figure 5-2: Figure showing the whole system circuitry in proteus 8 professional.

ii) When the microcontroller through the sensors picks this sensor data, then it pushes it to the virtual terminal that is connected to the COMPIM module configured and connected to a virtual serial port (COM 100) at a baud rate of 9600 to create a channel to be able to send this data to another software application on serial port Com 101 which is configured at the same baud rate in NODE-RED for further processing and visualization. Below is the screenshot of the settings for the serial node in NODE-Red; it shows details like the baud rate, parity, stop bits, and data bits. It also shows other settings like the input settings showing how long the software should wait before splitting a message in our case its 1000ms (1 second).



Serial Port COM101

Settings
Baud Rate 9600
Data Bits 8
Parity None
Stop Bits 1
DTR auto
RTS auto
CTS auto
DSR auto

Input
Optionally wait for a start character of , then
Split input after a timeout of 1000 ms
and deliver binary buffers

Output
Add character to output messages

Request
Default response timeout ms

○ Enabled
2 nodes use this config
On all flows

Figure 5-3: Configuration of the serial node in Node-red

iii) Upon receiving the data in NODE-RED also known as node.js, the data is received as a single string so there are a couple of nodes and node functions that we built using JavaScript(js) to separate the string into the different data sets according to the parameters of interest. Below is a figure showing all the nodes and functionalities of the system as modeled and programmed in NODE-RED using JavaScript.

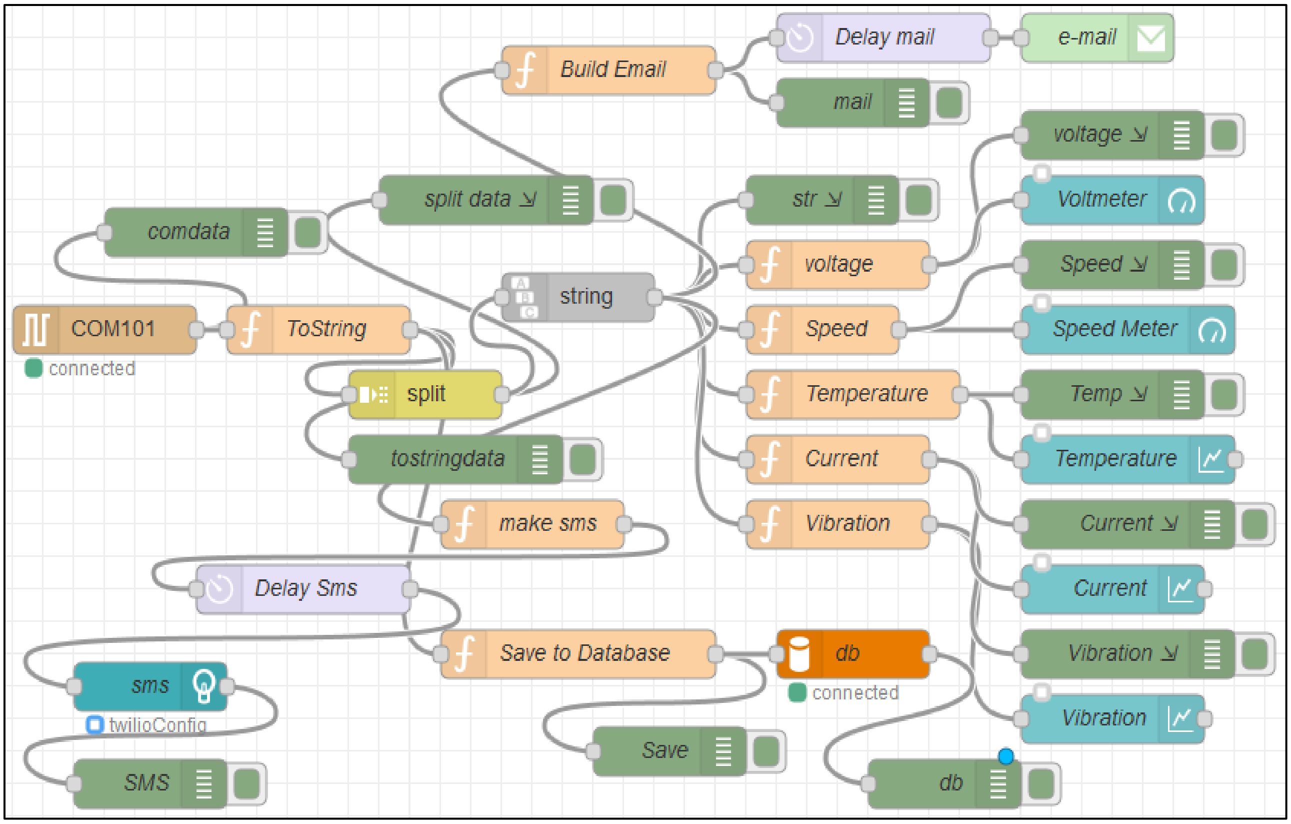


Figure 5-4: Figure showing all the nodes and functionalities of the system as modeled and programmed in NODE-RED using JavaScript.

5.1.2 System functionality nodes and data processing

i) COM101

This node is the basic start of the IoT system data processing, it's configured to a serial port COM101 to connect and receive data from the Proteus 8 professional COMPIM module configured to send data traffic to serial port COM100. These two ports are connected and made to appear like a single data channel using software called **Com0Com**. Both modules are configured to operate at the same baud rate of 9600 to synchronize the communication and data flow from application one (proteus 8 professional) and application two (NODE-RED).

ii) ToString function node

The data is received and it's converted into a single string. This is done using some Js. Code, however, it is also possible to make a string of incoming data using a single node. This data is then pushed to another node called Split node as seen from the figure above.

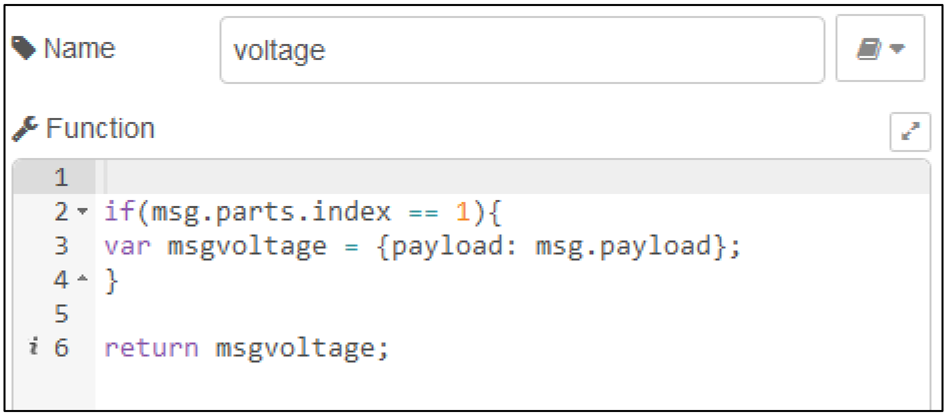
iii) Split node

The split node is what helps to separate the data and break it into the different data sets since various traction system parameters are supposed to be monitored. This node splits data sets on a special character. In our case, we used a space (‘ ‘) character. The node always splits the data as a separate data parameter for as long as there is a space before the data.

This process helps to also assign indices to the data sets and using the data index, we can fetch out the specific parameter and monitor it independently.

iv) Function nodes for the different parameters

The parameters are monitored using function nodes that are programmed to fetch data from the string according to the index of the parameter. These functions nodes include; the voltage, speed, temperature, current, and vibration nodes. An example of the js. code used to filter out the voltage parameter and build the voltage function node is shown in the figure below.



Name: voltage

Function

```

if(msg.parts.index == 1){
var msgvoltage = {payload: msg.payload};
}

return msgvoltage;
```

Figure 5-5: An example of the js. Code used to filter out the voltage parameter and build the voltage function node.

The string is held in a payload, it is then parsed to the ‘msgvoltage’ variable, and when this variable is returned it gives the voltage sensor data parameter as the output since it holds an index value equivalent to 1.

v) Dashboard nodes

The dashboards are the ones used to view the sensor data and train performance in real-time. The nodes used to construct our dashboard include; the chart and gauge. The nodes are configured and can be set the minimum and maximum of the parameters depending on the technical specifications. Below is a figure that shows the data being displayed in real-time as the sensors pick and send it over our serial com ports data channel.

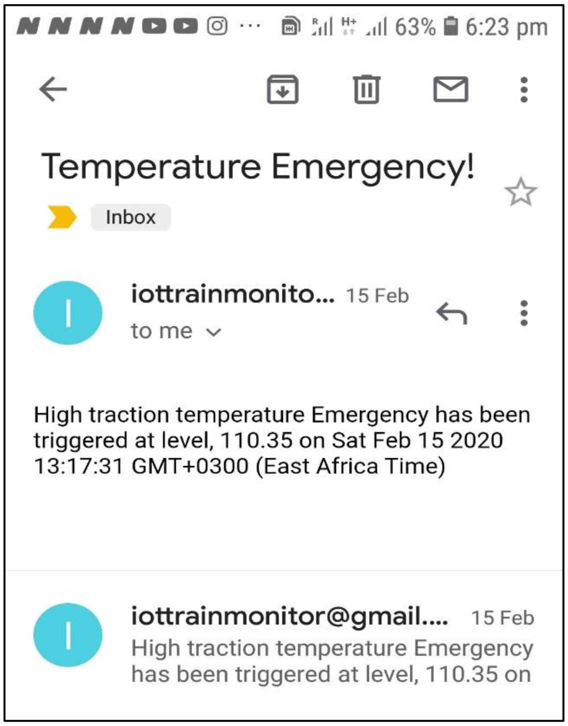
Figure 5-6: Figure showing sensor data being displayed on the dashboard in real-time.

On the dashboard for the train monitor, we incorporated two widgets that are the gauge and chart. The values on this dashboard change in real-time as the sensor data change hence giving the engineer or the technical team a preview of the train's performance in real-time as it is on the move or in operation.

vi) E-mail Node

Mainly the role/purpose of including the Email node is to give-off notifications to the engineers or the technical team about any fault that arises as to the train in on the move on the track. This notification is prompt and it reduces on the time it would take to discover the fault, it also reduces on other risks such a fault would cause to the entire system. This way the meantime to repair (MTTR) will be greatly reduced and also the Swiss cheese model principle steps in here, advocating for predictive rather than preventive maintenance in the railways' industry. It should also note that the email node can be configured or programmed to send emails to various email addresses or recipients, the email node is also configured with the server: smtp.gmail.com, port 465 and the sender address is an account created to purposely serve as the train data sender email address which is iottrainmonitor@gmail.com.

Below is an example of triggered email notification when the system detects a fault on the train.



Temperature Emergency!

iottrainmonito...

High traction temperature Emergency has been triggered at level, 110.35 on Sat Feb 15 2020 13:17:31 GMT+0300 (East Africa Time)

iottrainmonitor@gmail....

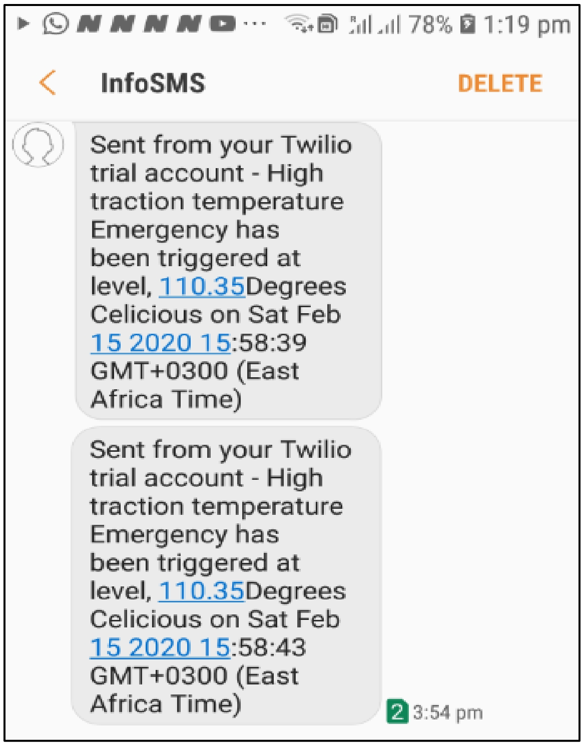
High traction temperature Emergency has been triggered at level, 110.35 on

Figure 5-7: An example of a triggered email notification when the system detects a fault on the train.

vii) SMS Node

The SMS node was thought of such that in case the engineer is offline (no internet connection) then he/she would also receive an SMS notification on their mobile phone. An API from Twilio was used because it’s readily available and its rates are relatively low. A trial account was used because Twilio API needs a subscription fee to get a fully activated account, this means that the SMS text sent will be fully customizable without trial information being sent along in the text as we shall see in the example screenshot is taken from a mobile phone.

Below is a figure showing an SMS sent when a fault was detected, as in the temperature level was beyond the preset threshold in the code or program. This was done and repeated for all parameters that are being monitored and it should furthermore noted that any parameter on a train can be monitored remotely for as long as there is a sensor to constantly track or pick the parameter data. Lastly, it should also be noted that it does not require an internet connection to receive the SMS notification on the recipient's mobile but the train will always require the connection to send the data over the communication channel since the system always needs to access and make use of the Twilio SMS API.



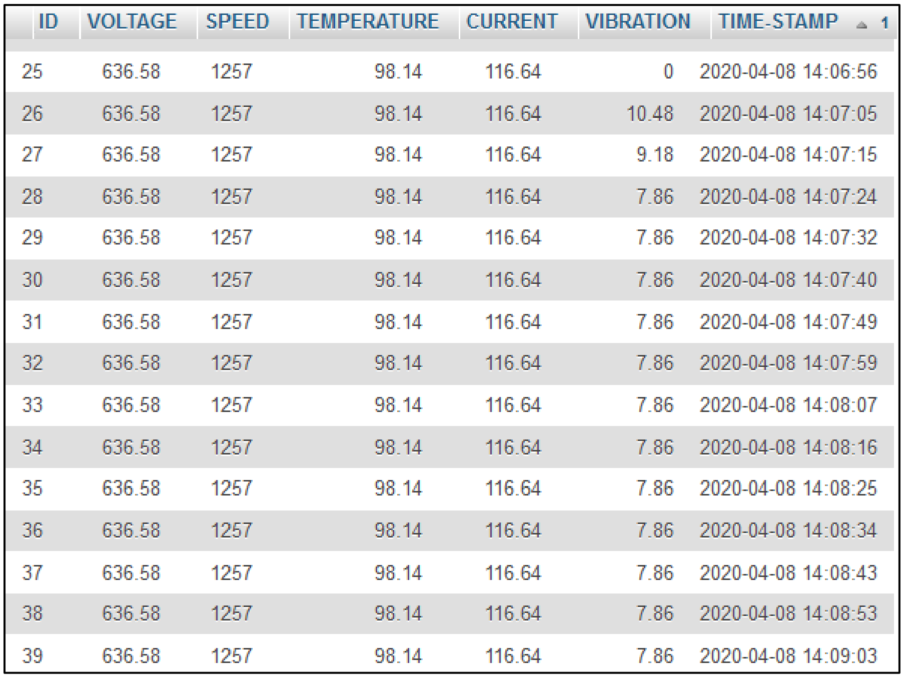
Sent from your Twilio trial account - High traction temperature Emergency has been triggered at level, 110.35Degrees Celicious on Sat Feb 15 2020 15:58:39 GMT+0300 (East Africa Time)

Sent from your Twilio trial account - High traction temperature Emergency has been triggered at level, 110.35Degrees Celicious on Sat Feb 15 2020 15:58:43 GMT+0300 (East Africa Time)

Figure 5-8: An example of a triggered SMS notification when the system detects a fault on the train.

viii) Database node (db)

This node is of type MYSQL and is configured and connected to the database as created in PhpMyadmin. This idea to save the data became necessary whereby if the need arises to backtrack the train data longs, then it is possible to know exactly when a certain fault occurred. This is because the data logs include a time-stamp, also the stored data can be used to generate reports. That means that it is possible to use this data to analyze the train performance in detail. An example of the saved data is shown in the figure below;



ID	VOLTAGE	SPEED	TEMPERATURE	CURRENT	VIBRATION	TIME-STAMP
25	636.58	1257	98.14	116.64	0	2020-04-08 14:06:56
26	636.58	1257	98.14	116.64	10.48	2020-04-08 14:07:05
27	636.58	1257	98.14	116.64	9.18	2020-04-08 14:07:15
28	636.58	1257	98.14	116.64	7.86	2020-04-08 14:07:24
29	636.58	1257	98.14	116.64	7.86	2020-04-08 14:07:32
30	636.58	1257	98.14	116.64	7.86	2020-04-08 14:07:40
31	636.58	1257	98.14	116.64	7.86	2020-04-08 14:07:49
32	636.58	1257	98.14	116.64	7.86	2020-04-08 14:07:59
33	636.58	1257	98.14	116.64	7.86	2020-04-08 14:08:07
34	636.58	1257	98.14	116.64	7.86	2020-04-08 14:08:16
35	636.58	1257	98.14	116.64	7.86	2020-04-08 14:08:25
36	636.58	1257	98.14	116.64	7.86	2020-04-08 14:08:34
37	636.58	1257	98.14	116.64	7.86	2020-04-08 14:08:43
38	636.58	1257	98.14	116.64	7.86	2020-04-08 14:08:53
39	636.58	1257	98.14	116.64	7.86	2020-04-08 14:09:03

Figure 5-9: An example of the saved data in the database.

ix) Debug Node

The final node is the debug node, this node is one of the most important nodes when building and simulating systems. It is mostly used while troubleshooting and viewing data flow from the payloads being generated from any node of interest.

To simplify the development and simulation process, the debug nodes can be renamed depending on the node it is fetching data from. This is important for very huge and complex systems to eliminate any kind of data confusion and also it simplifies the troubleshooting during the development as said earlier.

5.2. Safety modeling

5.2.1 Bowtie model

System safety and reliability of the system were modeled using the bowtie method, this method was suitable because it is used to the model system with real-time data. Such systems could include CCTV, sensor data from a certain sensor node, and dynamic systems with changing conditions and variations.

Specifically, this IoT system is a big data generating system with changing sensor data of the parameters from the sensor nodes. So the safety of this system was analyzed using the bowtie method and below is a diagram showing the safety model.

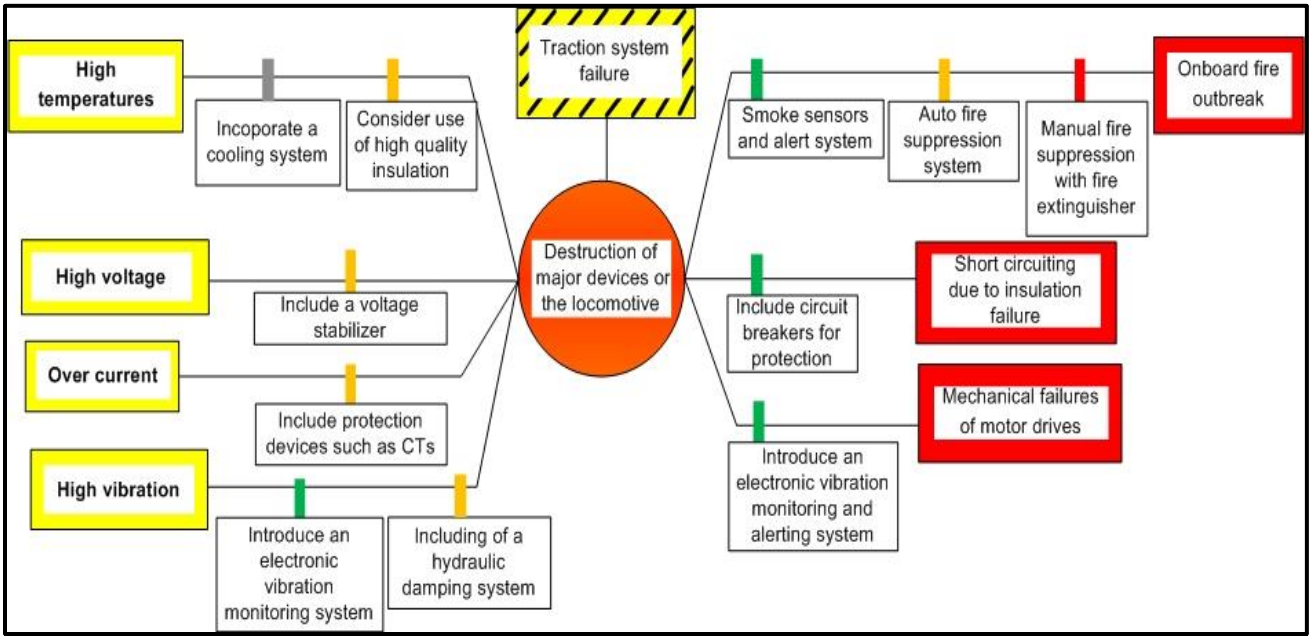


Figure 5-10: Figure showing the Bowtie safety model for the system.

5.2.3 System Model explanation

Basing on the basic structure of the bowtie, the hazard in this analysis is the traction system failure, the top event would be the destruction of major devices of the traction system or the locomotive.

The left side of the model is referred to as the causes’ side. The parameters being monitored are shown on this part of the model and the faults that could occur are projected here. Proceeding are the barriers that can be implemented by the operator companies to minimize the occurrence of the threats. These barriers can be classified or categorized into high-level barriers and low-level barriers. The barriers that are implemented are dictated by the company policy and budget.

On the right side is what we call the consequences, and the barriers are called mitigation barriers. There are put in place to always limit the impact of the consequence as much as possible. When all the mitigation measures are bypassed that is when the system consequences occur and eventually leading to the top event.

i) High temperatures condition

Electrical components of the traction system and the motor drives, in general, are usually designed to withstand a certain degree of temperature. This depends on the material and purpose of the component.

In case the temperature is shooting higher than the normal, then the safety model suggests the use of high-quality insulation as one of the low-level barriers. When this barrier is broken or bypassed then the model illustrates incorporating a cooling system.

ii) High voltage

A scenario could occur and the voltage levels rise high or shoot higher than the normal or nominal. When such a fault occurs in the power supply system, who knows what it could cause to the traction system. Therefore our safety model suggests the use of voltage stabilizers. However, sometimes such errors can be fixed by a simple system restart.

iii) Overcurrent

The traction system usually shows signs of overcurrent when there is a fault. Such a cause of the hazard can be minimized or avoided by using protection devices such as current transformers (CTs). This way in case of any fault, the protection device isolates the traction system, hence protecting it from damage.

iv) High vibration

Vibration is an inevitable event in a dynamic system especially a train with steel on steel interface between wheels and the rails. The safety model first advocates for a basic low-level barrier to include hydraulic damping systems to reduce the vibration intensity. Considering that the traction system, with the converters and inverters, is usually on the rooftop in most electric trains even as on the AALRT case study rolling stock. This means that the vibration levels will usually keep around the nominal level. However in case if an extreme condition should the damping system experience any over vibration, then the safety model suggests the inclusion of an electronic vibration monitoring system. Deploying such IoT systems would somewhat be expensive but it would be worth it because faults and errors would be identified immediately or at the nearest time possible.

The consequences in the safety model system are discussed as follows;

i) Onboard fire outbreak

One of the consequences, as studied or modeled by the bowtie model is an onboard fire outbreak. The mitigation barriers the model proposes to put in place are also categorized in levels and the highest of all is the use of smoke sensors and alert systems. These include the use of intelligent embedded systems to constantly monitor the status of the system for any smoke.

So in case, the system doesn’t detect the fire in the earlier stages then the model recommends the use of auto suppression systems. In case this barrier is also broken then this would now call for manual fire suppression using a fire extinguisher. However, we need to note that the fire detection system does not require the system to trigger a notification to the technical team. This is because even if there is a fire outbreak onboard it would only require the crew to firefight or suppress the fire. Therefore the IoT system only monitors the fire with a fire/smoke sensor and when it detects the fire, it then triggers an alarm on the train driver’s dashboard.

ii) Short-circuiting due to insulation failure

The mitigation barrier for this could be the use of high-quality insulators and mainly including circuit breakers for purposes of electrical protection.

iii) Mechanical failures in the traction motor drives

Mechanical failures in the traction systems and faults are usually caused by high vibrations. These vibrations can cause some systems not to function well as required because there could be loose connections. The safety system model proposes the introduction of an electronic vibration monitoring and alert system. In other words, when the vibration level is beyond the required then the IoT system would send an email notification to the engineer or the technical team.

5.3.1 System Reliability

By definition, reliability of a traction system can be defined as its ability to continuously supply electrical power of adequate quality during sudden disturbances or incidences such as a short circuit or loss of system elements, while operating with a normal scheme configuration, or during scheduled maintenance and repairs, without causing safety hazards, train delays or public nuisance[45].

Terminologies and reliability evaluation indices may include;

- Failure rate(λ)

$$\lambda = \frac{Nf}{\sum L} \quad (5.1)$$

Where;

Nf is the number of failures on all EMUs.

$\sum L$ is the cumulative running mileage of all EMUs

- Mean distance before failure (MDBF)

The MDBF is defined as the ratio of the cumulative running mileage to the total number of failures during the EMUs specified lifetime. This can be expressed as follows;

$$MDBF = \frac{\sum L}{Nf} = \frac{1}{\lambda} \quad (5.2)$$

- Reliability

The reliability of a component or a system is defined as the probability that the system can perform its required function under given conditions and given time intervals. However usually the failure rate is exponential, therefore the expression for reliability can be expressed as follows[46];

$$R(x) = e^{-\lambda x} \quad (5.3)$$

Where x is the random variable of the failure interval distance.

- Mean time to repair (MTTR)

$$MTTR = \frac{Totald\_duration\_of\_breakdown}{Frequency\_of\_breakdowns} \quad (5.4)$$

- Availability

$$Availability = \frac{MTBF - MTTR}{MTBF} \quad (5.5)$$

As seen from the above reliability parameters, an interview was conducted with the technical staff at AALRT, Kality.

- The Meantime to repair a fault on the traction system takes between 24 to 72 hours.

- The average of the time it takes the driver or the trainmaster to get to know of a critical fault is between 1 to 2 hours.
- The number of failures in six (6) months was given, 77 times only on the traction system. This means that it's a collective failure but not specific to certain equipment or devices of the traction system, as shown in the table below.

Table 5-I: Number of failures on the East-west line in 2018 for rolling stock systems

SN	**System**	**No. of Failure On Mainline in 2018**						**SUM**
		Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	
1	TCMS	2	0	0	0	1	0	3
2	PIS	4	5	1	3	0	4	17
3	Main circuit	0	0	0	0	1	0	1
4	Auxiliary	2	3	0	3	1	2	11
5	Air condition	2	2	8	3	2	3	20
6	**Traction**	**11**	**10**	**17**	**14**	**14**	**11**	**77**
7	Brake	0	2	2	3	0	1	8
8	Bogie	2	0	0	0	0	1	3
9	Door	8	15	9	11	9	16	68
10	Lighting	0	0	0	0	0	0	0
11	Car body and gangway	5	4	3	4	2	3	21
12	Cab	3	4	2	2	1	5	17
13	Coupler	0	0	0	0	0	0	0
SUM		39	45	42	43	31	46	**246**
Sum of six months								**246**

From the above rolling stock number of failure statistics, the traction system dominates with the highest system failures. These failures are a collection from the various traction subsystems.

5.3.2 Failure Mode Effects, criticality Analysis (FMECA)

FMECA safety technique is desired here because it focuses on individual failure modes for the components of the subsystem. The traction system is made up of various components and these components experience individual failure rates[47].

Table 5-II: Failure Mode Effects and Criticality Analysis (FMECA)

No	Component/ subsystem	Failure rate: failures/10^6h	System effect	Criticality 3=high, 1= Low	Importance: FRxCriticality	Remarks
1	Motor drive	0.0833	No movement possible	2	0.1666	Schedule ensures check
2	Inverter	0.25	AC component failure	3	0.7500	Restart needed
3	**Converter**	**0.5833**	**DC component failure**	**2**	**1.1666**	**Technical check required**
4	Brakes	0.3333	Fail-safe mode activated	1	0.3333	Schedule ensures check
5	Pantograph	0.1667	Arcing, total power supply cut-off	3	0.5001	Technical check required

From the interview with the technical team at AALRT, Kality the above FMECA analysis table shows that the device that fails most is the converter. Therefore this device and the other traction subsystems would make good use of the IoT system under investigation in this research.

5.3.3 Safety risk Matrix

The safety matrix categorizes the impact that risk could cause, it comprises of the likelihood multiplied with the consequence. Using these two categories the safety matrix can be constructed.

a) Likelihood categories

Table 5-III: Likelihood categories

Frequency category	Qualitative definition	Times per year
A(5)	Likely once a year	10-12
B(4)	Possible but not likely	7-9
C(3)	Unlikely	6-8
D(2)	Very unlikely	3-5
E(1)	Remote	0-2

b) Consequences categories

Table 5-IV: Consequences categories

Likelihood Severity categories	5	4	3	2	1
A(5)	25	20	15	10	5
B(4)	20	16	12	8	4
C(3)	15	12	9	6	3
D(2)	10	8	6	4	2
E(1)	5	4	3	2	1

5.3.4 Risk evaluation

After we have determined all the consequences and the frequencies of the hazards have been identified then a qualitative definition of the risk can be used to estimate risk from the formula below; therefore the whole essence of the above tables and data is for risk evaluation.

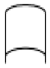
$$R = \sum R_i \quad \text{Where} \quad R_i = P_i * C_i \tag{5.6}$$

P_i is the likelihood or frequency and C_i is consequence or severity

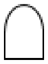
1-9	Can be managed or monitored
10-16	Ought to be reduced or transferred
20-25	Should be given immediate action

5.3.5 Fault Tree Analysis (FTA)

FTA uses AND & OR gates in its logic to predict a failure rate of the top event[47],[48] with the help of a combination of the various events. It helps to analyze complex systems and in real-time just like the previous bowtie technique we illustrated. This, therefore, means that this technique is relevant to be applied to the IoT system simulated and understudy. One objective of FTA is to compute the likelihood of top occasions events and it is likewise helpful to assess the significance of minimum slice sets to the top occasion or the significance of the predetermined fundamental occasions to the top occasion[48]. The symbols used are as follows;



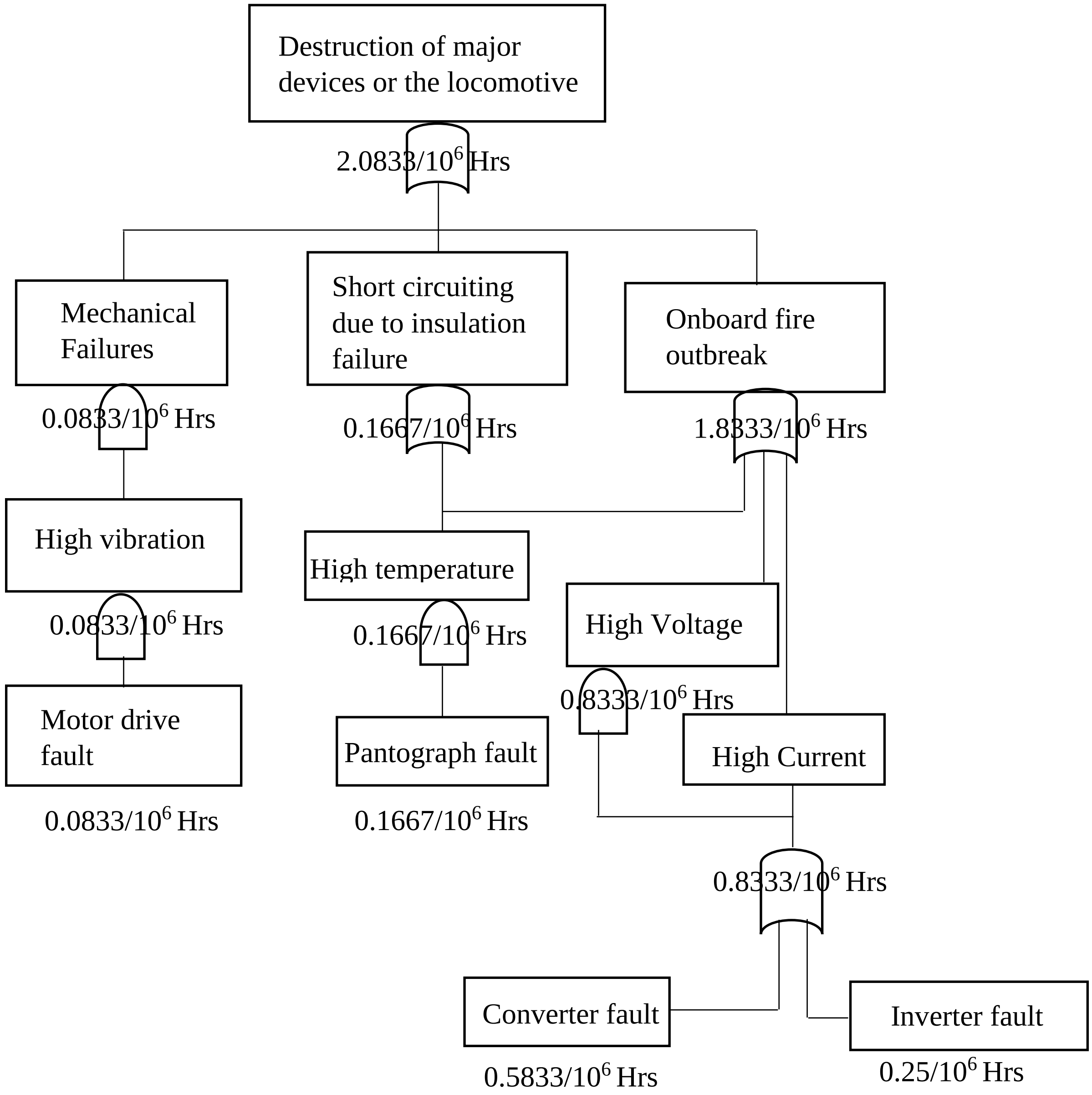
OR gate.



AND gate

EVENT or CONSEQUENCE

Below is the FTA analysis diagram for AALRT for one of the electric trains;



Fault tree evaluation may be qualitative, quantitative, or both. This usually depends on the scope of the analysis and the objective of FTA evaluation is to check if there is an acceptable level of safety in the proposed system or design[48]. Below is a representation of the qualitative evaluation;

$$\psi(Y) = \coprod_{s=1}^{n} \prod_{i \in k_s} Y_i \qquad Y_i = \{1 \text{ if basic event } i \text{ occurs, } 0 \text{ otherwise} \tag{5.6}$$

Where Y_i is a Boolean indicator variable of basic events; k1, k2,…, kn

n is the number of minimum cut sets.

$\coprod$ and $\prod$ represent logically AND & OR operators respectively in the equation.

The quantitative evaluation can be represented as shown below;

$$P = P(K_1) + P(K'_1)P(K_2) + ... + P(K'_1)P(K'_2)...P(K'_i)...P(K'_{n-1})P(K_n) \tag{5.7}$$

Where $P(K_i)$ denotes the probability of occurrence of minimum cut sets K_i

and K'_i represents the opposite event of K_i

5.4 System effect or Comparison with the AALRT industrial operations

Upon interviewing the engineers at the rolling stock maintenance department about the maintenance schedule, the common devices that fail in the traction system, and how often the traction system fails. Some of the discussed parameters are shown in the table below, this table compares the existing situation and the effect of the IoT proposed system that has been simulated in this research;

For parameters like MDBF in reference to equation (5.2) $MDBF = \frac{\sum L}{Nf} = \frac{1}{\lambda}$, it is for single component. Therefore in this research the converter will be used as an example to determine this parameter.

$$MDBF = \frac{1}{0.5833\text{x}10^{-6}}$$

$$= 1{,}714{,}383.68KM$$

Table 5-IV: Table showing calculation of MDBF in Km

No.	Component	Fairlure rate (λ)	MDBF(1/λ) (KM)
1	Motor drive	0.0833×10^{-6}	12,004,801.92
2	Inverter	0.25×10^{-6}	4,000,000.00
3	Converter	0.5833×10^{-6}	1,714,383.68
4	Brakes	0.3333×10^{-6}	3,003,003.00
5	Pantograph system	0.1667×10^{-6}	5,998,800.24

As for the parameter of mean time to repair (MTTR), in reference to the eqaution (5.4) following the formula below, it can be calculated.

$$MTTR = \frac{Totald\_duration\_of\_breakdown}{Frequency\_of\_breakdowns}$$

In addition, the parameter of mean time before failure is calculated in reference to the availability formular, equation (5.5).

$$Availability = \frac{MTBF - MTTR}{MTBF}$$

Table 5-VI: Table to calculate the time parameters of interest

No.	Month	Frequency	Total duration of breakdowns(Hrs)	MTTR(Hrs)	Availability	MTBF(Hrs)
1	July	11	396.0	36.00	0.5	72
2	August	10	400.1	40.01	0.75	160.04
3	September	17	350.8	20.63529	0.4	34.39
4	October	14	300.0	21.42857	0.6	53.57
5	November	14	415.5	29.67857	0.6	74.19
6	December	11	279.0	25.36364	0.5	50.72

The average duration of information about a fault was dependent upon timed when a train master detected an abnormality in the train's traction behavior and using tele-rail called the technical team. The train master has to explain the abnormality of the train so the technical team can diagnose to trace the error, and the average of this time is from the obtained data is 1.5 hours. With the inclusion of the idea of internet of things (IoT), where the traction devices would be monitored directly, incase of any abnormality then it would prompt the system to send an instant email and SMS notification to the technical team. On average upon simulation, this action would take an approximate of 1 minute or even less. Experimental values were taken using the simulation at stadium train station and a fault was caused in the simulation and an average taken.

Regarding the parameters of mean time to repair (MTTR) and mean time before failure (MTBF) from a single timed experiment, the time was taken considering a fault on the traction converter since it is the component that fails most according the failure rates and it was discovered that the internet of things (IoT) technology wouldn't have an effect of these two parameters.

Table 5-VII: Parameter comparison between the existing situation and the new IoT concept

No	**Parameter(Hours)**	**Existing situation**	**With IoT concept**
1	Mean time to repair (MTTR)	28.85	28.85
2	The average duration of information about the fault	1.5	0.02
3	Meantime before failure (MTBF)	74.15	74.15

Below is a graphical representation of the comparison between the time parameters' comparison between the existing situation and with the concept of IoT.

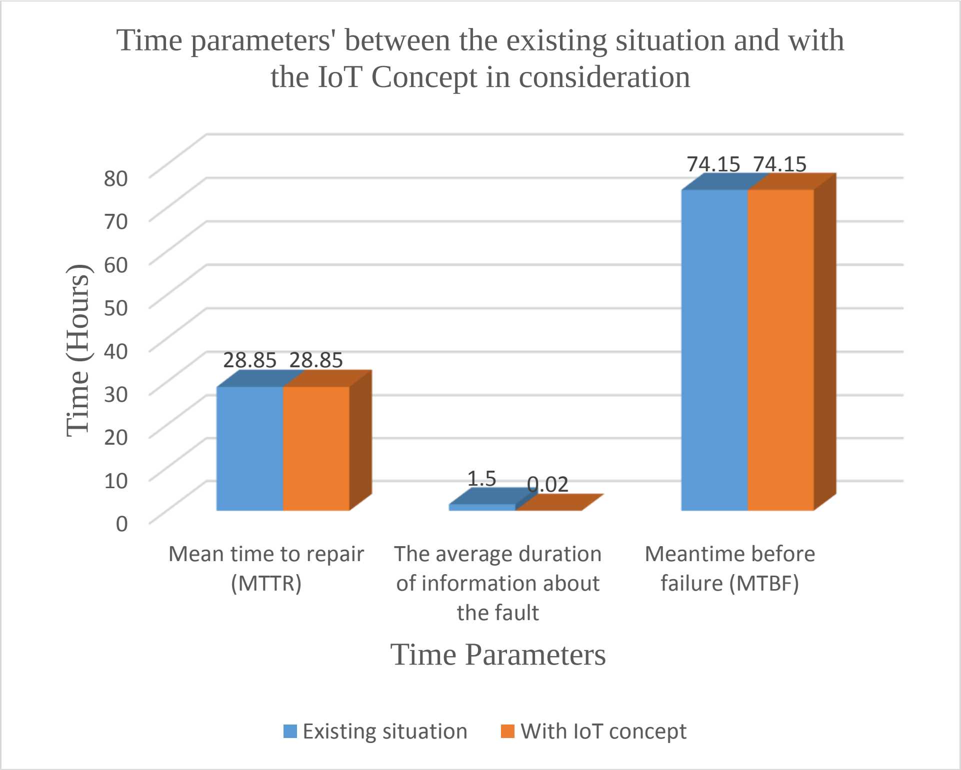


Figure 5-11: Time parameters' Comparison between Existing Situation and with the concept of IoT solution

From the figure 5-11 above, it is clear that the concept of introducing the internet of things technology would greatly improve on the time parameter of the average duration of information about the fault. The improvement is calculated as shown below;

$$Percentage\ improvemet = \frac{difference\ of\ average\ time\ parameters}{Total\ of\ time\ paramters} \times 100\% \qquad (5.8)$$

$$Total\ of\ time\ parameters = 1.5 + 0.02$$

$$= 1.52$$

$$difference\ of\ average\ time\ parameters = 1.5 - 0.02$$

$$= 1.48$$

$$Percentage\ improvemet = \frac{1.48}{1.52} \times 100\%$$

$$= 97.4\%$$

The percentage improvement of this parameter is 97.4% and this is a great improvement considering the fact that the earlier the notification about a fault the safer it is for the system devices and the public aswell.

However, the performance of the system entirely depends on various factors the network reliability, internet connectivity (Ethio-Tel telecommunications reliability). The system performance would also depend on the quality of the adopted to sensor devices and also on the processing power for the equipment and computers to be used since it would require servers with high performance specifications. Ethio-Tel telecommunications network connectivity reliability is a whole research topic that would require a great deal of time and data to study how it would affect the system performance and this topic is open for research. The cost to implement this system would depend on the supplier for the rolling stock equipment and the sensors. The network and internet connectivity installations would not be much of a concern since the LTE-R network infrastructure is already installed along the line. All it would require is an internet connection enhancement to this network and an inclusion of the sensor devices into the traction system.

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

This study aimed at investigating the effect of the internet of things (IoT) to improve traction safety. The case study was Addis Ababa Light Rail Transit (AALRT), and data were obtained from Kality deport rolling stock and maintenance department. From the data collected and the interviews conducted with the technical team, it was found out that the traction system fails most amongst all the systems on rolling stock. The failures are carried on overtime and they could occur at any time during the journey. This is dangerous and highly compromises the safety of the equipment, the rolling stock, and the general public.

Railways nowadays are constructed with an integration of a telecommunications network along the line known as GSM-R and this network along the AALRT line is advanced to LTE-R. This advancement provides better data rates, bandwidth, and reduction in mean latency time, enabling fast and more data to be transferred over the communication channel. Therefore this network can be utilized with the IoT technology to provide connectivity to the internet to be able to improve the services provided in the railway industry. This network is private and can be secured using various techniques and algorithms. Furthermore, this network infrastructure is one of the major building blocks of the RIoT as it is the communication layer in the system architecture.

Mainly the time parameters that this research was interested in include; meantime to repair (MTTR), meantime before failure (MTBF), and the average duration of information about the fault show potential of being greatly improved. The average duration it takes to know about a fault to also be reduced from 1.5 hours to around 0.025 hours, and the percentage improvement is 97.4%.

Besides, the internet of things technology and internet connectivity on the train in general also has the potential to improve on the customer travel experience by providing services like Wi-Fi enabling passengers to use their devices like mobile phones and laptops hence making it possible to carry on with their work on board. Internet connectivity onboard would also enable services like live TV, and hence attracting more customers or passengers to opt for this mode of transport. However, this technology would somewhat add a cost to the rail transport service and it would eventually increase the cost of a single trip. This would most definitely call for research on the capacity variations and how much this increment can be thorough studies on the behavior of the passengers.

Therefore the conclusion, in summary, is that the inclusion of the internet of things technology in railway services would improve on traction safety, it would also improve on the traction system safety and reliability, and also improves on customer experience and hence increasing capacity in railways. This technology also would help with the idea of focusing on predictive rather than preventive maintenance.

6.2 Recommendations

The internet of things technology (IoT) is an emerging technology that has the potential to improve various sectors like health, agriculture, trade, and transportation among others. In the railways industry, this technology could boost revenue and capacity. As specified earlier, nowadays railway networks/lines are usually equipped with a telecommunications network mainly for communication through tele-rail and train control services. However, this infrastructure is not fully utilized to its potential. Therefore, the following are some of the recommendations this research commends for AALRT;

i) The maintenance method or system should be improved and shifted from only using preventive and corrective maintenance to also including predictive maintenance. Predictive maintenance calls for high-tech methods like automation, big data analytics, and data mining techniques that improve on machine learning and artificial intelligence systems.

ii) Train services that include passenger experience should be improved and through the internet of things technology and services like Wi-Fi and live TV onboard. Currently, the only entertainment services onboard are recordings and local files from archives.

iii) Internet services in railways could also improve on advertisement techniques and hence boosting the revenue the industry could generate. This is because trains are usually full at peak hours and hence calling for large masses of passengers per trip.

Lastly, after this research was conducted, a couple of areas remain potential research areas and could be tackled, they include;

1. Investigation or study on the effect of the internet of things (IoT) on capacity in railways. The focus of this idea would be on the study on how this technology and improved services would affect the cost of a trip and the expense it would require to make it a reality.
2. A study on the Ethio-Tel network unreliability and its effect on the IoT system performance and reliability.

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APPENDICES

Appendix I: System Simulation Code

i) C++ Arduino Code

```
#include <LiquidCrystal.h>

LiquidCrystal LCD(9,8,5,4,3,2);
//Current
double AcsOffset=2.5;
double Sensibl=0.066;
double current=0;
double tension=0;
int potentiovalue=0;
int Speed;
//Temperature
int val;
int tempPin = 1;
//int Gas = 5;
//voltage
int analogInput=A3;
float vout = 0.0;
float vin = 0.0;
float R1=30.0;
float R2=75.0;
int value=0;
int ndata = 6;
void setup() {
  LCD.begin(20,4);
  pinMode(12,OUTPUT);
  pinMode(13,OUTPUT);
```

```
  pinMode(0,INPUT);
  pinMode(analogInput, INPUT);
  pinMode(4,INPUT);
  pinMode(10,OUTPUT);
  pinMode(11,OUTPUT);
  pinMode(6,INPUT);
}
void loop() {
  Serial.begin(9600);
  //Temperature
  val = analogRead(tempPin);
  float mv = (val/1024.0)*5000;
  float cel = mv/10;
  //Smoke
  int smoke = digitalRead(6);
  //vibration
  int vibrationvalue = analogRead(A2);
  float vibration = vibrationvalue *(15.0/1023.0);
  double ValeurLue = analogRead(A0);
  tension=(ValeurLue*5.0/1023);
  current=((tension-AcsOffset)/Sensibl)*150;
  value = analogRead(analogInput);
  vout = (value*5.0)/1024;
  vin=(vout/(R2/(R1+R2)))*101;
  potentiovalue=analogRead(A4);
  potentiovalue=map(potentiovalue,0,1023,0,255);
  analogWrite(10,potentiovalue);
  Speed=potentiovalue*(1400.0/255);
```

```
  String Payload_Speed = (String)Speed;
  String Payload_vin = (String)vin;
  String Payload_cel = (String)cel;
  String Payload_current = (String)current;
  String Payload_vibration = (String)vibration;
  String Payload_smoke = (String)smoke;
  String Payload;
  //String Payload_print;
   Payload+=ndata;
  Payload+=" "+ Payload_vin;
  Payload+=" "+ Payload_Speed;
  Payload+=" "+ Payload_cel;
  Payload+=" "+ Payload_current;
  Payload+=" "+ Payload_vibration;
  Payload+=" "+ Payload_smoke;
  //Payload+="\n";
  //delay(1000);
  //Payload_print = Payload;
  Serial.println(Payload);
  delay(1000);
if (vibration >= 9){
  digitalWrite(12,HIGH);
  digitalWrite(11,HIGH);
  delay(250);
  digitalWrite(11,LOW);
  digitalWrite(12,LOW);
  digitalWrite(13,LOW);
```

```
 LCD.clear();
 LCD.setCursor(0,0);
 LCD.print("DANGER,SLOW DOWN!");
 LCD.setCursor(0,1);
 LCD.print("High Vibration");
 LCD.setCursor(0,2);
 LCD.print(vibration);
 LCD.print("Hz");
}
else if(cel>100){
 digitalWrite(12,HIGH);
 digitalWrite(11,HIGH);
 delay(250);
 digitalWrite(11,LOW);
 digitalWrite(12,LOW);
 digitalWrite(13,LOW);
 LCD.clear();
 LCD.setCursor(0,0);
 LCD.print("DANGER,SLOW DOWN!");
 LCD.setCursor(0,1);
 LCD.print("High Temperature");
 LCD.setCursor(0,2);
 LCD.print(cel);
 LCD.print("*C");
}
else if (current> 120){
 LCD.clear();
 digitalWrite(12,HIGH);
```

```
  digitalWrite(11,HIGH);
  delay(250);
  digitalWrite(11,LOW);
  digitalWrite(12,LOW);
  digitalWrite(13,LOW);
  LCD.clear();
  LCD.setCursor(0,0);
  LCD.print("DANGER,SLOW DOWN!");
  LCD.setCursor(0,1);
  LCD.print("High Current");
  LCD.setCursor(0,2);
  LCD.print(current);
  LCD.print("Amp");
}
  else if (smoke == 1){
  LCD.clear();
  LCD.setCursor(0,1);
  digitalWrite(12,HIGH);
  digitalWrite(11,HIGH);
  delay(250);
  digitalWrite(11,LOW);
  digitalWrite(12,LOW);
  digitalWrite(13,LOW);
  LCD.clear();
  LCD.setCursor(0,0);
  LCD.print("DANGER,SLOW DOWN!");
  LCD.setCursor(0,1);
  LCD.print("Smoke Detected");
```

```
}
else
{
  digitalWrite(13,HIGH);
  LCD.clear();
  LCD.setCursor(0,0);
  LCD.print("CURRENT= ");
  LCD.print(current);
  LCD.print("Amp");
  LCD.setCursor(0,1);
  LCD.print("TEMPERATURE= ");
  LCD.print(cel);
  LCD.print("*C");
  LCD.setCursor(0,2);
  LCD.print("VIBRATION= ");
  LCD.print(vibration);
  LCD.print("Hz");
  LCD.setCursor(0,3);
  LCD.print("Normal Conditions");
 }
}
```

ii) Node.js Javascript Code

a) ToString Node code

```
var newMsg = {payload: msg.payload.toString()};

return newMsg;
```

b) Build Email Node code

```
//voltage email builder
```

```
if(msg.parts.index == 1){
var msgvoltage =  parseFloat(msg.payload);
if (msgvoltage< 4)
{
   msg = {
    payload : "High Voltage Emergency has been triggered, level"+" "+ msgvoltage+" " + "on" +"
" + Date().toString(),
    topic: "Voltage Emergency!"
};
return msg;
}
}
//Speed email builder
if(msg.parts.index == 2){
var msgspeed =  parseFloat(msg.payload);
if (msgspeed> 1000)
{
   msg = {
    payload : "Over Speed Emergency has been triggered of,"+" "+ msgspeed+"RPM"+" "
+"on"+" " + Date().toString(),
    topic: "Speed Emergency!"
};
return msg;
```

```
}

}

//Temperature email builder

if(msg.parts.index == 3){

var msgtemperature =  parseFloat(msg.payload);

if (msgtemperature> 100)

{

  msg = {

    payload : "High traction temperature Emergency has been triggered at level,"+" "+msgtemperature+"Degrees Celicious"+" "+"on"+" " + Date().toString(),

    topic: "Temperature Emergency!"

};

return msg;

}

}

//Current Email builder

if(msg.parts.index == 4){

var msgcurrent =  parseFloat(msg.payload);

if (msgcurrent> 2)

{

  msg = {

    payload : "High Current Emergency has been triggered at level,"+" "+msgcurrent+" "+"on"+" " + Date().toString(),
```

```
    topic: "Current Emergency!"
};
return msg;
}
}
//Vibration Email builder
if(msg.parts.index == 5){
var msgvibration =  parseFloat(msg.payload);
if (msgvibration> 2)
{
   msg = {
    payload : "High Vibration Emergency has been triggereda at level,"+" "+msgvibration+"
"+"on "+" " + Date().toString(),
    topic: "Vibration Emergency!"
};
return msg;
}
}
```

c) Make SMS Code

```
if(msg.parts.index == 1){
var msgvoltage =  parseFloat(msg.payload);
if (msgvoltage< 4)
{
```

```
  msg = {
   payload : "High Voltage Emergency has been triggered, level"+" "+ msgvoltage+" " + "on" +"
" + Date().toString(),
   //topic: "Voltage Emergency!"
};
return msg;
}}
//Speed email builder
if(msg.parts.index == 2){
var msgspeed =  parseFloat(msg.payload);
if (msgspeed> 1000)
{
  msg = {
   payload : "Over Speed Emergency has been triggered of,"+" "+ msgspeed+"RPM"+" "
+"on"+" " + Date().toString(),
   //topic: "Speed Emergency!"
};
return msg;
}
}
//Temperature email builder
if(msg.parts.index == 3){
var msgtemperature =  parseFloat(msg.payload);
```

```
if (msgtemperature> 100)

{

  msg = {

   payload : "High traction temperature Emergency has been triggered at level,"+" "+msgtemperature+"Degrees Celicious"+" "+"on"+" " + Date().toString(),

   //topic: "Temperature Emergency!"

};

return msg;

}

}

//Current Email builder

if(msg.parts.index == 4){

var msgcurrent =  parseFloat(msg.payload);

if (msgcurrent> 2)

{

  msg = {

   payload : "High Current Emergency has been triggered at level,"+" "+msgcurrent+" "+"on"+" " + Date().toString(),

   //topic: "Current Emergency!"

};

return msg;

}

}
```

```
//Vibration Email builder
if(msg.parts.index == 5){
var msgvibration =  parseFloat(msg.payload);
if (msgvibration> 2)
{
   msg = {
    payload : "High Vibration Emergency has been triggereda at level,"+" "+msgvibration+"
"+"on "+" " + Date().toString(),
    //topic: "Vibration Emergency!"
};
return msg;
}
}
```

d) Make SMS Node Code

```
if(msg.parts.index == 1){
var msgvoltage =  parseFloat(msg.payload);
if (msgvoltage< 4)
{
   msg = {
    payload : "High Voltage Emergency has been triggered, level"+" "+ msgvoltage+" " + "on" +"
" + Date().toString(),
    //topic: "Voltage Emergency!"
};
```

```
return msg;
}}
//Speed SMS builder
if(msg.parts.index == 2){
var msgspeed =  parseFloat(msg.payload);
if (msgspeed> 1000)
{
   msg = {
    payload : "Over Speed Emergency has been triggered of,"+" "+ msgspeed+"RPM"+" " +"on"+" " + Date().toString(),
    //topic: "Speed Emergency!"
};
return msg;
}
}
//Temperature SMS builder
if(msg.parts.index == 3){
var msgtemperature =  parseFloat(msg.payload);
if (msgtemperature> 100)
{
   msg = {
    payload : "High traction temperature Emergency has been triggered at level,"+" "+msgtemperature+"Degrees Celicious"+" "+"on"+" " + Date().toString(),
```

```
   //topic: "Temperature Emergency!"
};
return msg;
}
}
//Current SMS builder
if(msg.parts.index == 4){
var msgcurrent =  parseFloat(msg.payload);
if (msgcurrent> 2)
{
  msg = {
   payload : "High Current Emergency has been triggered at level,"+" "+msgcurrent+" "+"on"+"
" + Date().toString(),
   //topic: "Current Emergency!"
};
return msg;
}
}
//Vibration SMS builder
if(msg.parts.index == 5){
var msgvibration =  parseFloat(msg.payload);
if (msgvibration> 2)
{
```

```
  msg = {
   payload : "High Vibration Emergency has been triggereda at level,"+" "+msgvibration+"
"+"on "+" " + Date().toString(),
   //topic: "Vibration Emergency!"
};
return msg;
}
}
```

e) Voltage parameter node code

```
if(msg.parts.index == 1){
var msgvoltage = {payload: msg.payload};
}
return msgvoltage;
```

f) Speed Parameter node Code

```
if(msg.parts.index == 2)
{
var msgspeed = {payload: msg.payload};
}
return msgspeed;
```

g) Temperature Parameter node code

```
if(msg.parts.index == 3)
{
var msgtemp = {payload: msg.payload};
}
```

```
return msgtemp;
```

h) Current Parameter node code

```
if(msg.parts.index == 4)
{
var msgcurrent = {payload: msg.payload};
}
return msgcurrent;
```

i) Vibration Paramter node code

```
if(msg.parts.index == 5)
{
var msgvibration = {payload: msg.payload};
}
return msgvibration;
```

j) Save to database node code

```
var output = msg.payload.split(" ");
var voltage = parseFloat(output[1]);
var speed = parseInt(output[2]);
var current = parseFloat(output[3]);
var temp = parseFloat(output[4]);
var vb = parseFloat(output[5]);
msg.topic = "INSERT INTO iottraindata
(VOLTAGE,SPEED,TEMPERATURE,CURRENT,VIBRATION)
VALUES("+"\'"+voltage+"\'"+","+"\'"+speed+"\'"+","+"\'"+current+"\'"+","+"\'"+temp+"\'"+","+
"\'"+vb+"\'"+")"
return msg;
```

Appendix II: Tain data

Database: iottrainbd, Table: iottraindata, Purpose: Dumping data

ID	VOLTAGE	SPEED	TEMPERATURE	CURRENT	VIBRATION	TIME-STAMP
27	636.58	1257	98.14	116.64	9.18	2020-04-08 14:07:15
28	636.58	1257	98.14	116.64	7.86	2020-04-08 14:07:24
29	636.58	1257	98.14	116.64	7.86	2020-04-08 14:07:32
30	636.58	1257	98.14	116.64	7.86	2020-04-08 14:07:40
31	636.58	1257	98.14	116.64	7.86	2020-04-08 14:07:49
32	636.58	1257	98.14	116.64	7.86	2020-04-08 14:07:59
33	636.58	1257	98.14	116.64	7.86	2020-04-08 14:08:07
34	636.58	1257	98.14	116.64	7.86	2020-04-08 14:08:16
35	636.58	1257	98.14	116.64	7.86	2020-04-08 14:08:25
36	636.58	1257	98.14	116.64	7.86	2020-04-08 14:08:34
37	636.58	1257	98.14	116.64	7.86	2020-04-08 14:08:43
38	636.58	1257	98.14	116.64	7.86	2020-04-08 14:08:53
39	636.58	1257	98.14	116.64	7.86	2020-04-08 14:09:03
40	636.58	1257	98.14	116.64	7.86	2020-04-08 14:09:14
41	636.58	1257	98.14	116.64	7.86	2020-04-08 14:09:25
42	636.58	1257	98.14	116.64	7.86	2020-04-08 14:09:36
43	636.58	1257	98.14	116.64	7.86	2020-04-08 14:09:46
44	636.58	1257	98.14	116.64	7.86	2020-04-08 14:09:54
45	636.58	1257	98.14	116.64	7.86	2020-04-08 14:10:04
46	636.58	1257	98.14	116.64	7.86	2020-04-08 14:10:15
47	636.58	1257	98.14	116.64	7.86	2020-04-08 14:10:25
48	636.58	1257	98.14	116.64	7.86	2020-04-08 14:10:36
49	636.58	1257	98.14	116.64	7.86	2020-04-08 14:10:46
50	636.58	1257	98.14	116.64	7.86	2020-04-08 14:10:56
51	636.58	1257	98.14	116.64	7.86	2020-04-08 14:11:07
52	636.58	1257	98.14	116.64	7.86	2020-04-08 14:11:18
53	636.58	1257	98.14	116.64	7.86	2020-04-08 14:11:30
54	636.58	1257	98.14	116.64	7.86	2020-04-08 14:11:39
55	636.58	1257	98.14	116.64	7.86	2020-04-08 14:11:50
56	636.58	1257	98.14	116.64	7.86	2020-04-08 14:12:00
57	636.58	1257	98.14	116.64	7.86	2020-04-08 14:12:10
58	636.58	1257	98.14	116.64	7.86	2020-04-08 14:12:19
59	636.58	1257	98.14	116.64	7.86	2020-04-08 14:12:29

60	636.58	1257	98.14	116.64	7.86	2020-04-08 14:12:40
61	636.58	1257	98.14	116.64	7.86	2020-04-08 14:12:50
62	636.58	1257	98.14	116.64	7.86	2020-04-08 14:13:00
63	636.58	1257	98.14	116.64	7.86	2020-04-08 14:13:12
64	636.58	1257	98.14	116.64	7.86	2020-04-08 14:13:22
65	636.58	1257	98.14	116.64	7.86	2020-04-08 14:13:32
66	636.58	1257	98.14	116.64	7.86	2020-04-08 14:13:42
67	636.58	1257	98.14	116.64	7.86	2020-04-08 14:13:53
68	636.58	1257	98.14	116.64	7.86	2020-04-08 14:14:03
69	636.58	1257	98.14	116.64	7.86	2020-04-08 14:14:14
70	636.58	1257	98.14	116.64	7.86	2020-04-08 14:14:23
71	636.58	1257	98.14	116.64	7.86	2020-04-08 14:14:33
72	636.58	1257	98.14	116.64	7.86	2020-04-08 14:14:44
73	636.58	1257	98.14	116.64	7.86	2020-04-08 14:14:55
74	636.58	1257	98.14	116.64	7.86	2020-04-08 14:15:04
75	636.58	1257	98.14	116.64	7.86	2020-04-08 14:15:14
76	636.58	1257	98.14	116.64	7.86	2020-04-08 14:15:22
77	636.58	1257	98.14	116.64	7.86	2020-04-08 14:15:32
78	636.58	1257	98.14	116.64	7.86	2020-04-08 14:15:41
79	636.58	1257	98.14	116.64	7.86	2020-04-08 14:15:51
80	636.58	1257	98.14	116.64	7.86	2020-04-08 14:16:02
81	636.58	1257	98.14	116.64	7.86	2020-04-08 14:16:12
82	636.58	1257	98.14	116.64	7.86	2020-04-08 14:16:22
83	636.58	1257	98.14	116.64	7.86	2020-04-08 14:16:32
84	636.58	1257	98.14	116.64	7.86	2020-04-08 14:16:41
85	636.58	1257	98.14	116.64	7.86	2020-04-08 14:16:51
86	636.58	1257	98.14	116.64	7.86	2020-04-08 14:17:01
87	636.58	1257	98.14	116.64	7.86	2020-04-08 14:17:12
88	636.58	1257	98.14	116.64	7.86	2020-04-08 14:17:22
89	636.58	1257	98.14	116.64	7.86	2020-04-08 14:17:32
90	636.58	1257	98.14	116.64	7.86	2020-04-08 14:17:42
91	636.58	1257	98.14	116.64	7.86	2020-04-08 14:17:53
92	636.58	1257	98.14	116.64	7.86	2020-04-08 14:18:03
93	636.58	1257	98.14	116.64	7.86	2020-04-08 14:18:13
94	636.58	1257	98.14	116.64	7.86	2020-04-08 14:18:23
95	636.58	1257	98.14	116.64	7.86	2020-04-08 14:18:33

96	636.58	1257	98.14	116.64	7.86	2020-04-08 14:18:43
97	636.58	1257	98.14	116.64	7.86	2020-04-08 14:18:52
98	636.58	1257	98.14	116.64	7.86	2020-04-08 14:19:02
99	636.58	1257	98.14	116.64	7.86	2020-04-08 14:19:12
100	636.58	1257	98.14	116.64	7.86	2020-04-08 14:19:22

Appendix III: Interview Questionnaire

Research topic: Investigation on the effect of the internet of things (IoT) to improve traction safety and system reliability through real-time conditions monitoring.

Case study: Addis Ababa Light Rail Transit (AALRT) Service.

Department: Rolling stock and Maintenance department.

Student’s Name/Interviewer: JOHN KAJUBU

E-mail: kajubujohn@gmail.com

University: Addis Ababa University (AAU)

Addis Ababa Institute of Technology (AAiT)

African Railway center of excellence (ARCE)

Interview Questions

1) How long have you worked in the rolling stock maintenance department?

Less than 1 year	☐
2 – 3 years	☐
More than 3 years	☐

2) What is the type of maintenance you employ or use most in the rolling stock maintenance department?

a)	Preventive maintenance	☐
b)	Predictive maintenance	☐
c)	Corrective maintenance	☐
d)	Combination	☐

If it’s a combination, what is the combination? Indicate using the letters

……………………………………………………………………………………………

3) On average, how often do the rolling stock electrical or traction systems fail?

……………………………………………………………………………………………

4) What system fails more often on the rolling stock?

…………………………………………………………………………………………………

5) How does the technical team get to know about the fault or system abnormality?

…………………………………………………………………………………………………

6) Is the train driver or trainmaster technical personnel or well versed with the train system?

YES	☐
NO	☐

7) On average, how long does it take the technical team to get to know about a fault or abnormality?

…………………………………………………………………………………………………

8) Apart from tele-rail and information about the train movements or location, how else does the LTE-R network along with the railway line help in the maintenance department?

…………………………………………………………………………………………………

9) On average, how long does it take to trace an error or fault on the traction system?

…………………………………………………………………………………………………

10) On average, how long would it take for the system to fail again?

…………………………………………………………………………………………………

11) Do you think including or introducing the technology of the internet of things (IoT) and big data analytics in the railway network would improve on the maintenance operations, safety, reliability, and availability?

YES	☐
NO	☐

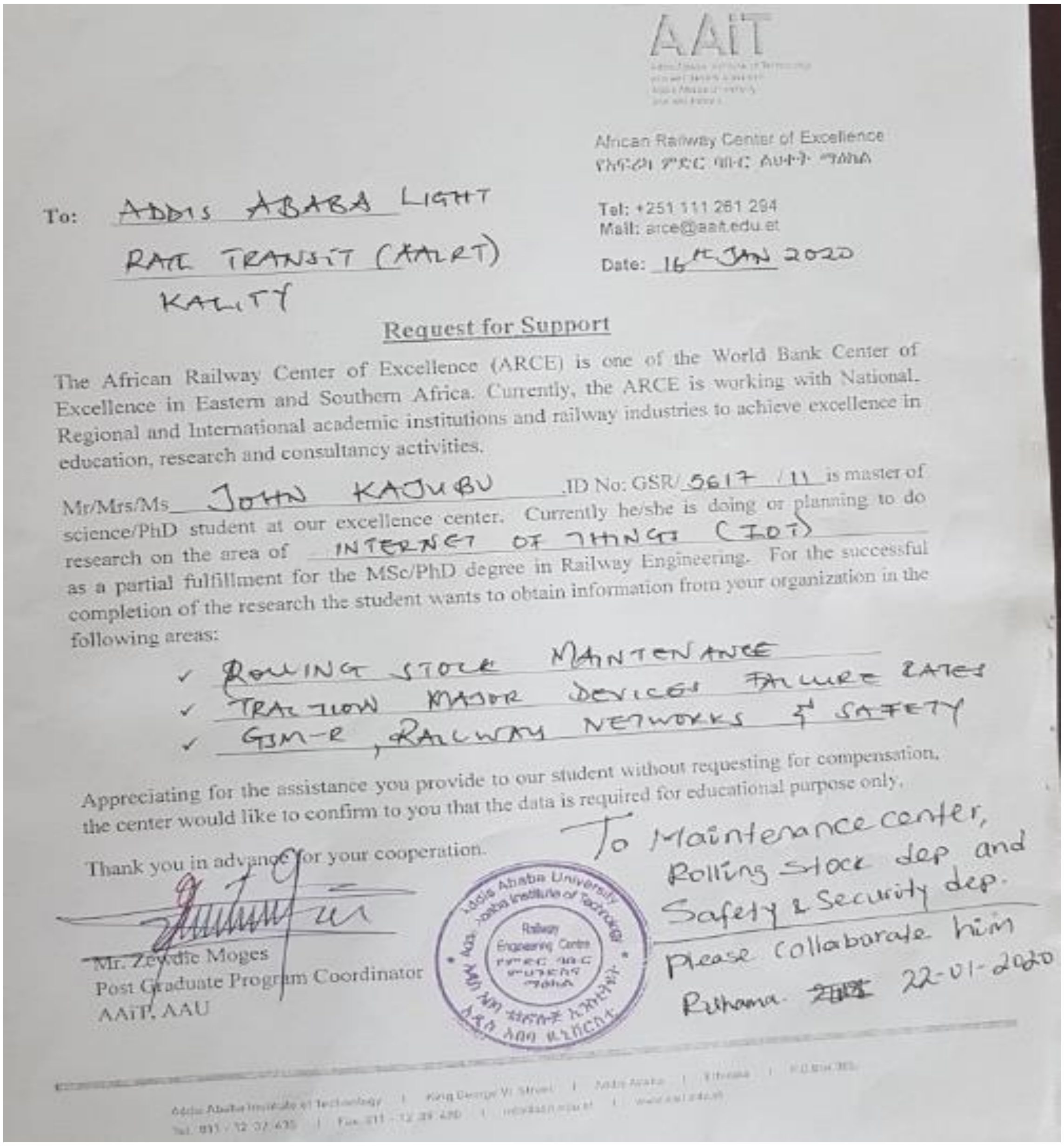
12) With regards to your answer for question 11) above, is there any comment or remark you would like to give about this research topic?

…………………………………………………………………………………………………

…………………………………………………………………………………………………

Appendix IV: AALRT Maintenance sheets

Below are some samples of maintenance sheets used at the AALRT rolling stock maintenance department. Included is also the letter from the ARCE, approved by the respective offices to conduct the research and obtain data from the various departments.



AAiT

African Railway Center of Excellence

Tel: +251 111 261 294
Mail: arce@aait.edu.et

Date: 16th JAN 2020

To: ADDIS ABABA LIGHT
RAIL TRANSIT (AALRT)
KALITY

Request for Support

The African Railway Center of Excellence (ARCE) is one of the World Bank Center of Excellence in Eastern and Southern Africa. Currently, the ARCE is working with National, Regional and International academic institutions and railway industries to achieve excellence in education, research and consultancy activities.

Mr/Mrs/Ms JOHN KAJUBU ID No: GSR/5617 /11 is master of science/PhD student at our excellence center. Currently he/she is doing or planning to do research on the area of INTERNET OF THINGS (IOT) as a partial fulfillment for the MSc/PhD degree in Railway Engineering. For the successful completion of the research the student wants to obtain information from your organization in the following areas:

- ✓ ROLLING STOCK MAINTENANCE
- ✓ TRACTION MAJOR DEVICES FAILURE RATES
- ✓ GSM-R, RAILWAY NETWORKS & SAFETY

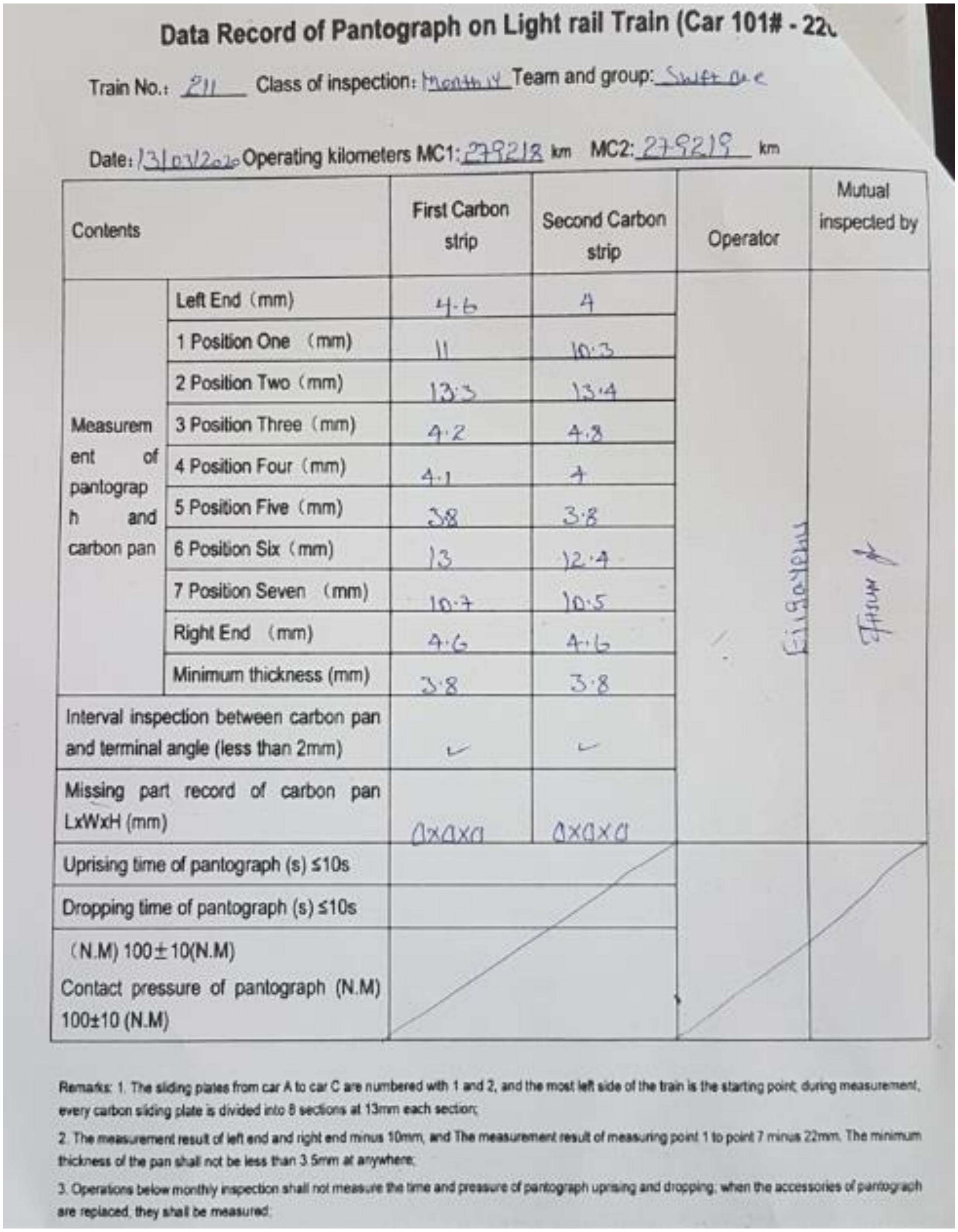
Appreciating for the assistance you provide to our student without requesting for compensation, the center would like to confirm to you that the data is required for educational purpose only.

Thank you in advance for your cooperation.

Mr. Zewdie Moges
Post Graduate Program Coordinator
AAiT, AAU

Railway Engineering Centre

To Maintenance center,
Rolling stock dep and
Safety & Security dep.
Please collaborate him
Ruhama. 22-01-2020



Data Record of Pantograph on Light rail Train (Car 101# - 22

Train No.: 211 Class of inspection: Monthly Team and group: Swift one

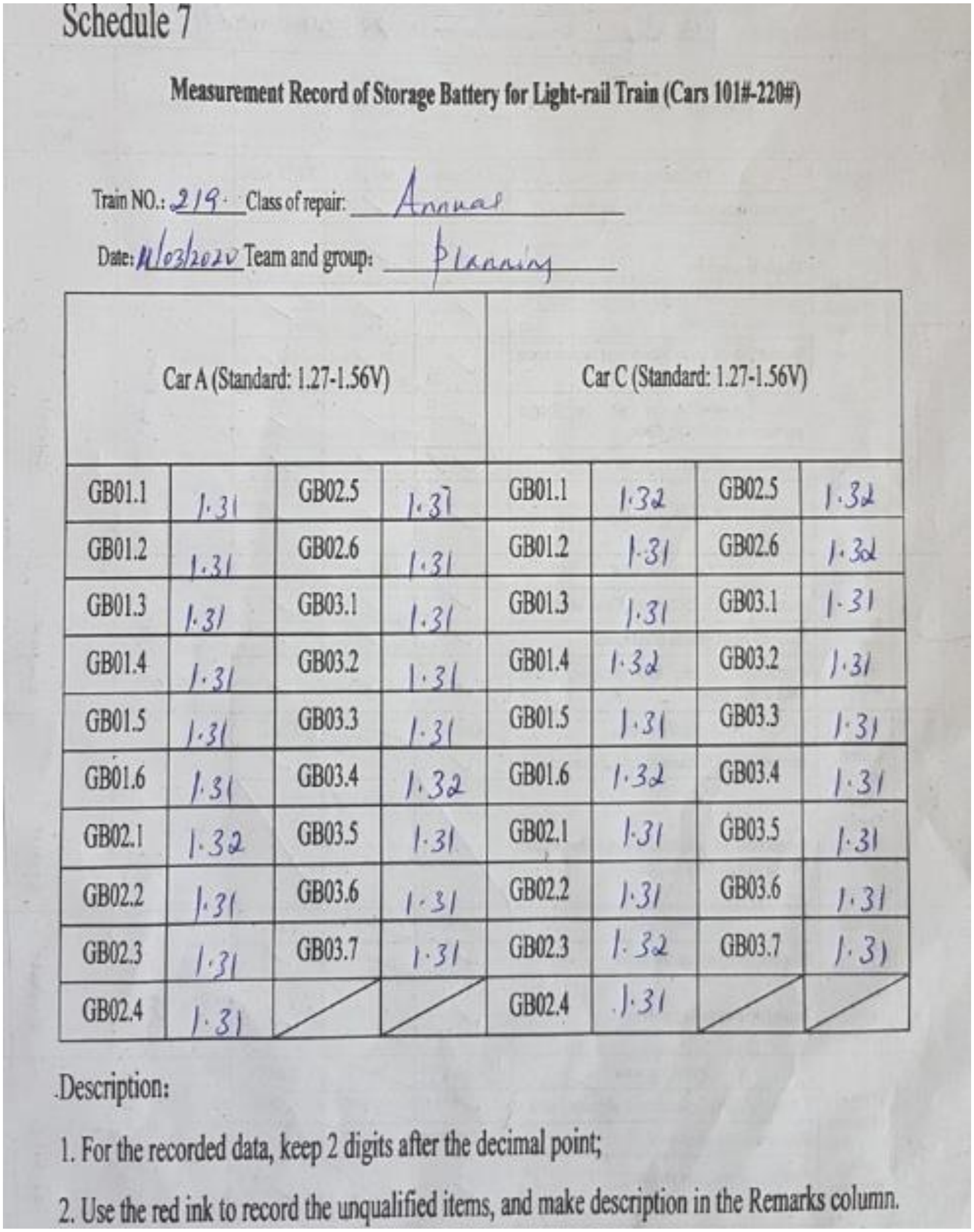
Date: 13/03/2020 Operating kilometers MC1: 279218 km MC2: 279219 km

Contents		First Carbon strip	Second Carbon strip	Operator	Mutual inspected by
Measurement of pantograph and carbon pan	Left End (mm)	4.6	4	Eligayehu	Fitsum
	1 Position One (mm)	11	10.3		
	2 Position Two (mm)	13.3	13.4		
	3 Position Three (mm)	4.2	4.8		
	4 Position Four (mm)	4.1	4		
	5 Position Five (mm)	3.8	3.8		
	6 Position Six (mm)	13	12.4		
	7 Position Seven (mm)	10.7	10.5		
	Right End (mm)	4.6	4.6		
	Minimum thickness (mm)	3.8	3.8		
Interval inspection between carbon pan and terminal angle (less than 2mm)		✓	✓		
Missing part record of carbon pan LxWxH (mm)		0x0x0	0x0x0		
Uprising time of pantograph (s) ≤10s					
Dropping time of pantograph (s) ≤10s					
(N.M) 100±10(N.M) Contact pressure of pantograph (N.M) 100±10 (N.M)					

Remarks: 1. The sliding plates from car A to car C are numbered with 1 and 2, and the most left side of the train is the starting point; during measurement, every carbon sliding plate is divided into 8 sections at 13mm each section;

2. The measurement result of left end and right end minus 10mm, and The measurement result of measuring point 1 to point 7 minus 22mm. The minimum thickness of the pan shall not be less than 3.5mm at anywhere;

3. Operations below monthly inspection shall not measure the time and pressure of pantograph uprising and dropping; when the accessories of pantograph are replaced, they shall be measured.



Schedule 7

Measurement Record of Storage Battery for Light-rail Train (Cars 101#-220#)

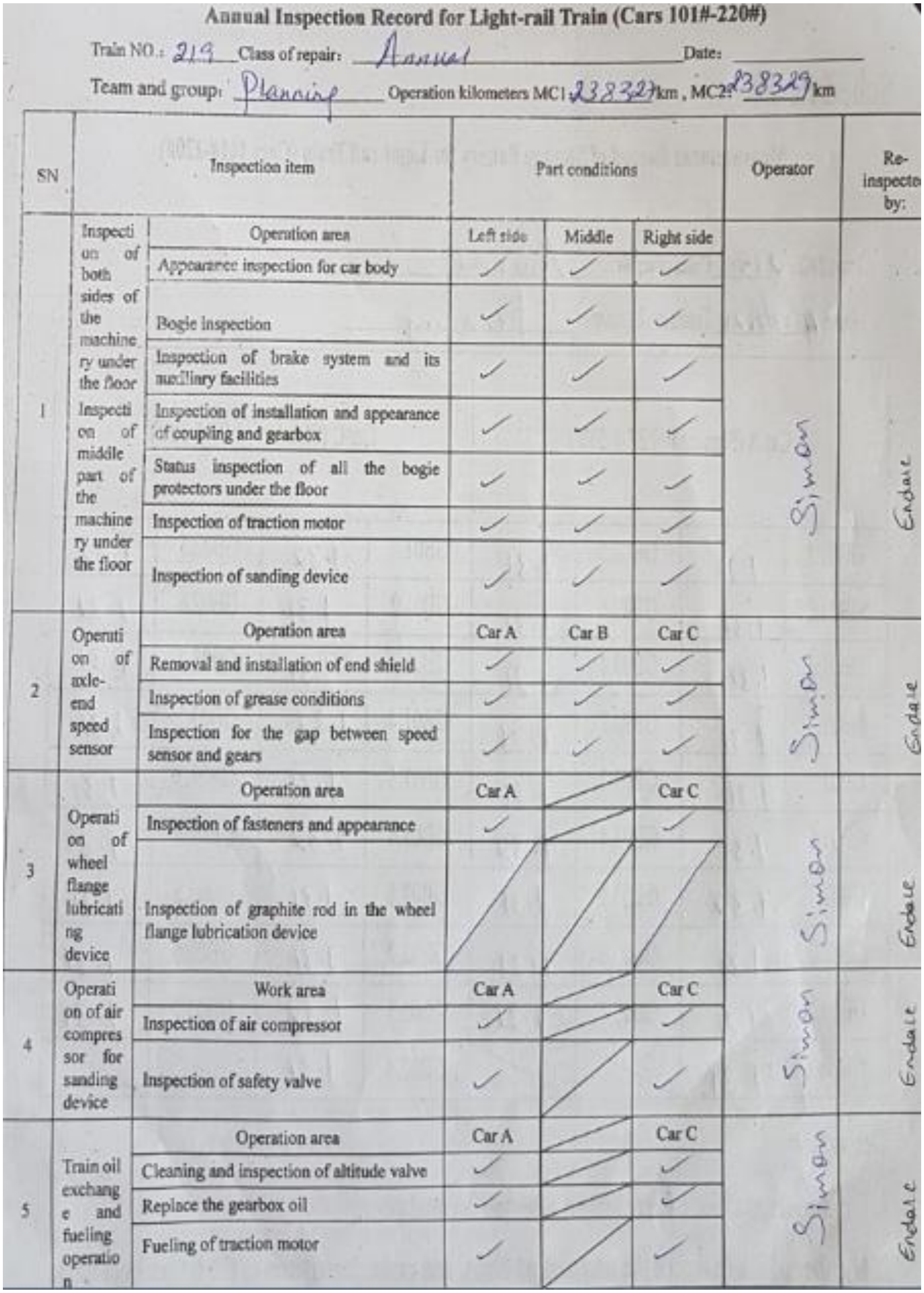
Train NO.: 219. Class of repair: Annual

Date: 11/03/2020 Team and group: Planning

Car A (Standard: 1.27-1.56V)				Car C (Standard: 1.27-1.56V)			
GB01.1	1.31	GB02.5	1.37	GB01.1	1.32	GB02.5	1.32
GB01.2	1.31	GB02.6	1.31	GB01.2	1.31	GB02.6	1.32
GB01.3	1.31	GB03.1	1.31	GB01.3	1.31	GB03.1	1.31
GB01.4	1.31	GB03.2	1.31	GB01.4	1.32	GB03.2	1.31
GB01.5	1.31	GB03.3	1.31	GB01.5	1.31	GB03.3	1.31
GB01.6	1.31	GB03.4	1.32	GB01.6	1.32	GB03.4	1.31
GB02.1	1.32	GB03.5	1.31	GB02.1	1.31	GB03.5	1.31
GB02.2	1.31	GB03.6	1.31	GB02.2	1.31	GB03.6	1.31
GB02.3	1.31	GB03.7	1.31	GB02.3	1.32	GB03.7	1.31
GB02.4	1.31			GB02.4	1.31		

Description:

1. For the recorded data, keep 2 digits after the decimal point;
2. Use the red ink to record the unqualified items, and make description in the Remarks column.

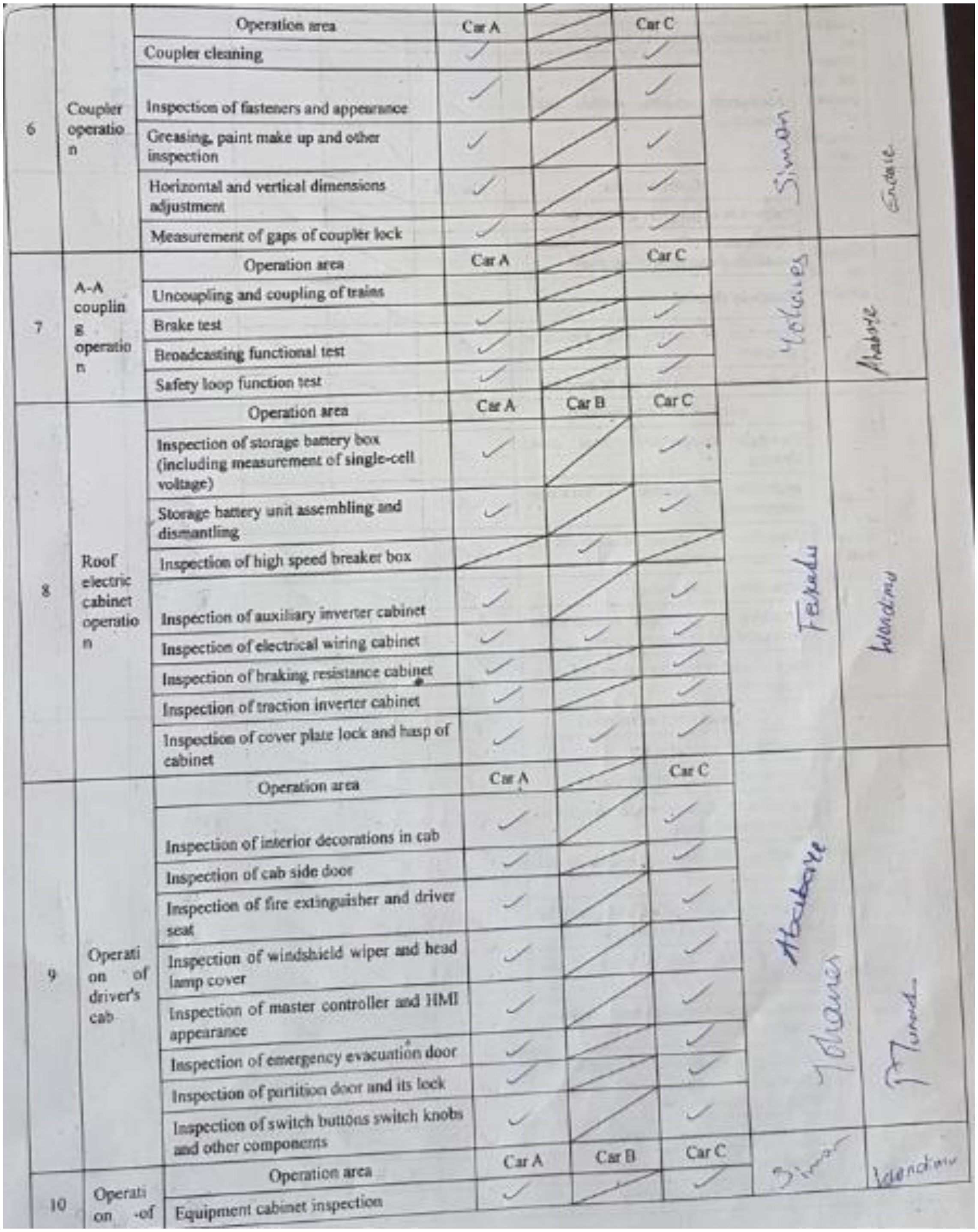


Annual Inspection Record for Light-rail Train (Cars 101#-220#)

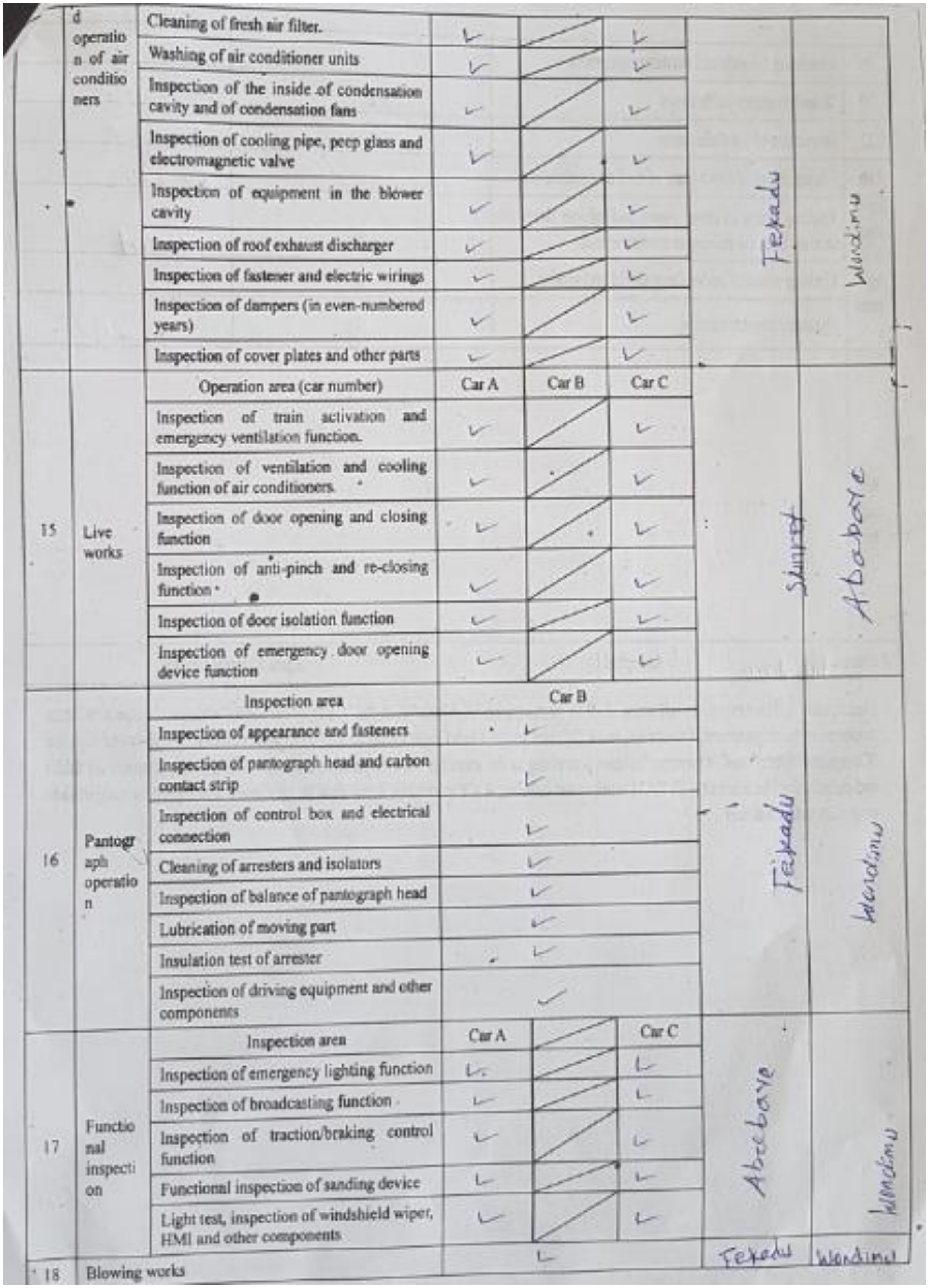
Train NO.: 219 Class of repair: Annual Date:

Team and group: Planning Operation kilometers MC1: 238327 km , MC2: 238329 km

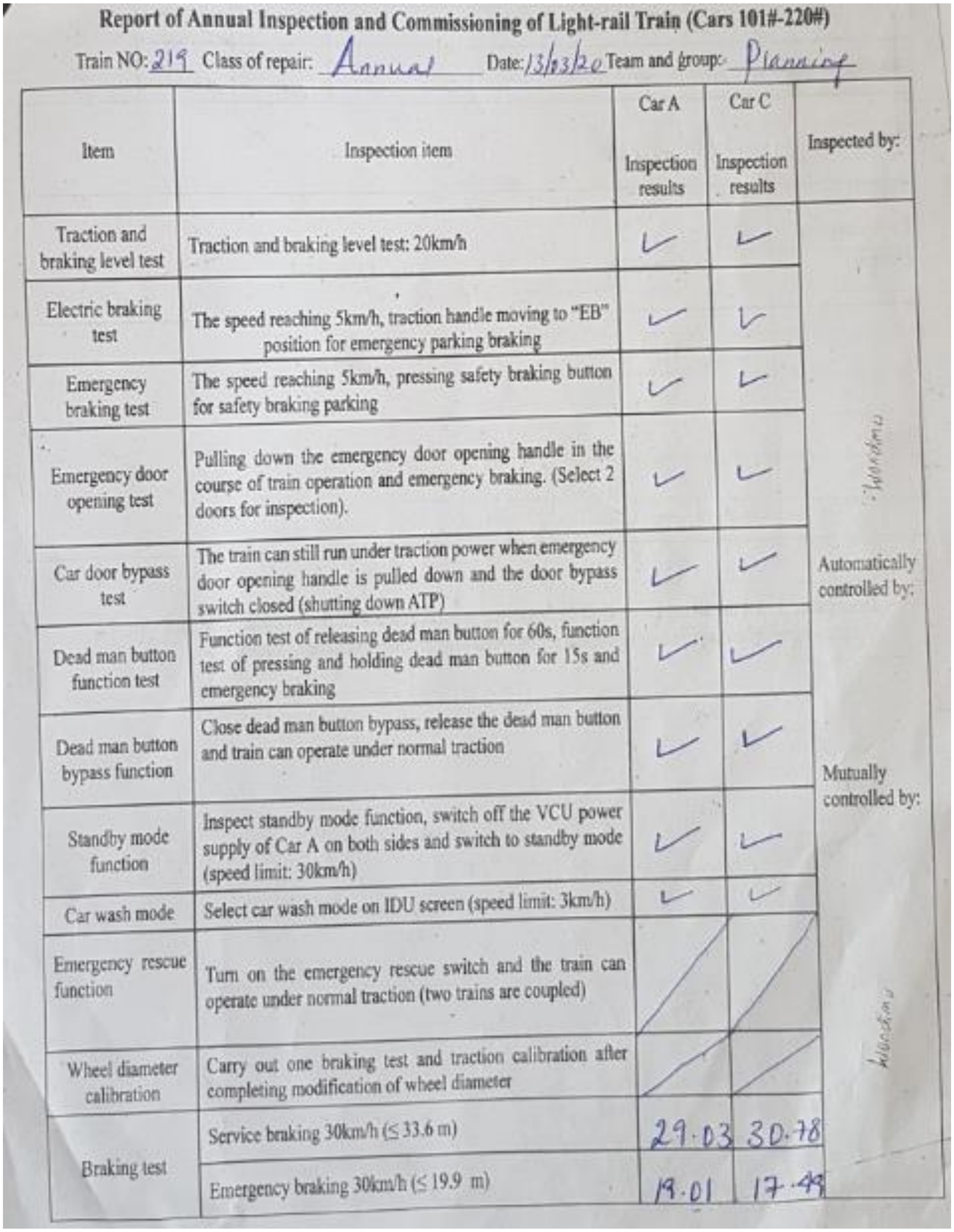
SN	Inspection item		Part conditions			Operator	Re-inspecto by:
1	Inspection of both sides of the machinery under the floor	Operation area	Left side	Middle	Right side	Simon	Endale
		Appearance inspection for car body	✓	✓	✓		
		Bogie inspection	✓	✓	✓		
		Inspection of brake system and its auxiliary facilities	✓	✓	✓		
	Inspection of middle part of the machinery under the floor	Inspection of installation and appearance of coupling and gearbox	✓	✓	✓		
		Status inspection of all the bogie protectors under the floor	✓	✓	✓		
		Inspection of traction motor	✓	✓	✓		
		Inspection of sanding device	✓	✓	✓		
2	Operation of axle-end speed sensor	Operation area	Car A	Car B	Car C	Simon	Endale
		Removal and installation of end shield	✓	✓	✓		
		Inspection of grease conditions	✓	✓	✓		
		Inspection for the gap between speed sensor and gears	✓	✓	✓		
3	Operation of wheel flange lubricating device	Operation area	Car A		Car C	Simon	Endale
		Inspection of fasteners and appearance	✓		✓		
		Inspection of graphite rod in the wheel flange lubrication device					
4	Operation of air compressor for sanding device	Work area	Car A		Car C	Simon	Endale
		Inspection of air compressor	✓		✓		
		Inspection of safety valve	✓		✓		
5	Train oil exchange and fueling operation	Operation area	Car A		Car C	Simon	Endale
		Cleaning and inspection of altitude valve	✓		✓		
		Replace the gearbox oil	✓		✓		
		Fueling of traction motor	✓		✓		



6	Coupler operation	Operation area	Car A		Car C	Simon	Endale
		Coupler cleaning	✓		✓		
		Inspection of fasteners and appearance	✓		✓		
		Greasing, paint make up and other inspection	✓		✓		
		Horizontal and vertical dimensions adjustment	✓		✓		
		Measurement of gaps of coupler lock	✓		✓		
7	A-A coupling operation	Operation area	Car A		Car C	Yohannes	Ababye
		Uncoupling and coupling of trains					
		Brake test	✓		✓		
		Broadcasting functional test	✓		✓		
		Safety loop function test	✓		✓		
8	Roof electric cabinet operation	Operation area	Car A	Car B	Car C	Fekadu	Wondimu
		Inspection of storage battery box (including measurement of single-cell voltage)	✓		✓		
		Storage battery unit assembling and dismantling	✓		✓		
		Inspection of high speed breaker box		✓			
		Inspection of auxiliary inverter cabinet	✓		✓		
		Inspection of electrical wiring cabinet	✓	✓	✓		
		Inspection of braking resistance cabinet	✓		✓		
		Inspection of traction inverter cabinet	✓		✓		
		Inspection of cover plate lock and hasp of cabinet	✓	✓	✓		
9	Operation of driver's cab	Operation area	Car A		Car C	Abebawe Yohannes	Murad
		Inspection of interior decorations in cab	✓		✓		
		Inspection of cab side door	✓		✓		
		Inspection of fire extinguisher and driver seat	✓		✓		
		Inspection of windshield wiper and head lamp cover	✓		✓		
		Inspection of master controller and HMI appearance	✓		✓		
		Inspection of emergency evacuation door	✓		✓		
		Inspection of partition door and its lock	✓		✓		
		Inspection of switch buttons switch knobs and other components	✓		✓		
10	Operation of	Operation area	Car A	Car B	Car C	Simon	Wondimu
		Equipment cabinet inspection	✓		✓		



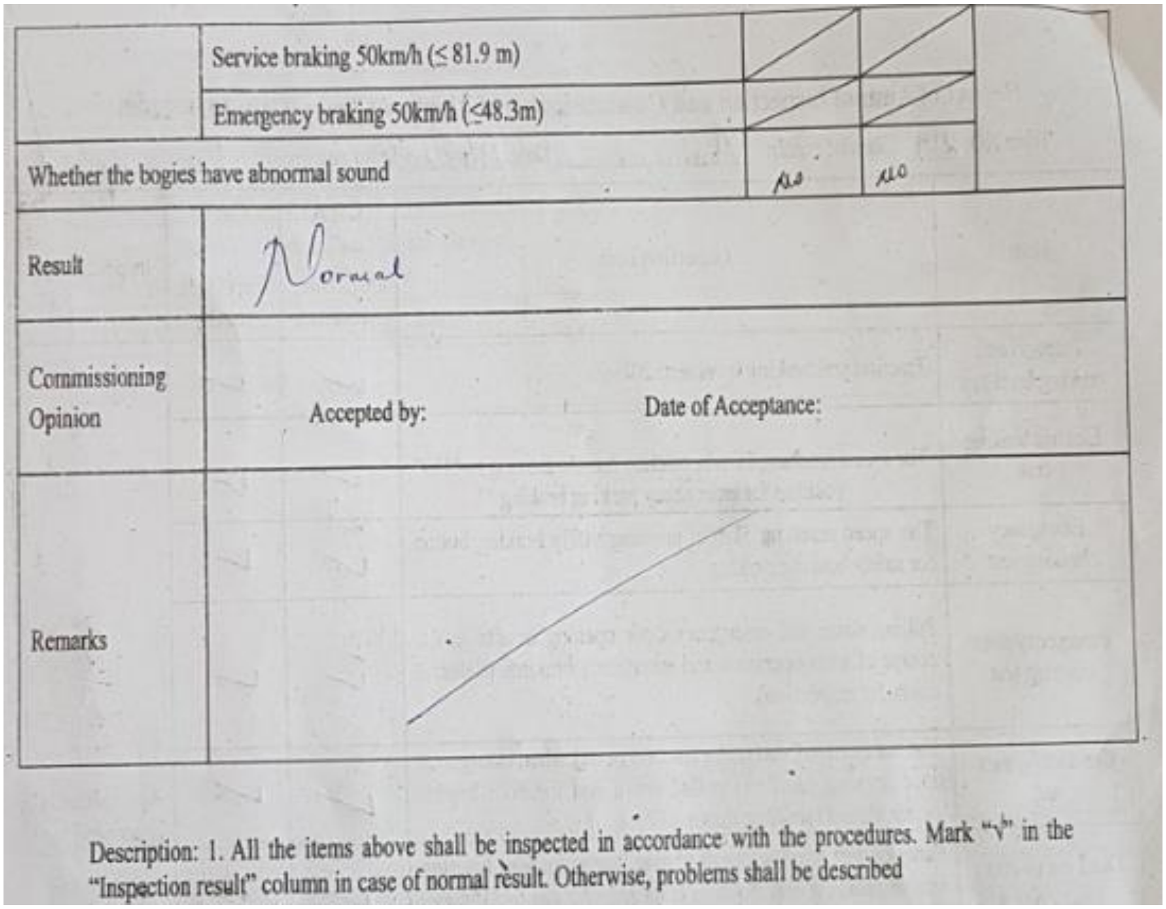
	d operation of air conditioners	Cleaning of fresh air filter.	✓	/	✓	Fekadu	Wondimu
		Washing of air conditioner units	✓	/	✓		
		Inspection of the inside of condensation cavity and of condensation fans	✓	/	✓		
		Inspection of cooling pipe, peep glass and electromagnetic valve	✓	/	✓		
		Inspection of equipment in the blower cavity	✓	/	✓		
		Inspection of roof exhaust discharger	✓	/	✓		
		Inspection of fastener and electric wirings	✓	/	✓		
		Inspection of dampers (in even-numbered years)	✓	/	✓		
		Inspection of cover plates and other parts	✓	/	✓		
15	Live works	Operation area (car number)	Car A	Car B	Car C	Shimet	Abebaye
		Inspection of train activation and emergency ventilation function.	✓	/	✓		
		Inspection of ventilation and cooling function of air conditioners.	✓	/	✓		
		Inspection of door opening and closing function	✓	/	✓		
		Inspection of anti-pinch and re-closing function	✓	/	✓		
		Inspection of door isolation function	✓	/	✓		
		Inspection of emergency door opening device function	✓	/	✓		
16	Pantograph operation	Inspection area		Car B		Fekadu	Wondimu
		Inspection of appearance and fasteners		✓			
		Inspection of pantograph head and carbon contact strip		✓			
		Inspection of control box and electrical connection		✓			
		Cleaning of arresters and isolators		✓			
		Inspection of balance of pantograph head		✓			
		Lubrication of moving part		✓			
		Insulation test of arrester		✓			
		Inspection of driving equipment and other components		✓			
17	Functional inspection	Inspection area	Car A	/	Car C	Abebaye	Wondimu
		Inspection of emergency lighting function	✓	/	✓		
		Inspection of broadcasting function	✓	/	✓		
		Inspection of traction/braking control function	✓	/	✓		
		Functional inspection of sanding device	✓	/	✓		
		Light test, inspection of windshield wiper, HMI and other components	✓	/	✓		
18	Blowing works			✓		Fekadu	Wondimu



Report of Annual Inspection and Commissioning of Light-rail Train (Cars 101#-220#)

Train NO: 219 Class of repair: Annual Date: 13/03/20 Team and group: Planning

Item	Inspection item	Car A Inspection results	Car C Inspection results	Inspected by:
Traction and braking level test	Traction and braking level test: 20km/h	✓	✓	
Electric braking test	The speed reaching 5km/h, traction handle moving to "EB" position for emergency parking braking	✓	✓	
Emergency braking test	The speed reaching 5km/h, pressing safety braking button for safety braking parking	✓	✓	
Emergency door opening test	Pulling down the emergency door opening handle in the course of train operation and emergency braking. (Select 2 doors for inspection).	✓	✓	
Car door bypass test	The train can still run under traction power when emergency door opening handle is pulled down and the door bypass switch closed (shutting down ATP)	✓	✓	Automatically controlled by:
Dead man button function test	Function test of releasing dead man button for 60s, function test of pressing and holding dead man button for 15s and emergency braking	✓	✓	
Dead man button bypass function	Close dead man button bypass, release the dead man button and train can operate under normal traction	✓	✓	Mutually controlled by:
Standby mode function	Inspect standby mode function, switch off the VCU power supply of Car A on both sides and switch to standby mode (speed limit: 30km/h)	✓	✓	
Car wash mode	Select car wash mode on IDU screen (speed limit: 3km/h)	✓	✓	
Emergency rescue function	Turn on the emergency rescue switch and the train can operate under normal traction (two trains are coupled)	/	/	
Wheel diameter calibration	Carry out one braking test and traction calibration after completing modification of wheel diameter	/	/	
Braking test	Service braking 30km/h (≤ 33.6 m)	29.03	30.78	
	Emergency braking 30km/h (≤ 19.9 m)	19.01	17.49	



	Service braking 50km/h (≤ 81.9 m)			
	Emergency braking 50km/h (≤48.3m)			
Whether the bogies have abnormal sound		no	no	
Result	Normal			
Commissioning Opinion	Accepted by: Date of Acceptance:			
Remarks				

Description: 1. All the items above shall be inspected in accordance with the procedures. Mark "√" in the "Inspection result" column in case of normal result. Otherwise, problems shall be described