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AFRICAN RAILWAY CENTRE OF EXCELLENCE

Impacts of rolling stock maintenance practices on Light Rail Transit operational performance

By

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A Thesis Presented to Addis Ababa University Addis Ababa Institute of Technology in Partial Fulfilment of the requirements for the Degree Master of Science in Railway Engineering (Rolling Stock)

Advisor: Dr. Bikila Teklu

October 2021

Declaration

I, the undersigned, declare that this thesis work is my original work, has not been presented for a degree in this or any other universities, and all sources of materials used for the thesis work have been fully acknowledged.

ISHIMWE Pascasie ____________________

Student's Name Signature

Date of submission: 12/09/2021

Place: Addis Ababa

The undersigned have examined the thesis entitled **Impacts of rolling stock maintenance practices on Light Rail Transit operational performance** presented by ISHIMWE Pascasie, a candidate for the Degree of Master of Science in Railway Engineering (Rolling stock) and hereby certify that it is worthy of acceptance.

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ABSTRACT

Addis Ababa population has rapidly grown and as the population grew, traffic increased with associated problems such as traffic jam, pollution and Due to the economic growth, there is increasing transport demand and growing mobility needs of people but there is Lack of transport infrastructure (limited connectivity).

Thus, long queues for very long time particularly at peak hours are getting additional rife drawback that affects operation time, thence reliability of railway operation system. In fact, delays in railway networks causes drawback in daily operation and result for reduced reliability, availability.

The general objective of this research was to study the impacts of rolling stock maintenance practices on Light Rail Transit operational performance while had to be delimited to the Light rail as one of transportation means in Ethiopia especially Addis Ababa, in Addis Ababa Light Rail Transit North South Line.

Research type used is qualitative one and collection of data methods are both primary and secondary data in order to acquire good results for the study. Data were analysed using Microsoft excel 2013 for all four years; from 2015 to 2019.

The calculated operational availability shows that it is higher than 99.8% which is showing that even if there are failures they didn’t have big bad impact on the operation as many of them few caused trip cancellation but replaced by the standby trains to continue the cancelled trip for the other train, failures occurred did take short time to be repaired as it is said by the respondents.

As the transportation sector continue to be more effective, among others this is railway transportation one in which maintenance has impact, types of maintenance for rolling stock are preventive maintenance and corrective maintenance or breakdown maintenance which have impact on LRT operation depending on how they are practiced. Lack of enough machineries and spare parts in the workshop causes the low availability of trains, even if sometimes corrective maintenance causes train delay and cancellation, the availability is still high to conclude that maintenance has to continue be implemented in railway transportation.

Finally, in all services, being punctual and reliable is a key to success, Data which will be produced from this study will be fruitful to AALRT and to the passengers and be productive to the country as a well and act as reference for future work.

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Glossary of Terms / List of Abbreviations

Term	**Explanation / Meaning / Definition**
LRT	Light Rail Transit
AALRT	Addis Ababa Light Rail Transit
RAMS	Reliability, Availability, Maintainability and Safety
O-D	Origin – Destination
ERC	Ethiopian Rail Corporation

NS Line	North south Line
EW Line	East -West Line
ANP	Analytic Network Process
PM	Preventive Maintenance
CM	Corrective Maintenance
APTA	The American Public Transportation Association
PdM	predictive maintenance
MU	Multiple Units
LCCA	Life Cycle Cost Analysis
MTBF	mean time between failure
MTTR	Mean Time To Restore

1 Introduction

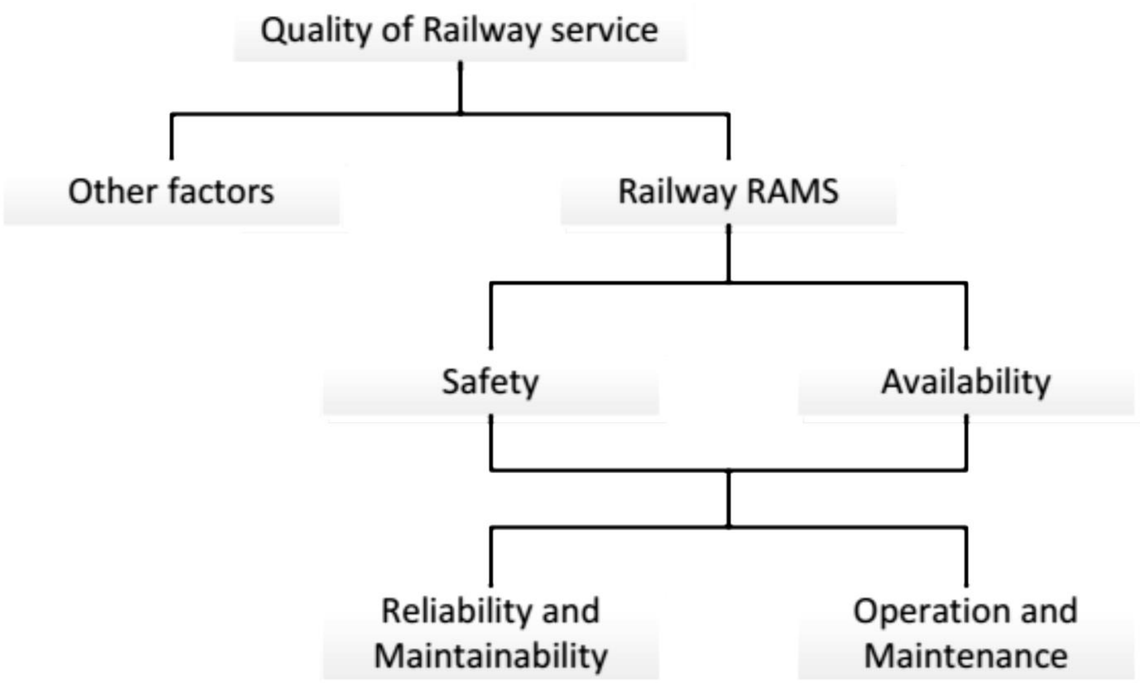
The introduction chapter begins with the background to the study, looking generally at maintenance as a support function in railway transportation and other modes of transportation related to their capacity and satisfaction to their customers. Further, the problem statement highlights and take into account the impact of maintenance in the operation processes of an organization. Research questions are also presented. Some limitations with regard to this study are also stated.

Punctuality and reliability of public (rail) transport are key components of quality of service and passenger satisfaction (Alex Landex, Anders H. Kaas & Sten Hansen, 2006), unreliable service means that customers are not satisfied. Punctuality is a result of a reliable rolling stock; to be punctual, a given train set has to be reliable according to its maintainability and availability to give a safe service to customers.

In the daily operation of a given railway company, if there is any kind of delays in the network, that is the major problem which has to be avoided taking different measures. Therefore, consideration to transit value and efficiency in general and reliability in particular has to be increased. For railway services, reliability can be defined as the continuity of correct service plus the ability to complete the entire process of planned OD (origin – destination) in expected transport time.

Refer from the passenger’s point of view, the reliability can be containing the closely related concept of punctuality, punctuality relates to the deviation from the scheduled arrival and departure times; without service quality.

It is well known that Service quality is the result of the comparison that customers make between their expectations about a service and their insight of the way the service has been performed (Hamed. F. Hamed Omar, Dr. Kamarudin Bin Saadan, Prof. Kamaruzziman Bin Seman, 2015). it depends on RAMS (Reliability, Availability, Maintainability and Safety) and other minor factors.



(Applications, 1999)

Figure 1: factors contributing to the quality of a railway service

Even if all these elements of RAMS are important in the operation of physical railway possessions, this research will emphasis on the Availability of railway operation mainly on rolling stock maintenance as studying the impact of its maintenance's practices on the operational performance.

1.1 Background

Addis Ababa is the capital city of Ethiopia founded in 1887 (Preceup, 1999), and has expanded rapidly and now is among the ten largest cities in Sub – Saharan Africa; its Population size is above 3.5 million with annual growth rate of above 3.8%, it serves as a transport hub of the nation on average 6.3 million trips per day are generated with expenditure of 10% on transport (Tolon, 2008). Its population has rapidly grown and as the population grew, traffic increased with associated problems such as traffic jam, pollution and accident because, it has diverse Transport problems like aged Fleet, chaotic movement, unacceptable emission, unsafe, Hazardous to life and property and weak traffic management system and because of this there is a wide gap between demand and supply; Due to the economic growth there is increasing transport demand and growing mobility needs of people but there is Lack of transport infrastructure (limited connectivity). In order to solve such a problem modern and reliable railway system is needed to sustain the economic growth momentum of the country by supporting the demand of passenger mobility. So, ERC (Ethiopian Rail Corporation) sought an effective solution in the form of non-polluting rail-based mass transit system with Capacity, cost effective plus good Impact on population, it is safe compared to the other modes of transportation, reliable and comfortable plus it is environmentally friendly and Efficient, attractive ((CPI), 2016).

1.2 Problem statement

The railway transportation can be said to be both wealth and creation of jobs (Aldagheiri, 2010); therefore, railway authority are fighting how they can increasingly study how they can maintain using developed methods in order to provide high quality service compared to the other modes of transport.

To achieve this, they make sure on different ways on how they can make this mode of transport competitive even if the cost of maintenance can't cease to be increasing. Hence, it has become authoritative to make the evaluation of current maintenance ways which are being used according to RAMS, and key performance indicators to support service needs, correct service can be given to the reliability as its definition (S. M. Famurewa, Mathias Asplund, Matti Rantatalo, Uday Kumar, n.d.).

Like it appears in national capital, LRT becomes morel used increasingly attributable to the very fact that population increment quicker than the transport facility. Thus, long queues for very long time particularly at peak hours are getting additional rife drawback that affects operation time, thence dependability of railway operation system. The matter is lack of dependability; reliability that result into delays and lack of timing.

In fact, delays in railway networks causes drawback in daily operation and result for reduced reliability, availability and of the railway operation system. Then a model with associate aim of minimizing average rider period, waiting time and providing variety of trains needed within the line (Konig, 2020). Therefore, the aim of studying the impact maintenance of rolling stock can cause to the Light Rail operation.

1.3 Research questions

The research presented in this thesis proposal will explore the following questions:

1. What are the types of maintenance applied at AALRT rolling stock workshop?
2. What are the influences of not having all maintenance machines in the workshop?
3. What is the effect of maintenance practices to the operation performance?

1.4 Objectives

1.4.1 General objectives

The general objective of this research is to study Impacts of rolling stock maintenance practices on Light Rail Transit operational performance.

1.4.2 Specific objectives

- To investigate rolling stock maintenance practices of the AALRT
- To study the effect current rolling stock maintenance practices have on train availability and customer satisfaction
- To identify and recommend countermeasures related to rolling stock maintenance practices that would help improve the operational performance of the AALRT.

1.5 Scope

The study will be delimited to the Light rail as one of transportation means in Ethiopia especially is Addis Ababa, where it is serving and the way travellers are being served punctually and reliably but because of duel time of trains at some stations and maintenance it causes increase of passengers waiting and cause overcrowding which results into the unsatisfaction, so the scope is about studying the impact of rolling stock maintenance on LRT operational performance in AARLT NS(North south) Line; from Kality to Menelik square based on train door maintenance using literatures, data collection in analysing them and come out with results and recommendations. As humans have a limited perception and capability to process information, the number of indicators one person can monitor is limited. Therefore, the research also includes data aggregation, to reduce the number of indicators, with minimum loss of information. Aggregation also facilitates comparison, as the output is an overall indicator or index.

1.6 Limitation

The research is limited to the rolling stock as of train door; one of components within the area of operation, i.e. design, construction and reinvestment are not considered. Aspects like infrastructures, power supply and climate variations are not considered. The case studies are limited to certain railway lines, with the primary aim of verifying the methods; i.e. the resulting performance of the rail lines is primarily used for discussion purposes.

The thesis will mainly be focused on quantitative assessment of the reliability and punctuality of AALRT operation based on rolling stock maintenance not qualitative method. the analysis will be done on the line segment of North-South line thus, East -West line will not be considered.

1.7 Significance of the study

- In all services, being punctual and reliable is a key to success.
- To get the study be valuable, it will create the knowledge of knowing how to overcome a challenge which can make an LRT fail because of low quality service.
- Data which will be produced from this study will be fruitful to AALRT and to the passengers and be productive to the country as a well.
- It will act as reference for future work

1.8 Thesis disposition

This study will be separated in the parts of Introduction, Methodology, Theoretical framework, and the Empirical findings. This is followed by the Analysis, Results and Conclusions which is a normal in writing a thesis. *Figure 1.1* below describes the disposition of this thesis.

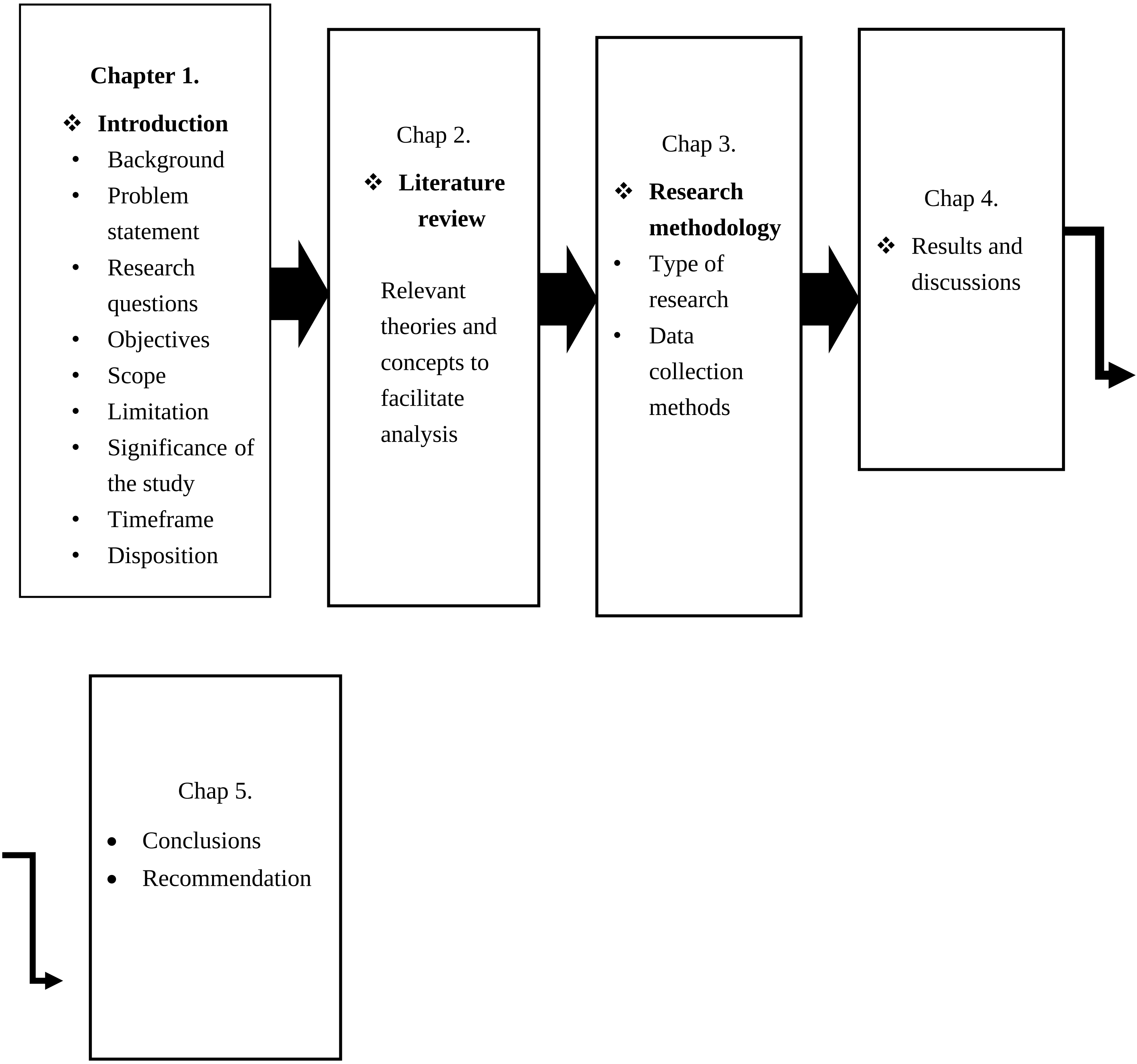


Figure 2: Thesis disposition

2 Literature review

The presented in this chapter are the necessary theories that are relevant for this study. It starts with describing Maintenance and its impact followed by the relationship between Maintenance and operation; rolling stock Maintenance; maintenance and performance. Also described in this chapter is the Maintenance Organization; Life Cycle Cost Analysis; as well as Maintenance cost. This is in view to increase the reader's understanding of the study.

There are many studies on railway maintenance and among them many emphasis on infrastructure maintenance and its operation (Stenstr¨om, 2014), Christer Stenström said that maintenance planning and optimisation of preventive maintenance can be made more effective, which can decrease interruptions of train operation, reduce costs and ensure safety. Also, that Railway performance and capacity can be enhanced by: expanding infrastructure; introducing better technology; and improving the efficiency and effectiveness of operation and maintenance.

Tomas Liden in his journal (Lidén, 2015) said that Railway infrastructure maintenance consumes very large budgets, is complicated to organize and has numerous challenging planning problems. Specifically, the coordination with train traffic operation is of crucial importance. Despite this, little work has been conducted in the operations research area regarding infrastructure maintenance as compared to train traffic operations

Sometimes it can be difficult to decide on which type of maintenance to use to make your equipment more effective that is why (Yung-Hsiang Cheng a,n, Hou-LeiTsao b, 2010) Yung-Hsiang Cheng and Hou-LeiTsao, their purpose was to permit an approach for selecting a maintenance approach for rolling stock and finding probable spare parts' sizes and replacement interludes for the components of rolling stock using an analytic network process (ANP) technique for the strategy evaluation, because ANP considers the important interactions among evaluation factors.

The ANP's result decides upon a proper rolling stock maintenance strategy formed by various combinations of preventive maintenance (PM) and corrective maintenance (CM). The ratio PM/CM, obtained by ANP, can help to predict spare parts' quantities of the components of rolling stock. The empirical result also indicated that preventive maintenance should be much more valued than corrective maintenance. They also concluded that safety is the most crucial factor for the selection of a rolling stock maintenance strategy.

P.D.F. Conradie and N.F. Treurnich in their Proceedings (P.D.F. Conradie 1, N.F. Treurnich 2, 2012), said that Rolling stock is maintained according to maintenance plans with a major goal being the prevention of in-service failures, but due to the nature of the equipment not all failures can be prevented. In-service failures normally result in train delays or the cancellations of trains not only disrupting commuter services but also causing financial losses.

A rolling stock failure may cause delays and disruptions to transport services or even result in catastrophic derailment accidents (Fateme Dinmohammadi1 Babakalli Alkali1 Mahmood Shafiee2 Christophe Be´renguer3,4 Ashraf Labib5, 2016).
N. Wilson, C.J. Fourie & R. Delmistro said in (N. Wilson1#, C.J. Fourie1* & R. Delmistro2, 2016) said that railway systems can pose complex problems for the scheduling and operation of trains. A passenger rail service's first priority is to provide a punctual and safe transport service to its customers. But doing so is a major challenge for rail network operators, as disruptions are inevitable, especially in densely-populated networks. Disruptions can be caused not only by infrastructure or rolling stock breakdowns, but also by maintenance activities, new rolling stock, or new train services. Managing these disruptions and predicting the extent of its effects is a crucial part of rail network operation.

2.1 Light rail transit

Light rail transit is a mode of urban transportation that uses predominantly reserved, but not necessarily grade-separated, rights-of-way. Electrically propelled vehicles operate singly or in trains. Light rail transit provides a wide range of passenger capacities and performance characteristics at moderate costs (Loins J. GAMBACCINI, WAYNE Mint, THOMAS B. DERN, May 8-11, 1988). The American Public Transportation Association (APTA), in its Glossary of Transit Terminology, defines light rail as a mode of transit service (also called streetcar, tramway, or trolley) operating passenger rail cars singly (or in short, usually two car or three-car, trains) on fixed rails in right of- way that is often separated from other traffic for part or much of the way. Light rail vehicles are typically driven electrically with power being drawn from an overhead electric line via a trolley [pole] or a pantograph; driven by an operator on board the vehicle; and may have either high platform loading or low-level boarding using steps” .

Depending on local needs, city size, low availability, and financing Capability, LRT systems can be developed to serve three principal classes of urban travel:

- Line haul transit from city or suburban residential areas to central business districts and other employment zones;
- Feeder service to rapid transit or commuter rail; and
- Local area transit within a portion of an urbanized area or activity centre, including central business districts distribution (Loins J. GAMBACCINI, WAYNE Mint, THOMAS B. DERN, May 8-11, 1988).

An important factor crucial to LRT is the train operator. Unlike rail rapid transit, which can travel unattended under automatic train operation, safe, high-quality LRT operation relies on a human operator as a key element. The reason that the operator is so important is because the train tracks often share the streets with automobiles, other vehicles, and pedestrians. If trains were fully automated on roads, nobody would be there to stop the train if a car pulled in front of it. Light rail trains are actually very securely built for passenger safety, and to reduce damage from impacts with cars.

About its power sources, overhead lines supply electricity to the vast majority of light rail systems. This avoids the danger of passengers stepping on an electrified third rail. The Docklands Light Railway uses an inverted third rail for its electrical power, which allows the electrified rail to be covered and the power drawn from the underside. Trams in Bordeaux, France, use a special third-rail configuration where the power is only switched on beneath the trams, making it safe on city streets (Anon., n.d.).

2.2 Rolling stock

Railway rolling stock comes in a variety of forms; passenger types and freight ones. The most common types of passenger services railway rolling stock are described below:

Locomotives; The sole purpose of locomotives is to pull or push trains; they carry no passengers or freight. Locomotives are distinguished by the prime mover or energy source used to propel them. Modern locomotives are either electric or diesel-electric. Electric locomotives draw power from an overhead wire or third rail, and use electric motors to turn the wheels. The prime-mover is a transformer on the locomotive that converts the overhead electricity to the type of electricity needed in electric traction motors that turn the wheels. Instead of a transformer, diesel-electric locomotives use a diesel engine to drive an alternator and generate electricity that powers traction motors that turn the wheels. Some diesel locomotives use a hydraulic torque converter rather than electric motors—these are referred to as diesel-hydraulic locomotives. Older generation steam locomotives, powered by coal, oil, or wood, are now used only in tourist operations or for occasional work on smaller railways or in museums.

Passenger rolling stock; A Passenger Rolling Stock (known as a coach or carriage in the UK, and also known as a bogie in India) is a piece of railway rolling stock that is designed to carry passengers. “Multiple-unit” passenger rolling stock is an important category, with two basic types— electric multiple-units, and diesel multiple-units. The Multiple Units (MU) equipment has no locomotive; multiple cars can be connected and operated from a single location. Some multiple-unit cars have powered axles; the unpowered vehicle towed by a powered vehicle are called ‘trailer’ cars. Typically, the first car has a driver’s station and accommodates passengers. Multiple unit equipment is popular for many reasons.

- MU trains can respond to changes in demand levels because cars can be added to or dropped from a train.
- MU trains can be driven from either end so two person crews can quickly prepare for return trip, making MUs popular for commuter services.
- MU trains offer more passenger space per track length, since they operate without a locomotive.
- MUs distribute traction and braking power throughout the train, achieving higher power-to-weight ratios, and greater acceleration and braking rates. The MUs’ flexibility and design characteristics are also ideal for high-speed train services because higher power levels are needed to overcome aerodynamic drag (Bank, n.d.).

Freight rolling stock, Freight railways carry only goods as opposed to passengers’ ones. they'll include bulk materials, rail cum road container, special materials or freight in special wagons, general merchandise, autos, even every now and then animals. Normally a train is made with one or multiple locomotives with variety of wagons and moves as a unit from origin to destination (SUMANT CHAK, 2015).

2.2.1 Rolling stock components

A railway rolling stock is usually composed of two main parts, namely car body and bogie parts, each consisting of different components and each performing certain essential function(s).

– Door unit, the train doors are ‘‘opened and ‘‘closed’’ at each station to allow passengers to enter or leave the coach.

– Scroll compressor It is a certain type of compressor used for Heating ventilation and air conditioning and brake systems to compress air.

– Bogie It is a framework carrying either four or six wheels attached to the coaches it is of two types which are Motor bogie and Trailer bogie.

– Pantograph It is a device mounted on the roof of the train to collect electric current from overhead lines.

– Coupling system, A coupler is a device used for connecting rolling stocks in a train.

– Braking unit It is used in order to decrease velocity of trains, enable deceleration, control acceleration and
keep them fix when parked.

– Air spring suspension It gives a better ride and the pressure can be adjusted automatically to compensate for additions or reductions in passenger loads.

– Heating ventilation and air conditioning, it provides fluid air through the facility providing either hot or cool air dependent on the desired temperature.

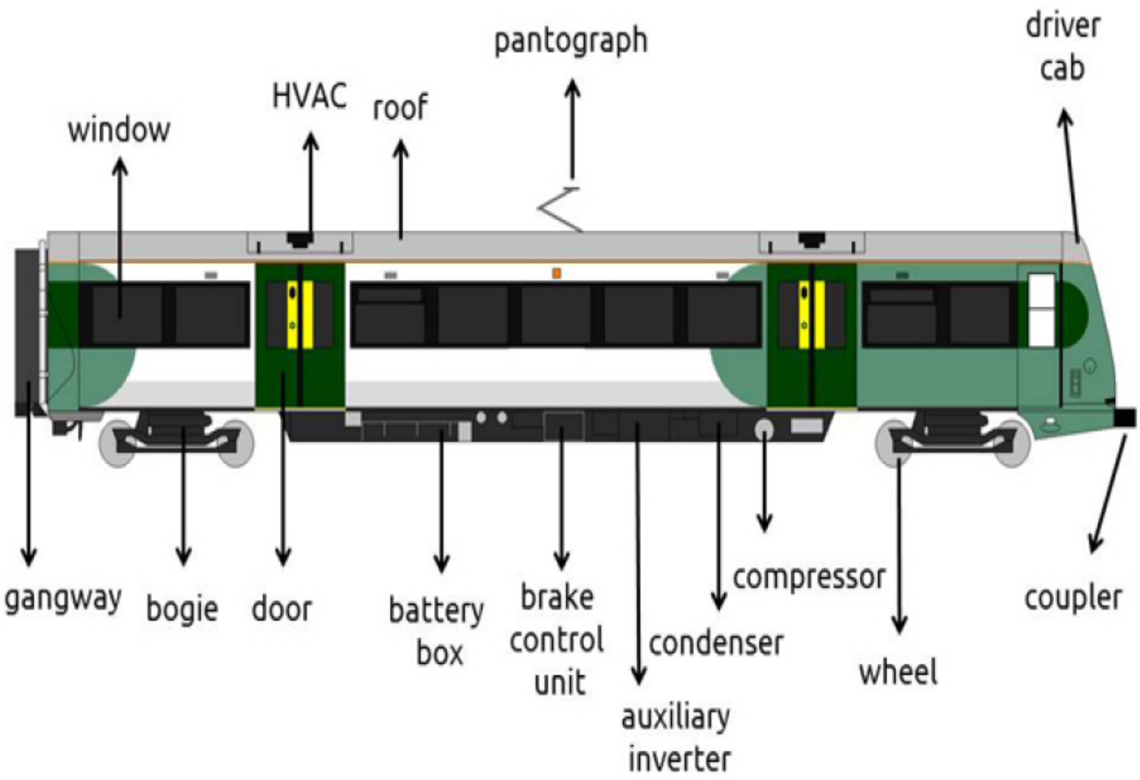


Figure 3: Rolling Stock Components (Bank, n.d.).

2.3 Maintenance

Maintenance and related terms are defined in the EN 13306:2001 standard

Maintenance is the combination of all technical, administrative and managerial actions during the life cycle of an item intended to hold it in, or reinstate it to, a state in which it can perform the required function. Observe that, according to this definition, maintenance is to assure the function of an item. Improving or changing the function of an item is not maintenance.

The scope of maintenance in a manufacturing environment is demonstrated in its frequent meanings. Maintenance includes engineering decisions and associated actions that are necessary for the optimization of detailed equipment capability, where capability is the ability to perform a specified function within a variety of performance levels that may tell to size, rate, quality, safety and responsiveness.

Kelly states that the objective of maintenance is to achieve the agreed output level and operating pattern at a minimum resource cost within the constraints of system condition and safety (John Kelly* and Ray Richardsont, 1988). The wanted production output is attained through high accessibility, which is influenced by equipment reliability, maintainability and maintenance supportability (EN 13306:2001). Finally, maintenance is also partially responsible for practical schemes' safety and for guaranteeing that the plant remains in respectable condition (J.K. Visser and M.W. Pretorius, 2003).

Maintenance must confirm the essential reliability, availability, efficiency and capability of the entire production system. It will confirm system life by keeping the equipment in respectable condition.

Usually, greatest maintenance professionals have combined numerous techniques, both quantitative and qualitative, in an effort to identify failure styles and mitigate stoppage in manufacturing facilities. But the increase of new linked technologies can enable machines to do these tasks for them, both maximizing the valuable life of machine mechanisms while still evading machine failure.

Nowadays, deprived maintenance policies can reduce a plant's general productive volume between 5 and 20 percent. Current studies also show that unintended stoppage prices industrial manufacturers an estimated $50 billion each year. It can be hard to regulate how frequently a machine would be taken down to be repaired as well as evaluate the dangers of lost production time against those of a likely failure. Traditionally, this dilemma forced greatest maintenance administrations into a trade-off condition wherever they had to select among maximizing the valuable life of a part at the risk of machine downtime, trying to maximize uptime through early replacement of potentially good parts, or, in some cases, using past knowledge to try to anticipate when Traditional components of a maintenance program often fall into four categories, each with its own series of challenges and benefits (figure 3):

Reactive maintenance

Planned maintenance

Proactive maintenance

Predictive maintenance

The fourth component, *predictive maintenance* (PdM), has become likely using smart, connected technologies that bond digital and physical possessions. While PdM is not a new idea, the enormous investments in technology typically needed to handle the massive capacities of data required often limited disposition to only the principal organizations. Today, the high accessibility and low cost of digital technologies, coupled with the rise of the digital supply network, have made it possible for PdM to scale on a broad level across facilities and organizations of all sizes.

Reactive maintenance

Reactive maintenance (also known as breakdown maintenance) denotes to repairs that are done when equipment has previously broken down, in order to reinstate the equipment to its usual working condition. In a purely reactive maintenance strategy, assets are fixed or replaced after they fail. In result, the policy looks rearward rather than onwards – 'after the event' maintenance. A purely reactive maintenance policy has the subsequent structures:

♦ maintenance prioritization is rule-based, for example on the severity of the significances of asset failure, but does not reflect the up-to-date risks of asset failure

♦ very high asset maintenance costs

♦ very high asset replacement costs

♦ very high significance costs due to, for example, pollution, flooding and service interruption, and fines from controllers for breaking environmental bounds or service marks

♦ takes much longer than proactive maintenance.

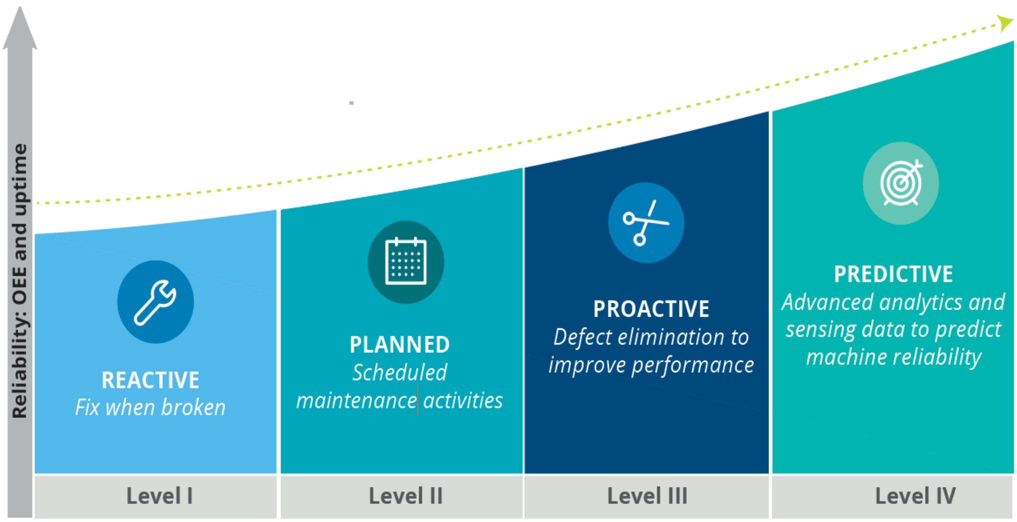


Figure 4: Maintenance strategy continuum

2.3.1 Maintenance and its impact

Maintenance is very important to make sure that plants or equipment are available, reliable, maintainable, and operable. Although this can be important some kinds of maintenance which is applied when equipment fail, can reduce the provision because it takes time to be repaired.

The net result sort of maintenance management is higher maintenance cost and lower availability of process machinery. Scheduling the repair provides the flexibility to reduce the repair time and associated labour costs. It also delivers the means of dropping the negative influence of expedited deliveries and missing production.

The problem with preventive or maintenance is that the mode of operation and system or plant-specific variables directly affect the traditional operating lifetime of machinery. The common premise of predictive maintenance is that regular monitoring of the mechanical condition of machine-trains will make sure the maximum interval between repair and minimize the amount and it’s the means of improving productivity, product quality, and overall effectiveness of manufacturing and production plants.

A predictive maintenance program can minimize unscheduled breakdowns of all mechanical equipment within the plant and make sure that repaired equipment is in acceptable mechanical condition. The program may identify machine-train problems before they become serious. Most mechanical problems are often minimized if they're detected and repaired early (Mobley, 2004).

2.3.2 Maintenance and operation

Operations and Maintenance are the choices and activities concerning the control and maintenance of stuff and equipment. These are comprehensive, but not partial to, the following: Activities attentive on scheduling, actions, and effort/systems control and optimization; and Act of routine, preventive, predictive, scheduled and unscheduled actions meant at preventing equipment failure or weakening with the goal of growing efficiency, reliability, and safety.

Operational Efficiency represents the life-cycle, cost-effective mix of preventive, predictive, and reliability-centred maintenance technologies, coupled with equipment calibration, tracking, and computerized maintenance management capabilities all targeting reliability, safety, occupant comfort, and system efficiency.

Operations

Administration – to make sure effective implementation and control of operation activities.

• Conduct of Operations – to make sure efficient, safe, and reliable process operations.

• Equipment Status Control – To remember of status of all equipment.

• Operator Knowledge and Performance – to make sure that operator knowledge and performance will support safe and reliable plant operation.

Maintenance

• Administration – To guarantee real application and control of maintenance actions.

• Work Control System – To control the act of maintenance in a well-organized and safe way such that economical, safe, and reliable plant operation is improved.

• Conduct of Maintenance – To conduct maintenance in a safe and well-organized way.

• Preventive Maintenance – To give to finest act and reliability of plant organisations and equipment.

• **Maintenance Procedures and Documentation** – To provide instructions, when suitable, for the performance of work and to guarantee that maintenance is done safely and professionally.

The necessity for maintenance is recognised on real or pending failure – rather, maintenance is accomplished to retain equipment and systems running capably for at least design life of the essential(s). As such, the everyday operation of a component is time-based purpose. in the figure 3 the Y axis represents the failure rate and the X axis is time. From its form, the curve can be separated into three discrete: infant mortality, useful life, and wear-out periods.

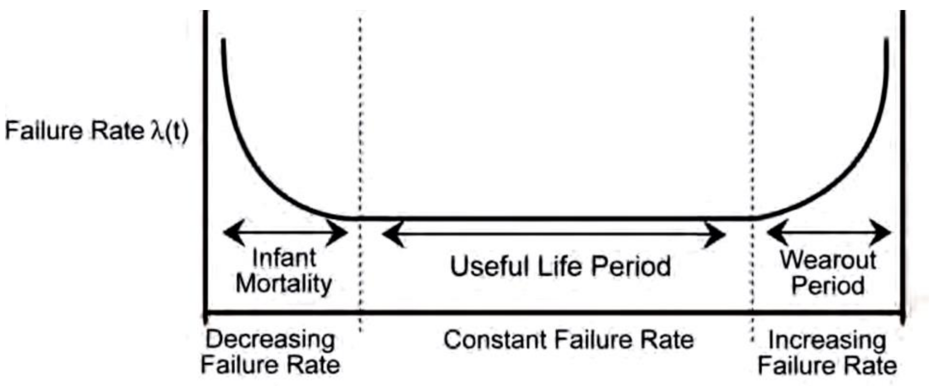


Figure 5: Component failure rate over time for component population

The initial infant mortality period of bathtub curve is characterized by high failure rate followed by a period of decreasing failure. Many of the failures associated with this region are linked to poor design, poor installation, or misapplication. The infant mortality period is followed by a nearly constant failure rate period known as useful life. There are many theories on why components fail in this region, most acknowledge that poor O&M often plays significant role. It is also generally agreed this period. The wear-out period is characterized by a rapid increasing failure rate with time. In most cases this period encompasses the normal distribution of design life failures.

The design life of most equipment requires periodic maintenance. Belts need adjustment, alignment needs to be maintained, proper lubrication on rotating equipment is required, and so on. In some cases, certain components need replacement, (e.g., a wheel bearing on a motor vehicle) to ensure the main piece of equipment (in this case a car) last for its design life. Anytime we fail to perform maintenance activities intended by the equipment's designer, we shorten the functioning life of the equipment. But what options do we have? Over the last 30 years, diverse methods to how maintenance can be achieved to guarantee equipment grasps or exceeds its design life have been established in the United States. In accumulation to waiting for a piece of equipment to flop (reactive maintenance), we can utilize preventive maintenance, predictive maintenance, or reliability centred maintenance (G. P. Sullivan(a), R. Pugh, A. P. Melendez, W. D. Hunt, 2010).

2.3.3 Maintenance and performance

From the perspective of the maintenance manager, maintenance resources are finite, and usually below the level they should be. Production stoppages, breakdowns, power stoppages, shortage in manpower, lack of materials (supply), demand (external) and others business factors, directly or indirectly affect the level of production.

In the past, operating ratios were considered to be adequate indicators of maintenance performance. In this context, most commonly used ratios include maintenance cost ratio to the plant area, maintenance cost ratio to the number of people directly employed, and maintenance cost ratio to the number of units produced. The limitation of these ratios is that they were dependent on each specific plant for which they were developed.

2.3.4 Maintenance organization

The mission of maintenance in a world-class organization is to achieve and sustain optimum availability even if too many maintenance organizations continue to pride themselves on how fast they can react to a catastrophic failure or production interruption rather than on their ability to prevent these interruptions. While few will admit their continued adherence to this breakdown mentality, most plants continue to operate in this mode. Contrary to popular belief, the role of the maintenance organization is to maintain plant equipment, not to repair it after a failure (Mobley, 2004).

Some of maintenance organization goals are listed below:

2.3.4.1 Optimum Availability

The production capacity of a plant is, in part, determined by the availability of production systems and their auxiliary equipment. The primary function of the maintenance organization is to ensure that all machinery, equipment, and systems within the plant are always on line and in good operating condition.

2.3.4.2 Optimum Operating Condition

Availability of critical process machinery is not enough to ensure acceptable plant performance levels. The maintenance organization has the responsibility to maintain all direct and indirect manufacturing machinery, equipment, and systems so that they will be continuously in optimum operating condition. Minor problems, no matter how slight, can result in poor product quality, reduce production speeds, or affect other factors that limit overall plant performance.

2.3.4.3 Maximum Utilization of Maintenance Resources

The maintenance organization controls a substantial part of the total operating budget in most plants. In addition to an appreciable percentage of the total plant labour budget, the maintenance manager, in many cases, controls the spare parts inventory, authorizes the use of outside contract labour, and requisitions millions of dollars in repair parts or replacement equipment. Therefore, one goal of the maintenance organization should be the effective use of these resources.

2.3.4.4 Optimum Equipment Life

One way to reduce maintenance cost is to extend the useful life of plant equipment. The maintenance organization should implement programs that will increase the useful life of all plant assets.

2.3.4.5 Minimum Spares Inventory

Reductions in spares inventory should be a major objective of the maintenance organization. However, the reduction cannot impair their ability to meet goals 1 through 4. With the predictive maintenance technologies that are available today, maintenance can anticipate the need for specific equipment or parts far enough in advance to purchase them on an as-needed basis.

2.3.4.6 Ability to React Quickly

Not all catastrophic failures can be avoided. Therefore, the maintenance organization must maintain the ability to react quickly to the unexpected failure.

The principal goal of the maintenance organization is always to improve the availability. This means that the machines / equipment must continue to operate as expected during planned operations. To succeed, the maintenance organization requires a clear vision and strategy with established procedures and goals. Here, Mikael Andersson, Project Manager at MaintMaster, gives some tips on how to build up your work through the European standard EN13306:2017 to ensure a stable and sustainable work approach to your maintenance organization.

Start by generating a clear set of goals to improve the operational reliability of a facility, i.e. to operate as expected during planned operations, the organization needs to develop a clear vision of what it wants to achieve with its maintenance and formulate a strategy for how to get there. A maintenance vision must obviously support the company's overall vision and long-term goals that the organization needs to actively work towards as a way of ensuring greater operational reliability. Strategy is a plan for how the organization is to achieve this vision, while the policy is a statement of intent and a guideline to regulate decisions and achieve the desired goals.

"One example of a maintenance strategy could be to achieve more effective production through preventive and condition-based maintenance. It is important that as part of your daily work you also focus on long-term factors such as root cause analyses in corrective maintenance to eventually increase the planning level, thereby ensuring cost effective maintenance.”

2.3.4.7 Evaluation of the maintenance organization

One means to quantify the upkeep philosophy in your plant is to analyse the upkeep tasks that have occurred over the past two to 3 years. Attention should be to the indices that outline management philosophy.one in all the simplest indices of management attitude and therefore the effectiveness of the upkeep function is that the quantity of production disruptions caused by maintenance-related complications. If production delays represent over 30% of total production hours, reactive or breakdown response is that the dominant management philosophy. To be competitive in today’s market, delays caused by maintenance-related problems should represent but 1% of the entire production hours (Mobley, 2004).

Another indicator of management effectiveness is that the amount of maintenance overtime required to take care of the plant. in a very breakdown maintenance environment, overtime cost may be a major negative cost. If your maintenance department’s overtime represents over 10% of the entire labour budget, you actually qualify as a breakdown operation.

Special projects and therefore the 1% of delays caused by machine failures will force some expenditure of overtime premiums, but these abnormal costs should be a tiny low percentage of the total labour costs as Manpower utilization is another key to management effectiveness. Evaluate the proportion of maintenance labour as compared with total available labour hours that are expended on the particular repairs and maintenance prevention tasks (Mobley, 2004).

Maintenance structure is presented here below:

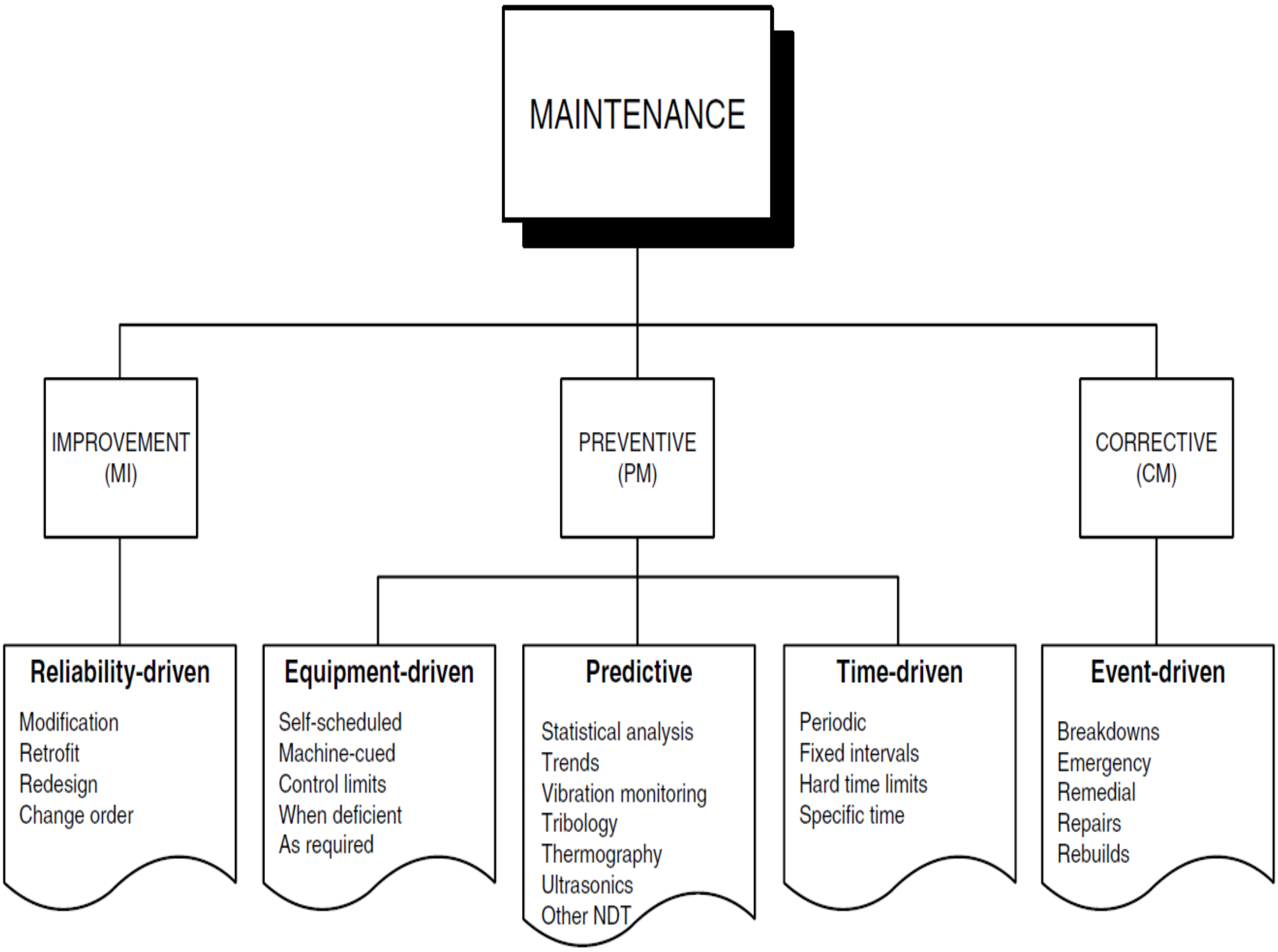


Figure 6: Structure of maintenance (Mobley, 2004).

2.3.5 Life Cycle Cost Analysis (LCCA)

Life-cycle analysis could be a method of determining the whole cost of a structure, product, or component over its expected useful life. The price of operating, maintaining, and using the item is added to the acquisition price. For items that last longer than a handful of years, this can be a more realistic way of evaluating cost than simply viewing the acquisition price (USDA Forest Service, 2013).

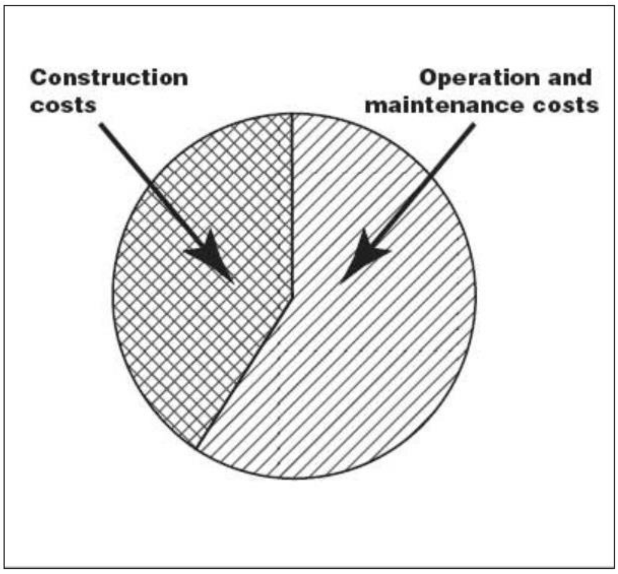


Figure 7: 1—Over 30 years, the cost of operation and maintenance for buildings is more than the initial construction cost.

As the chart below illustrates, over 30 years of a building's life, the present value of maintenance, operations, and utility costs is nearly as great as the initial project costs.

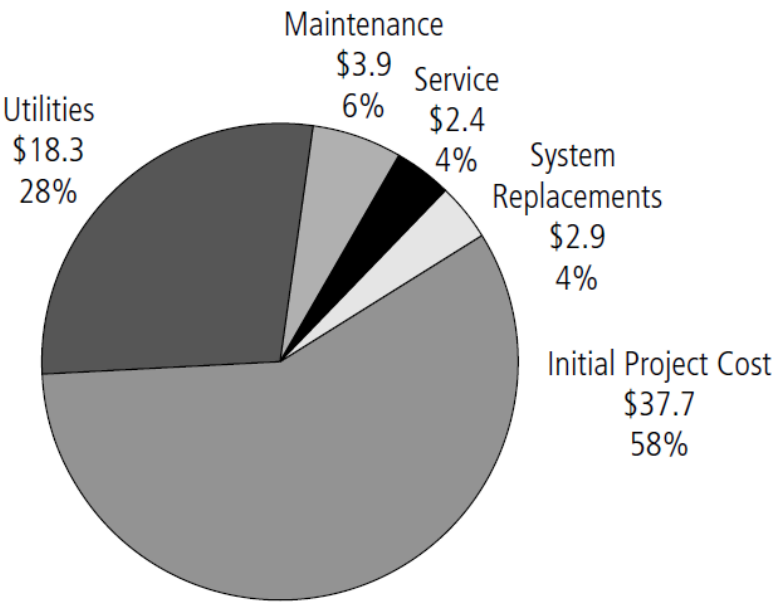


Figure 8: over 30 years of a building's life, the present value of maintenance, operations, and utility costs is nearly as great as the initial project costs.

2.3.6 Maintenance cost

Maintenance cost or maintenance related costs in general are usually divided into direct and indirect cost without putting maintenance savings and profit into consideration (Ingwald, 2009) include cost that are connected with in-house and out-house (outsourcing) maintenance activities. *Al-Najjar and Alsyouf* further refer to direct maintenance costs as costs associated directly to the maintenance activities, which include the internal costs that are required to carry out the maintenance functions e.g. labour, tools, spare parts, training etc. and other maintenance expenses that are directly related.

Indirect costs on the other hand includes all costs that are indirectly related or associated with maintenance, which can be attributed to issues like profit loss due to production losses during planned and unplanned stoppages, customer losses, reputation and consequently loss of market share as a result of maintenance related factors. In addition, indirect maintenance costs includes performance inefficiency costs due to short stoppages and reduced speed, poor quality cost due to maintenance deficiency, idle fixed cost resources e.g. idle machine and idle worker costs during breakdowns, delivery delays penalty cost as a result of unplanned down time, assurance claim from dissatisfied customers as a result of maintenance related poor quality (Damjan Maletic, Matjaz Maletic, Basim Al-Najjar, Bostjan Gomiscek, 2014).

2.3.7 Maintenance Function Deployment

Appropriate maintenance of plant equipment and machineries significantly reduces overall operating cost of manufacturing. Additionally, it contributes to customer satisfaction through desired quality and on time delivery. Deterioration and failure of systems result to high costs, due to production losses and delays, unplanned intervention on the system and safety hazards (Rahul Baidya1 & Prasanta Kumar Dey1 & Sadhan Kumar Ghosh1 &Konstantinos Petridis2, 2016). From that it is good to have appropriate maintenance strategies to prevent failures.

The importance of preventive and planned corrective maintenance is that these two systems are primarily responsible for moving organizations from a reactive mode to a proactive mode. In order to address preventive maintenance, though, we have to spend time focusing on preventive maintenance. In order to address corrective maintenance, we likewise have to focus our attention on corrective maintenance. At the same time, we must also respond to emergency work. Preventive, planned corrective and emergency work has an egalitarian relationship; they pull equally against our resources and we act in kind by trying to cover all the bases while in a crisis mode. We must, however, be prepared to and structured to address all three at the same time.

Consider your structure. Complete this simple paper-work exercise with your maintenance supervisors; answer these three questions:

•Are we completing all PMs on time, every time?

•Are we responding to all emergency work requests without pulling someone from scheduled maintenance or deferring preventive maintenance?

•Are we completing every corrective maintenance or routine maintenance work order within 6 months?

If you cannot answer yes to each of these questions, maybe you need to re-organize to bring your reactive, preventive, and corrective work under control through a different maintenance structure. If so, I suggest that you Do It Now (John L. Ross, 2019)!

2.3.7.1 Useful key performance indicators

For the effective management of maintenance operations, it is vital to measure what we do, how much we do and how well we do it. For this to be possible, you will need to identify a few key performance indicators. The standard identifies 71 key performance indicators that are defined in three various categories: financial, technical and organizational indicators.

Once you have determined the key performance indicators you want to apply, it is important to use the indicators that adds value to maintenance activities and demonstrate progress over time. Choose an overall key performance indicator for each of the following areas, financial, technical and organizational, and indicators that all staff can relate to. Then expand the level of key performance indicators with time when you have achieved a solid foundation in your organization. Implement European standards in the maintenance system. Once you have decided on your goals, strategies and work approaches, it is important that the structure of the maintenance system follows the same common thread.

2.3.8 Types of maintenance used in railway industries

Maintenance activities can be grouped and categorized in deferent ways. The classical way is to distinguish between preventive and corrective maintenance, but as will be shown, this distinction can be hard to make and is somewhat less appropriate when discussing planning problems. Maintenance organizations often make a more practically oriented categorization into diagnostic and restoring actions.

2.3.8.1 Preventive vs corrective.

The European standard EN 13306 for maintenance terminology divide maintenance into the term's preventive and corrective maintenance, for work taking place before and after a fault has been detected. Preventive maintenance is further divided into condition-based and predetermined maintenance, where the former uses measurements and inspections to determine when actions are needed and the latter uses fixed maintenance intervals/schedules. In addition to these categories Trafikverket uses the term operational maintenance1 for activities that handle normal operational conditions, although these activities are sometimes classified as corrective maintenance.

This categorization is mostly used for contractual, budgetary and follow up reasons, but unfortunately the distinction can be somewhat arbitrary.

Some examples of typical activities are as follows:

- ❖ Preventive
- Condition-based: measurements and inspection, grinding, tamping etc.
- ❖ Predetermined: exchange of components such as light bulbs, batteries, signalling relays etc.
- ❖ Corrective: fixing short circuits, repairing broken fasteners, welding, work after accidents etc.
- ❖ Operational: snow removal, handling slippery rail etc.

2.3.9 Rolling stock maintenance

Rolling stock is the greatest maintenance rigorous part of the railway system and therefore, the most susceptible if maintenance is mistreated. Maintenance of the rolling stock is a result of its wear and tear, technical defects and accidents along the railway line and within the workshop.

A stalled train will block a railway immediately and will reduce a timetable on an intensively used system to an unmanageable shamble for the remainder of the day. Reliability is the key to successful railway operation and maintenance should be the number one priority to ensure reliability is on-going. The objective of maintaining the rolling stock is to ensure that the asset continues to function and meet the required quality standards throughout the anticipated life or even beyond the original design life.

Subject to usage, environment and aging, conditions of components deteriorate with time. Regular maintenance has to be carried out to restore their conditions and prevent them from failure. However, the decisions on the suitable length of maintenance intervals often lead railway operators to the dilemma of minimising both risk of failure and operation cost, Maintenance is essential to restore system conditions and keep the operation free of disruption due to outage. (T.K. Ho1, Y.L. Chi1, L. Ferreira2, K.K. Leung3 and L.K. Siu4, 2006). The importance of the maintenance purposes and maintenance administration has greatly grown in all sectors of manufacturing and service organizations. The principal reason for this growth is the continuous expansion in the capital inventory, the necessities for the running of schemes and the subcontracting of maintenance (O.O. Asekun1 & C.J. Fourie2∗, May 2015 Vol).

Rolling stock has a huge consequence on the service level of the system because the service level of the rail system is directly proportional to the safety and comfort of the passengers. In order to achieve the required service level, the quality of the rolling stock performance needs to be improved continually and this can be achieved with proper maintenance. A train is also classified as rolling stock and it comprises of several rail vehicles connected in series. The combination of these vehicles is complex, but can be redistributed and reconfigured to include embedded systems, which are combined together to provide a high-quality transportation service. Rolling stock maintenance has been categorized generally into Corrective maintenance (CM) and preventive maintenance.

Nevertheless, these maintenance strategies have been found to be ineffective. Majority of maintenance activities in rolling stock companies are directed towards preventive maintenance, which often leads to incorrect maintenance work, frequent down time, unnecessary maintenance tasks and often reverts to CM or breakdown maintenance. Given this scenario, rolling stock industries need to be able to manage these strategies effectively by creating efficient schedules to perform the selected maintenance strategy.

Historically, the rail industry’s maintenance regime is to service trains on a time or mileage basis. Though this approach has been used successfully for many years, it does not take account of whether parts actually need replacing. Inspection can only take place when trains aren’t running, and maintenance actions require rolling stock to be taken out of service, or lines to be closed for extended periods.

2.3.10 Railway operations and performance

Railway has long been one of the most important modes of public transportation. It serves as an important means for transporting both passengers and freight. Ever since its first appearance in the 1800s, railways worldwide have prospered with a lot of innovations and engineering breakthroughs.

Apart from being a vital part of the public transport around the world, railways also help support economic growth, manage road congestion, and combat climate change. With its connectivity and universal access, railways serve not only as a means of transportation, but also as a modern national identity for customers (Fiona Preston and Peter Jones, 2012).

With rapid economic growth and social development, there has been a high demand for more train paths and services, in developing strategies for railway performance improvement, the first step is to adopt an effective approach for the evaluation of performance. There have been a number of methods applied for performance evaluation in the railway industry, such as the measurement of effectiveness and efficiency, customer satisfaction and service quality measures.

The usual way railways manage their performance is through carefully designed plans of operations, followed by real-time policies to manage disturbances. Railway planning involves a number of steps from prediction of traffic demand to the control of daily operations. In this process, trade-offs are required to balance between traffic demand and provided services, to achieve both high customer satisfaction and smooth operations.

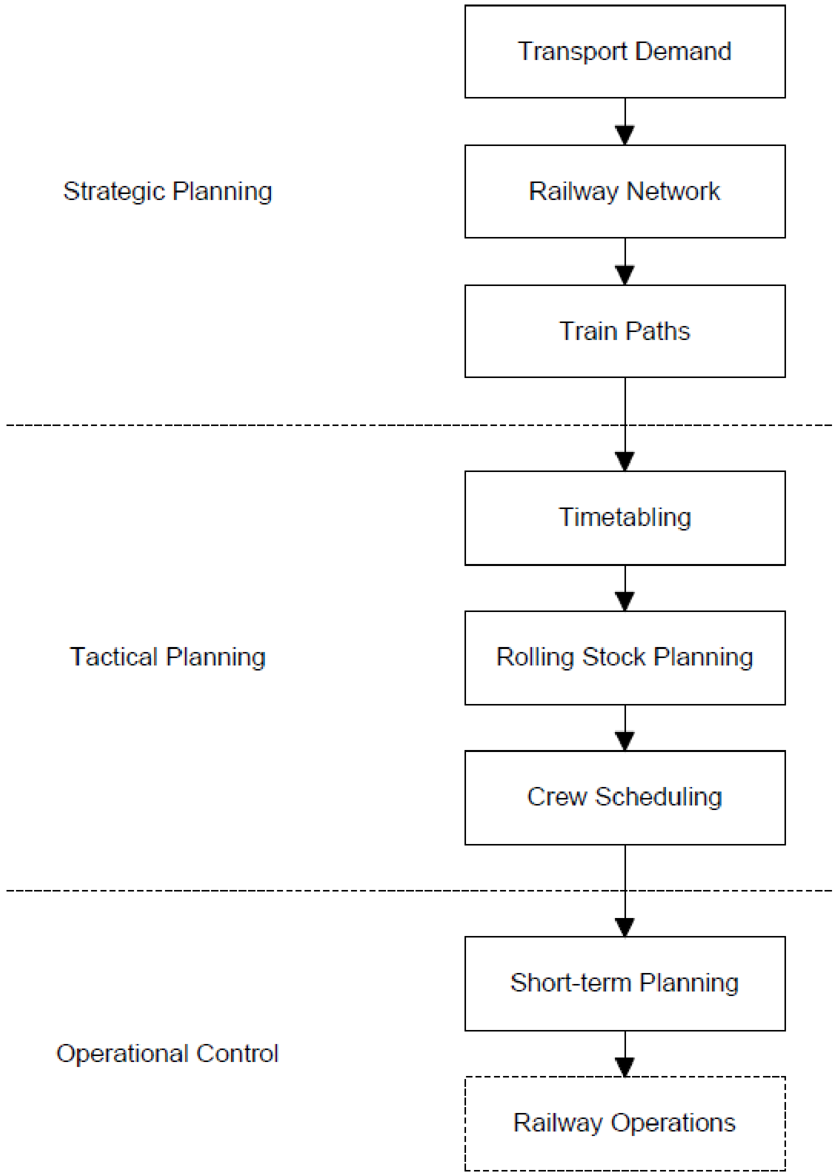


Figure 9: The railway planning and operation process (Lu, 2016).

Strategic planning is concerned with strategic, fundamental policy decisions regarding the capability of the railway network to meet future demand. In this phase major investments and long-term planning are engaged such as construction of new lines, hiring and training new staff and amending operational rules. The time horizon is often several years. Through management of capacity and resources, strategic planning aims at delivering the sufficient structure of train services to meet market requirements.

Tactical planning deals with intermediate phase management which translates strategic decisions into specific plans relevant to each area of operation. With tactical planning, schedules for rolling stock and crew are planned alongside timetables.

Operational control thinks about with short-term management of traffic and operations. The strategies are performed to form weekly timetable plans, and to deal with rescheduling during disruptions and disturbances on a day-to day basis (Lu, 2016).

Rolling stock operation

In addition to periodic equipment maintenance and training to improve the accuracy of operations, rapid response to unexpected vehicle problems and operational delays is essential to achieve stable, highly punctual railway transportation services. As such, timetables and vehicle/ crew schedules for the day's train services must be adjusted depending on the operating state.

To be able to adjust the vehicle operation schedules for the day's train services in response to train service problems, an operator must make quick decisions while considering a wide range of information such as of operating state predictions, vehicle conditions, and crew member locations (TOMOE TOMIYAMA,1 TATSUHIRO SATO,1 TOMOHIRO MURATA,2 SHIGEKI IWAMURA,1 and OSAMU SAKAMOTO1, 2017).

Railway companies are required by law to operate through scheduling patterns to create schedules that can compete with manual schedules. These patterns can represent experiences by rolling stock managers like the rotations of train routes.

Japanese laws require railway companies to regularly inspect their rolling stock at stated intervals to ensure safe transportation, which are based on running distances and inspection periods. Each railway company manages their rolling stock by creating schedules of rolling stock operations and checking the results. The schedules for rolling stock operations define the assignments of cars to trains and the dates of inspections. The schedules for rolling stock operations are based on train timetables. Once transport disorders occur, the schedules are changed. As a result, the running distances of individual trains differ from those that are planned, and some trains finish operations at unscheduled stations. Railway companies have to recreate their schedules in these cases for the days after transport disorders occurred. Rescheduling requires a lot of time because these schedules are manually prepared to ensure consistency with relevant departments such as departments for inspection, those for planning train timetables, and those for crew management. The rate of change in schedules has to be low to reduce the time and labour spent in rescheduling (T. Tomiyama1, 2012).

A set of timetabled train trips (each with a departure time, a departure station, an arrival time, and an arrival station) to be performed every day of the considered planning horizon is given. Each trip has a demand of passenger seats, which represents the estimated number of passengers traveling on the trip. The train operator has a set of available train units (self-contained trains with an engine and a set of wagons with passenger seats), each with a cost, and a capacity representing the number of available passenger seats. The train units can be combined to satisfy the passenger seat demand, but a maximum number of train units, equal to two in our real-world application, can be assigned to each trip (Valentina Cacchiani,a Alberto Caprara,a,* Paolo Totha, 2019).

2.4 Literature review summary

Rolling stock is the most maintenance intensive part of the railway system and therefore, the most vulnerable if maintenance is neglected. its failure may cause delays and disruptions to transport services or even result in catastrophic derailment accidents, maintenance planning and optimisation of preventive maintenance can be made more effective, which can decrease interruptions of train operation, reduce costs and ensure safety.

A passenger rail service's first priority is to provide a punctual and safe transport service to its customers. But doing so is a major challenge for rail network operators, as disruptions are inevitable, especially in densely-populated networks. Disruptions can be caused not only by infrastructure or rolling stock breakdowns, but also by maintenance activities, new rolling stock, or new train services. Managing these disruptions and predicting the extent of its effects is a crucial part of rail network operation.

Light rail as a mode of transit service (also called streetcar, tramway, or trolley) operating passenger rail cars singly (or in short, usually two car or three-car, trains) on fixed rails in right of- way that is often separated from other traffic for part or much of the way. Light rail vehicles are typically driven electrically with power being drawn from an overhead electric line via a trolley [pole] or a pantograph; driven by an operator on board the vehicle; and may have either high platform loading or low-level boarding using steps” .

Operations and Maintenance are the decisions and actions regarding the control and upkeep of property and equipment. These are inclusive, but not limited to, the following: Actions focused on scheduling, procedures, and work/systems control and optimization; and Performance of routine, preventive, predictive, scheduled and unscheduled actions aimed at preventing equipment failure or decline with the goal of increasing efficiency, reliability, and safety.

Rolling stock has a huge effect on the service level of the system because the service level of the rail system is directly proportional to the safety and comfort of the passengers. In order to achieve the required service level, the quality of the rolling stock performance needs to be improved continually and this can be achieved with proper maintenance as its maintenance has been categorized generally into Corrective maintenance (CM) and preventive maintenance. In addition to periodic equipment maintenance and training to improve the accuracy of operations, rapid response to unexpected vehicle problems and operational delays is essential to achieve stable, highly punctual railway transportation services. As such, timetables and vehicle/ crew schedules for the day’s train services must be adjusted depending on the operating state. to be able to adjust the vehicle operation schedules for the day’s train services in response to train service problems, an operator must make quick decisions while considering a wide range of information such as of operating state predictions, vehicle conditions, and crew member locations.

3 Research Methodology

This chapter intents at highlighting the various tactics that may be utilized when conducting a study. It specifically addresses the research study area, research approach, research method and data collection method. It further highlights the methods utilized in conducting this study and their relevance to the study.

3.1 Research study area

Addis Ababa is the capital city of Ethiopia among the ten largest cities in Sub – Saharan Africa, founded in 1886 by Menelik II of Ethiopia (Tolon, 2008), this capital city holds 527 square kilometers of area in Ethiopia. The population density is estimated to be near 5,165 individuals per square kilometer available. The city is organized in to 10 sub cities and 116 weredas, Expenditure on transport is 10% as About 4 million trips are generated on an average daily. A large share of trip is by Walk (60%) Average trip length is 4.3 km; Average trip length of walk is 1.5 km; Work and education are the predominate purposes of trips (32% and 47% respectively).

It is where the African Union is and also hosts the headquarters of the United Nations Economic Commission for Africa (ECA) and numerous other continental and international organizations. Addis Ababa is therefore often referred to as "the political capital of Africa" for its historical, diplomatic and political significance for the continent. Addis Ababa lies at an elevation of 2,300 meters (7,500 ft), located at 9°1′48″N 38°44′24″. The city lies at the foot of Mount Entoto and forms part of the watershed for the Awash. From its lowest point, around Bole International Airport, at 2,326meters (7,631 ft) above sea level in the southern periphery, the city rises to over 3,000 meters (9,800 ft) in the Entoto Mountains to the north (AYNALEM, JUNE 2018).

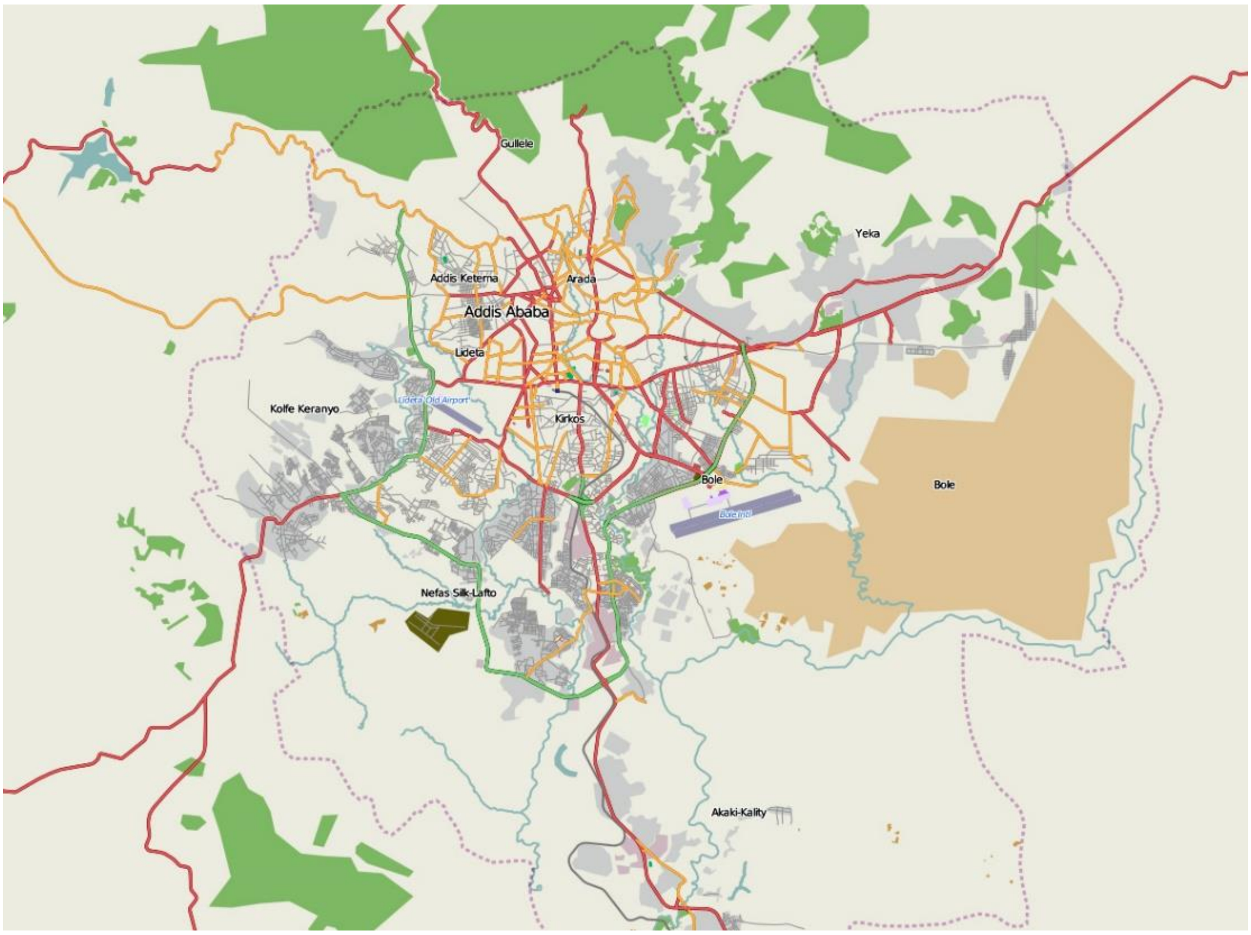


Figure 10: Addis Ababa general map (Anon., n.d.)

3.1.1 Addis Ababa City Transport

Public Transport is that the leading mode of transport of the town. There are many conveyance service providers and among this Anbessa City Bus, Alliance, Sheger mass transport, conveyance Service Enterprise (PTSE), Taxis, Highers, Lonchins and LRT (Light Railway Transport) are the key players. increment combined with lack of efficient infrastructure, disorganized land use and management, increase of private car ownership, inefficient conveyance service and other related factors are a big bottle neck for the city's transit (NATNAEL MULATU, TEWFIK SULEMAN, MAIRUF SULEMAN, ADMASU BANKSRA, ADMASU BANKSRA, 2019).

The city administration developed the city's transport plan which consists of a public mass transport (PMT) system and also light rail transit system (LRT); nevertheless, of these major actions, the city's remains faced with a big setback in satisfying the daily demand.

3.1.1.1 *The general objective of the Addis Ababa City Transport Policy*

- To provide safe, efficient, comfortable, affordable, reliable and accessible transport service for the urban dwellers.
- To enable the sector to provide for the socio-economic development, good governance, improve the livelihood of the society and adopt environmental protection of the city.
- To enhance the status of the city as international seat, by introducing seamless traffic flow through modern traffic management system (ETHIOPIA, 2011).

3.1.1.2 *Addis Ababa Light Rail*

Addis Ababa Light Rail is a light rail transportation system in Addis Ababa, Ethiopia. It is the first light rail and rapid transit in eastern and sub-Saharan Africa. A 17-kilometre line running from the city centre to industrial areas in the south of the city opened on 20 September 2015, inaugurated by Prime Minister Hailemariam Desalegn. Service began on 9 November 2015 for the second line (west-east). The total length of both lines is 31.6 kilometres (19.6 mi), with 39 stations. Trains are expected to be able to reach maximum speeds of 70 km/h (43 mph) (Anon., 2016).

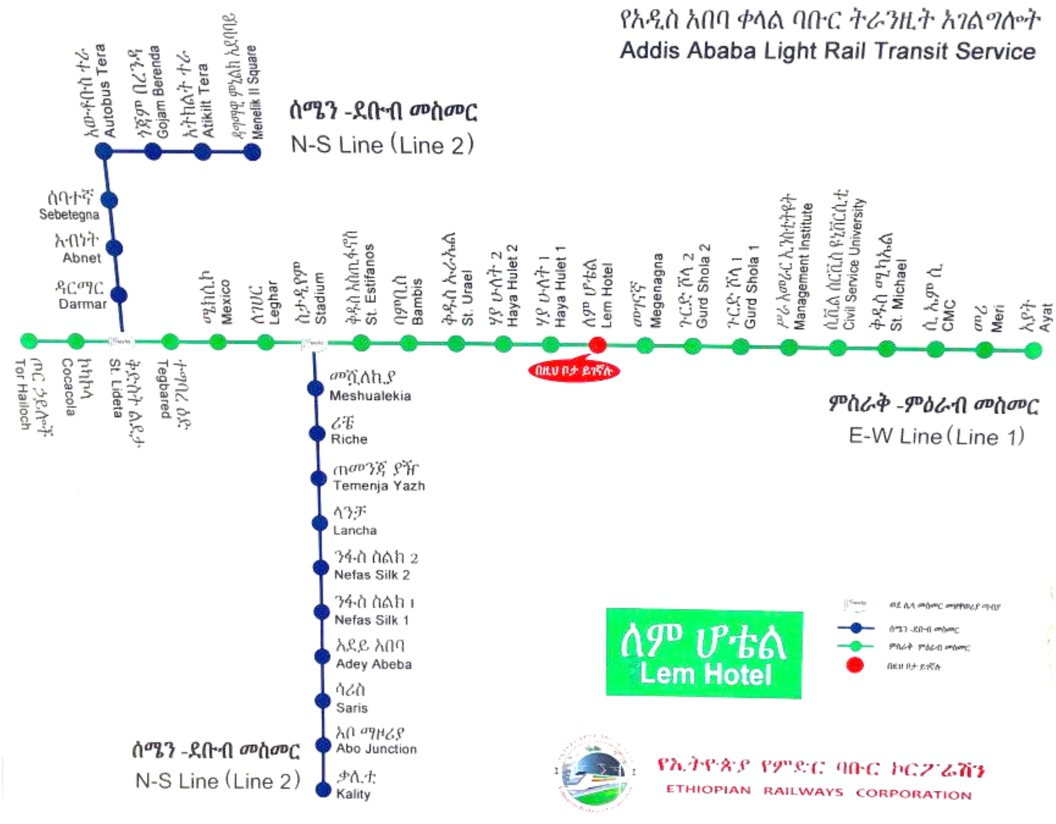


Figure 11: Addis Ababa light rail map (Waldemariam, 2015)

3.2 Research type - Qualitative Research

Qualitative research is the one involves collecting and analysing non- numerical data and opposite of quantitative research, which involves collecting and analysing numerical data for statistical analysis.

Interviews: personally, asking people questions in one-on-one conversations.

Researcher conducted unstructured interviews with employees in the office to learn about their experiences and perspectives in greater detail.

Surveys: distributing questionnaires with open-ended questions.

Researcher distributed open-ended surveys to employees (Rolling stock engineers) across the company herself to get responses for research questions.

Secondary research: collecting existing data in the form of texts, images, audio or video recordings to understand concepts or respondent's opinions as the researcher did in this research.

3.3 Data collection

Data collection is that the process of gathering and measuring information on variables of interest, in a long-time systematic fashion that permits one to answer stated research questions, test hypotheses, and evaluate outcomes. the info collection component of research is common to all or any fields of study including physical and social sciences, humanities, business, etc. While methods vary by discipline, the stress on ensuring accurate and honest collection remains constant. The goal for all data collection is to capture quality evidence that then translates to rich data analysis and allows the building of a convincing and credible answer to questions that have been posed (Kabir, 2018.)

3.3.1 Data collection methods

3.3.1.1 Primary data

Primary data is that the data collected directly from the origin and Primary data collection is that the process of gathering data directly from original sources. Even if there are different types of primary data collection, in this study the used ones are questionnaires, and unstructured interviews just to strengthen the study.

There are questions to be asked accordingly in order to able to get answers for research questions especially question number one and question number two, the first one asking about the types of maintenance which are being used at Addis Ababa Light Rail transit in rolling stock department and the second one is about to know the influences lack of some tools or machines in the workshop can have on its operational performance. and they are structured as follow:

- What is the importance of having a maintenance department?
- What types of maintenance do you use?
- Do you have the outsourcing; subcontracting of maintenance?

Yes/no-----------------------

- How is LRT rolling stock performance measured?
- What performance indicators do you use?
- Is there any interruption caused by maintenance?

Yes/no----------------------

- Do you have breakdown records?

Yes/no----------------------

- What failures occurred concerning the rolling stock (train door)?
- How long did it take to correct such failure?
- What was its cost; approximate?
- What was its effect on LRT performance during that time?
- How effective maintenance planning is?
- Do you have enough tools to perform maintenance operations?

Yes/no----------------------

- Are you able to repair your own components?

Yes/no----------------------

- What are the major reasons for not repairing some components?
- Summarize problems of maintenance in AALRT in order to find out the major ones (vital few problems) as Efficient maintenance is a prerequisite for ensuring economical and secure operations?

Sampling strategy/ method for questionnaires

Once the research question and the research design have been finalized, it is important to select the appropriate sample for the study. The method by which the researcher selects the sample is the Sampling Method or strategy. There are essentially two types of sampling methods: 1) probability sampling – based on chance events (such as random numbers, flipping a coin etc.); and 2) non-probability sampling – based on researcher's choice, population that accessible & available.

In this research, the researcher's choice for choosing non-probability as she founds the population accessibility and availability.

In AALRT rolling stock division there are different departments in which the research can draw the population to collect data from and among them some have to be chosen accordingly. As this concerns the maintenance the decision made is to take sample from rolling railway engineers; rolling stock engineers according to their flexibility as not all of them can provide their time to answer questions they are asked.

Among others, to answer questionnaire question, rolling stock engineers are the one selected to distribute questionnaires to because they first of all are the one who deal with maintenance day per day even if there are technicians but their knowledge about maintenance theory is different, in addition to that they also flexible compared to how managers can give their time to fill questionnaires, Sample size is of nine (9) respondents.

The engineers also have knowledge and are the one in charge of maintenance; planning and follow-up plus taking daily maintenance records. In operation section the one to deal with is the operation manager as he is the one with all records taken from operation control centre.

Interview method will be used to support questionnaires as the questions are the same, it is just to strengthen the research and increase its quality. Here the subject is about types of maintenance and influence of lack of some tools and machines in the workshop, impact maintenance has on the LRT operation performance, sample size is of 2 respondents; operation manager and rolling stock manager.

3.3.1.2 *Secondary data*

The secondary data is data which is collected to support the primary data and as comparison to other studies. When the information is collected by some other person for a purpose apart from the researcher’s current project and has already undergone the statistical analysis is named as Secondary Data. Reading related literatures about the topic, overall feature about railway transport operation in Addis Ababa and maintenance furthermore has to be done in order to get quality data.

Design data and facility concerning the study from Addis Ababa light rail transit office reviewing manuals for light rail transit. The secondary data during this research will be obtained from the Ethiopian Rail Corporation (ERC), AALRT Database about failures and their effect on the train operation.

Collection of operation and maintenance data

Rolling stock operation and maintenance data will be collected from Ethiopian Rail corporation database. The data will include rolling stock systems; components of rolling stock and critical ones among others means the ones which can affect LRT operation the most when they are not maintained as it is intended to be.

The data will consist of preventive maintenance (PM), corrective maintenance (CM), train delays and rolling stock structure data. The PM information includes inspections data and rectification of inspection notes data. The CM data, also known as failure data, consist of urgent inspection remarks reported by the maintenance contractor, as well as failure events and failure symptoms identified outside the inspections, commonly reported by train drivers. The train delay data, in turn, is the trains' deviation in minutes from the time table at a given point, recorded through the track circuits and signalling systems.

Those data will be helpful for calculating the train availability as it is depend on MTBF (mean time between failure)and MTTR (mean time to restore) which include failure time, communication time to dispatcher, ordering the technician to come to where failure takes place and repair time; that means data has to include operation time and downtime in order to be able to calculate uptime which will in turn reveal the impact maintenance can have on operation performance especially corrective maintenance when this occurs on the mainline during service. Preventive maintenance cannot affect the train operation during service as it is the maintenance type which is done following maintenance timetable contrary to corrective one.

Table 1: Operation record for vehicle problems and corrections for 2015

	Dates	**Delay time in minutes**
	20th September 2015	19
	21st September 2015	5
	22nd September 2015	24
	23rd September 2015	5
	25th September 2015	5
	27th September 2015	7
	29th September 2015	10
	30th September 2015	1
	1st October 2015	13

	3rd October 2015	8
	4th October 2015	35
	7th October 2015	6
	10th October 2015	6
	13th October 2015	38
	25th October 2015	4
	9th November 2015	4

Table 2: Operation record for vehicle problems and corrections for 2016

	Dates	**Delay time in minutes**
	2nd January 2016	4
	3rd January 2016	14
	18th January 2016	16
	20th January 2016	6
	30th January 2016	29, trip cancelled
	31st January 2016	2
	18th February 2016	40
	17th March 2016	5
	23rd March 2016	2
	16th May 2016	2
	17th May 2016	2
	2nd July 2016	4
	26th July 2016	2
	13th August 2016	16, trip cancelled

	20th August 2016	70
	24th August 2016	3
	3rd September 2016	7
	6th September 2016	9
	8th September 2016	11
	5th October 2016	1
	15th October 2016	3
	16th October 2016	4
	17th October 2016	13
	18th October 2016	2
	25th October 2016	54
	26th October 2016	6
	30th October 2016	1
	31st October 2016	2, trip cancelled
	1st November 2016	3
	13th November 2016	3
	14th November 2016	3
	25th November 2016	3
	1st December 2016	1
	8th December 2016	8
	22nd December 2016	27
	26th December 2016	36

Table 3: Operation record for vehicle problems and corrections 2017

	Dates	**Delay time in minutes**
	4th January 2017	13
	11th January 2017	4
	16th January 2017	5
	17th January 2017	7
	22nd January 2017	5
	28th January 2017	5
	4th February 2017	6
	5th February 2017	4
	7th February 2017	4
	27th February 2017	4
	1st March 2017	5
	10th March 2017	8
	16th March 2017	2
	12th May 2017	6
	16th May 2017	4
	17th May 2017	10
	24th May 2017	4
	23rd June 2017	12
	27th June 2017	7
	28th June 2017	10
	5th July 2017	2
	2nd August 2017	5

	5th August 2017	15
	8th August 2017	2
	10th August 2017	2
	12th August 2017	11
	24th August 2017	4
	29th August 2017	17
	15th September 2017	4
	3rd October 2017	4
	4th October 2017	5
	5th October 2017	4
	15th October 2017	4
	18th October 2017	8
	19th October 2017	5
	14th November 2017	2
	17th November 2017	20
	24th November 2017	2
	20th December 2017	4
	21st December 2017	7
	22nd December 2017	6
	28th December 2017	7
	29th December 2017	5

Table 4: Operation record for vehicle problems and corrections 2018

	Dates	**Delay time in minutes**
	9th January 2018	11
	13th January 2018	4
	18th January 2018	9
	21st January 2018	4
	31st January 2018	5
	2nd February 2018	4
	10th February 2018	4
	13th February 2018	6
	4th March 2018	61, trip cancelled
	29th March 2018	30
	30th March 2018	3
	7th April 2018	9, trip cancelled
	17th April 2018	4
	2nd October 2018	18
	6th October 2018	4
	19th October 2018	10
	20th October 2018	5
	23rd October 2018	15
	26th October 2018	42
	30th October 2018	56
	8th November 2018	10
	9th November 2018	3

	11th November 2018	7
	23rd November 2018	7
	4th December 2018	5
	7th December 2018	5
	11th December 2018	5
	12th December 2018	40
	15th December 2018	7
	20th December 2018	10
	25th December 2018	2

Table 5: Operation record for vehicle problems and corrections 2019

	Dates	**Delay time in minutes**
	2nd January 2019	4
	12th January 2019	12
	8th February 2019	11
	9th February 2019	8
	16th February 2019	4
	20th February 2019	15
	23rd February 2019	30
	24th February 2019	8
	27th February 2019	4
	28th February 2019	6
	4th March 2019	10
	24th March 2019	45, trip cancelled

	30th March 2019	4
	25th April 2019	24
	15th June 2019	5
	28th June 2019	36, trip cancelled
	8th August 2019	75
	10th August 2019	28
	14th August 2019	7
	19th August 2019	7
	31st August 2019	6
	3rd September 2019	46
	18th September 2019	10
	20th November 2019	4
	23rd November 2019	53
	10th December 2019	3
	20th December 2019	36, trip cancelled

3.4 Inspection conduction and results

The information was gathered from railway depot visitation concerning maintenance practices, discussions and consultation with operation and rolling stock managers from AALRT.

Interviews and questionnaires were carried out focusing on how they operate; objectives and planning maintenance strategies plus types of maintenance currently used, performance of rolling stock and about outsourcing in maintenance. Then after, results from those survey subjects will be evaluated.

3.5 Results evaluation

Here, further evaluation of results from interviews are conducted, and suggestions are proposed looking on what is going to be found; in line with what is going to be found because the impacts of maintenance practices on light rail operation. Validity and reliability of result are measures which will be wont to judge the standard of research result.

Reliability is that the consistency of your measurement, or the degree to which an instrument measures constant way whenever it's used under constant condition with constant subjects. A measure is taken into account reliable if a human score on constant test given twice is comparable. It's important to recollect that reliability isn't measured, it's estimated. There are two ways in which reliability is typically estimated: test/retest and internal consistency.

Test/Retest Test/retest is that the more conservative method to estimate reliability. Simply put, the thought behind test/retest is that you simply should get constant score on test 1 as you are doing on test 2.

Internal Consistency, Internal consistency estimates reliability by grouping questions in an exceedingly questionnaire that measure constant concept. For instance, you'll write two sets of three questions that measure constant concept (say class participation) and after collecting the responses, run a correlation between those two groups of three inquiries to determine if your instrument is reliably measuring that idea.

Validity is that the strength of conclusions, inferences or propositions, best available approximation to the reality or falsity of a given inference, proposition or conclusion.

Types of Validity: There are four forms of validity commonly examined in social research:

1. Conclusion validity asks is there a relationship between the program and also the observed outcome? Or, during this research, the question is often is there a connection between the wheeled vehicle maintenance practices and also the outcome which can be observed?
2. Internal Validity asks if there's a relationship between the program and also the outcome, is it a causal relationship? For instance, will the rolling stock maintenance practices cause positive or negative impact on LRT operation performance?
3. Construct validity is that the hardest to grasp in my opinion. It asks if there's there a relationship between how I operationalized my concepts during this study to the particular causal relationship I'm trying to study? Or during this thesis, will the rolling stock maintenance practices reflect the construct of fine performance, and can measured outcome – positive or negative impact- reflect the construct of Overall, what's trying to be done is to generalize the

conceptualized treatment; maintenance and outcomes to broader constructs of constant concepts.

4. External validity refers to the flexibility to generalize the results of this study to other settings. During this thesis research, will the author generalize her results to other maintenance practices?

3.6 Generalization of study results

In empirical research, generalization is an act of inferring from specific, observed instances, such as those in a case setting, to general statements. Generalization is a type of inference that leverages information and insights from the social facts that researchers measure – through statistics, interviews, participant observation, archival research, and the like – to help explain broader collections of social phenomena that they do not measure. This larger aspiration is often described as the scope or domain of a study (Steinberg, 2015).

Generalizability is applied by researchers in an educational setting. It can be defined as the extension of research findings and conclusions from a study conducted on a sample population to the population at large. Because sound generalizability requires data on large populations, quantitative research -- experimental for instance -- provides the best foundation for producing broad generalizability (Jeffrey Barnes, Kerri Conrad, Christof Demont-Heinrich, Mary Graziano, Dawn Kowalski, Jamie Neufeld, Jen Zamora, and Mike Palmquist, 2012).

3.7 Thesis research method

In this thesis, scientific and research methods were utilized in order to perform a comprehensive report according to the use of the (electronic thesis, dissertation, or report) ETDR Word Template.

This research will acquire case study methods as one among different research methods as it focuses on single or multiple cases.

This study will be dealing with both descriptive and explorative approaches, the descriptive approach of the study will look into the object of study (operational system); evaluation of the effect of failures associated with the study object due to maintenance, thus, highlighting the importance of maintenance implementation. The exploratory approach will look at ways through which maintenance can be implemented in the study object; operation. It can then be believed that this method is best for this study because as a researcher, i have little or no influence over the object of study.

Quantitative method will be mostly used to gather data from the case company through interviews /questionnaire to key personnel at the case company; Ethiopian Railway Corporation/ Addis Ababa Light Rail Transit service, observation and archival documents. While the review of the literatures will be structured through literature survey, scientific journals, articles and books relevant to this study as it is a continuous action done from the beginning of the research.

In this thesis, validity and reliability are going to be accustomed test the standard of this thesis, the discussion and analysis of the gathered data are going to be meted out carefully with key personnel at the case company, Ethiopian Railway Corporation/ Addis Ababa Light Rail Transit service. Thus, my conclusion is going to be supported the end result of the gathered data from the case company, therefore increasing the reliability of the thesis.

3.8 Summary

The selected procedure decisions which enfold the methods and procedures employed in scheming this thesis is briefed below in order to give the reader a clear overview of the methods used:

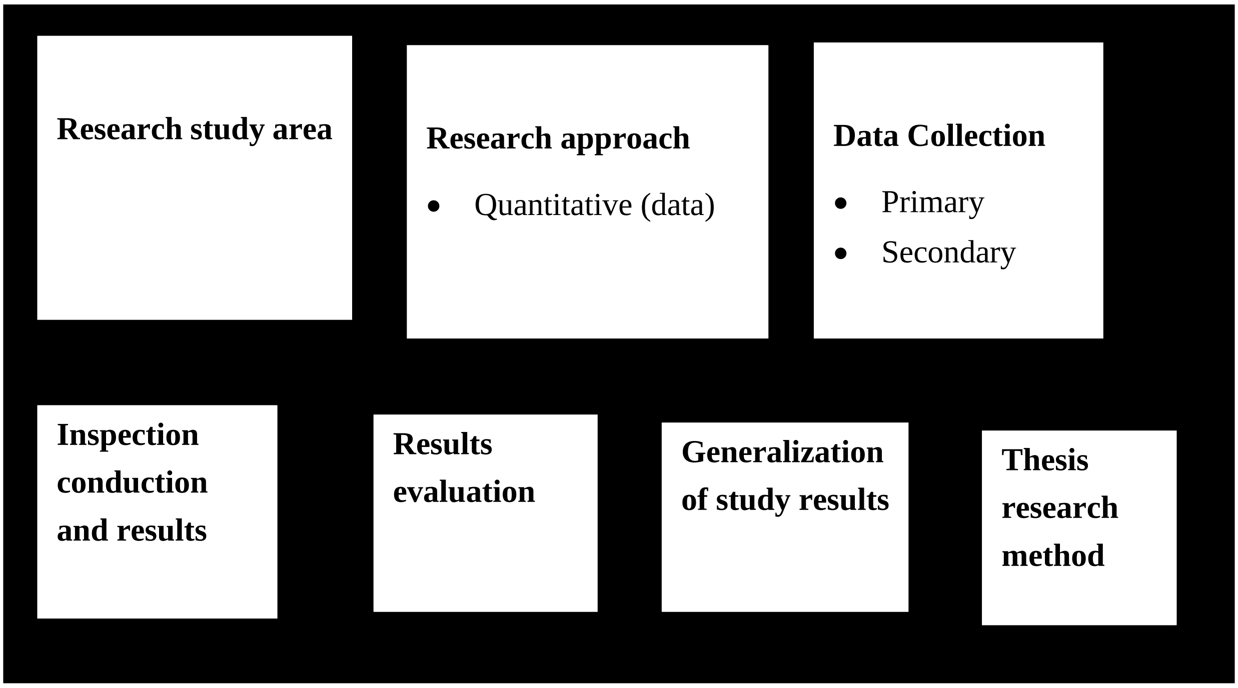


Figure 12: Summary of research methodology

4 Results and discussions

In this chapter, the gathered data from ERC – AALRT database, the participants via questionnaires and semi-structured interviews have to be presented, analysed accordingly. The main objective of the study is to study the impact of rolling stock maintenance practices on Light Rail Transit operational performance. Data are analysed using Microsoft excel version 2013 licensed software.

4.1 Quantified operations analysis and its impacts

The collected data from ERC – AALRT database, the participants via questionnaires and semi-structured interviews.

The failure data are between 20th September 2015- 31st December 2019, i.e. 3 years. Reported number of failures is 154, with 9 % of the failures resulting in trip cancellation, i.e. 14 train-door failures affect the operation in cancelling the trip. Figure 12 shows the train delaying failures (downtime) happened from the start of AALRT operation; September 2015. Train delay is the delay in minutes caused by failures, which in turn is recorded through the OCC (operation control centre).

Table 6: Data combination and results

year	uptime (min)	downtime(min)	availability (%)
2015	116936	184	99.84
2016	351006	354	99.9
2017	351097	263	99.92
2018	350049	351	99.89
2019	349980	420	99.88

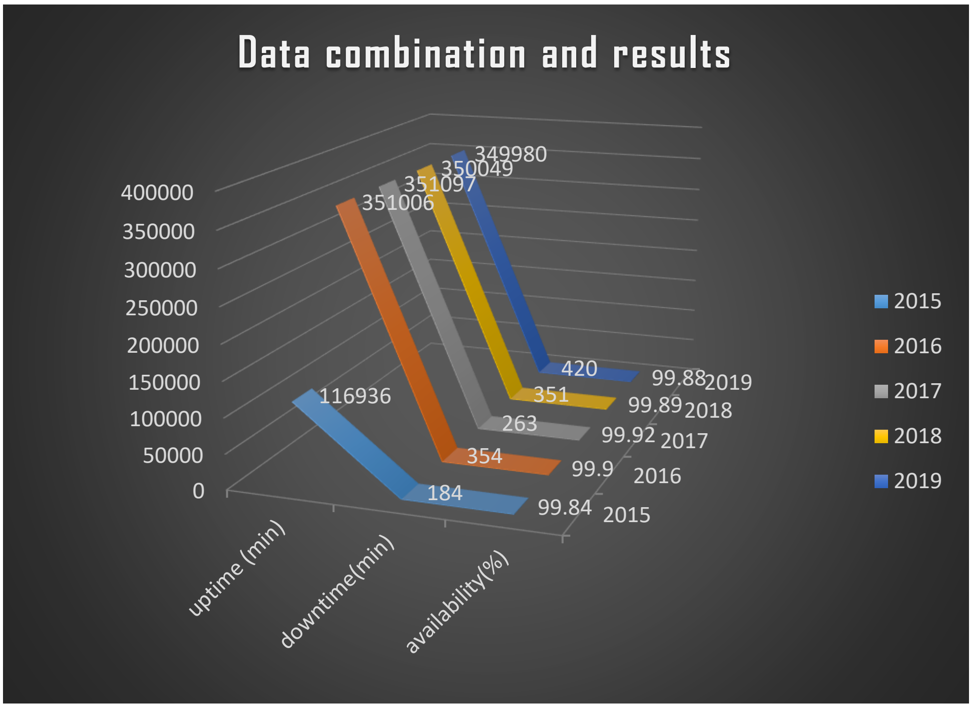


Figure 13: train delaying failures happened from the start of AALRT operation

4.1.1 Operational availability

Rolling stock Availability is the ability of the rolling stock to be in a state to perform a required transport function under a designed conditions at a specified instant of time or over a agreed time interlude Assuming that the required external resources Such as no traffic disturbance, no infrastructure damage or obstacle and no power interruption provided.

Operational availability (Ao) is the probability that the system will be ready or train for operation in a real-life environment. This availability measure considers the total maintenance downtime, i.e. both the active maintenance time and the time waiting for maintenance. *Ao* is the preferred availability measure when assessing a system in a realistic operational environment. The operational availability is expressed as:

Mathematically, A_O, $= \frac{Uptime}{Uptime+Downtime} = \frac{MTBF}{MTBF+MTTR}$

Mean Time Between Failures (MTBF) is the mean operating time (up time) between failures of a specified item of equipment or a system.

MTBF is often want to express the reliability of things of apparatus and systems. MTBF is that the correct term when talking about an item of apparatus that's repairable. once we consider items that aren't repaired after they fail, then time unit To Failure (MTTF) is that the more correct term, but it doesn't much matter as they mean the identical thing, Often MTBF is employed when talking about non-repairable items too.

Operational availability includes the corrective maintenance time, preventive maintenance time and maintenance support. It is the one under given operating environment and maintenance support.

Requirements to get operational availability:

- Down time
- Failure rates
- Corrective maintenance time
- Preventive maintenance time
- maintainability
- Maintenance time

As the issue of measuring availability is concerning railway during operation and preventive maintenance does not affect the operation as the corrective maintenance, the preventive maintenance is not included in this study.

Corrective maintenance carried out after a failure is recognised. The failure is recognised by train driver and dispatchers. When a fault is recognised, maintenance support is contacted and work is set up as it is followed at Addis Ababa LRT.

After a failure has been rectified and approved, the maintenance work is done and the operation continue or stop according to how the fault is.

Data field includes:

- Administrative delay
- Logistic delay
- Repair time

The noted or registered time taken by the train dispatchers is the one used for availability calculation. Not all failures that will affect the operation and results in train delays, the aim of operational availability is to have a measure of the real experienced availability.

Corrective maintenance data consists of urgent inspection remarks required immediate repair reported by train driver of dispatcher, failure events collected from AALRT daily records database from September 2015 to December 2019.

4.1.2 Operation availability for year 2015

A_O, $=\frac{Uptime}{Uptime+Downtime}=\frac{MTBF}{MTBF+MTTR}$

Mean time to failure, MTBF=$\frac{up\ time}{number\ of\ failures}$

Number of failures. Nf=28

Downtime (DT); Failure time and corrective maintenance time = 184minutes

Total operating time is 4months

Operating time per day is 16 hours; means from 6AM to 10PM

Total operating time =122days *(16hrs*60minutes) = 117,120minutes

Uptime= total operating time (OP) – Downtime (DT)= 117,120minutes - 184minutes=116936min

MTBF = $\frac{116936}{28}=4176.285714min/Nf$

MTTR=$\frac{Downtime}{number\ of\ failures}=\frac{184}{28}=6.571428571min/Nf$

A_O, $=\frac{Uptime}{Uptime+Downtime}=\frac{MTBF}{MTBF+MTTR}=\frac{4176.285714}{4176.285714+6.571428571}=99.84\%$

The better way to present and analyse the result of this simulation of collected data from ERC – AALRT database is to draw a dynamic histogram in Excel following yearly daily records as follow:

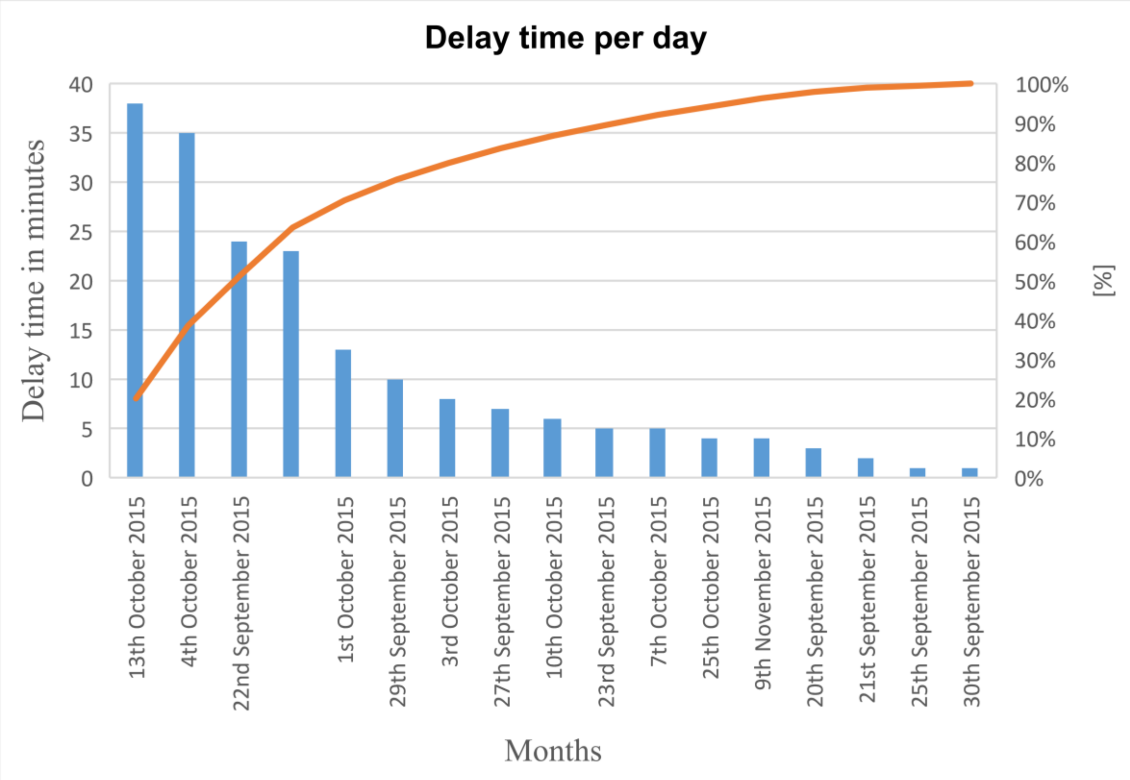


Figure 14: Operation record for train delays 2015

As the availability is of 99.84%, the trains which were operating on the daily basis during those 4months can be said that are of high availability which doesn't have negative impact on the company performance and passenger's satisfaction but positive one.

4.1.3 Operation availability for year 2016

A_O, $=\frac{Uptime}{Uptime+Downtime} = \frac{MTBF}{MTBF+MTTR}$

Mean time to failure, MTBF=$\frac{up\ time}{number\ of\ failures}$

Number of failures. Nf=41

Downtime (DT); Failure time and corrective maintenance time = 354minutes

Total operating time is 12months=

Operating time per day is 16 hours; means from 6AM to 10PM

Total operating time = 366days *(16hrs*60minutes) = 351,360minutes

Uptime= total operating time (OP) – Downtime (DT)= 351,360minutes - 354minutes=351,006min

$$\text{MTBF} = \frac{351{,}006}{41} = 8561.121951 min/Nf$$

$$\text{MTTR} = \frac{Downtime}{number\ of\ failures} = \frac{354}{41} = 8.634146341 min/Nf$$

$$\text{A}_\text{O}, = \frac{Uptime}{Uptime+Downtime} = \frac{MTBF}{MTBF+MTTR} = \frac{8561.121951}{8561.121951+8.634146341} = 99.899\%$$

The better way to present and analyse the result of this simulation of collected data from ERC – AALRT database is to draw a dynamic histogram in Excel following yearly daily records as follow:

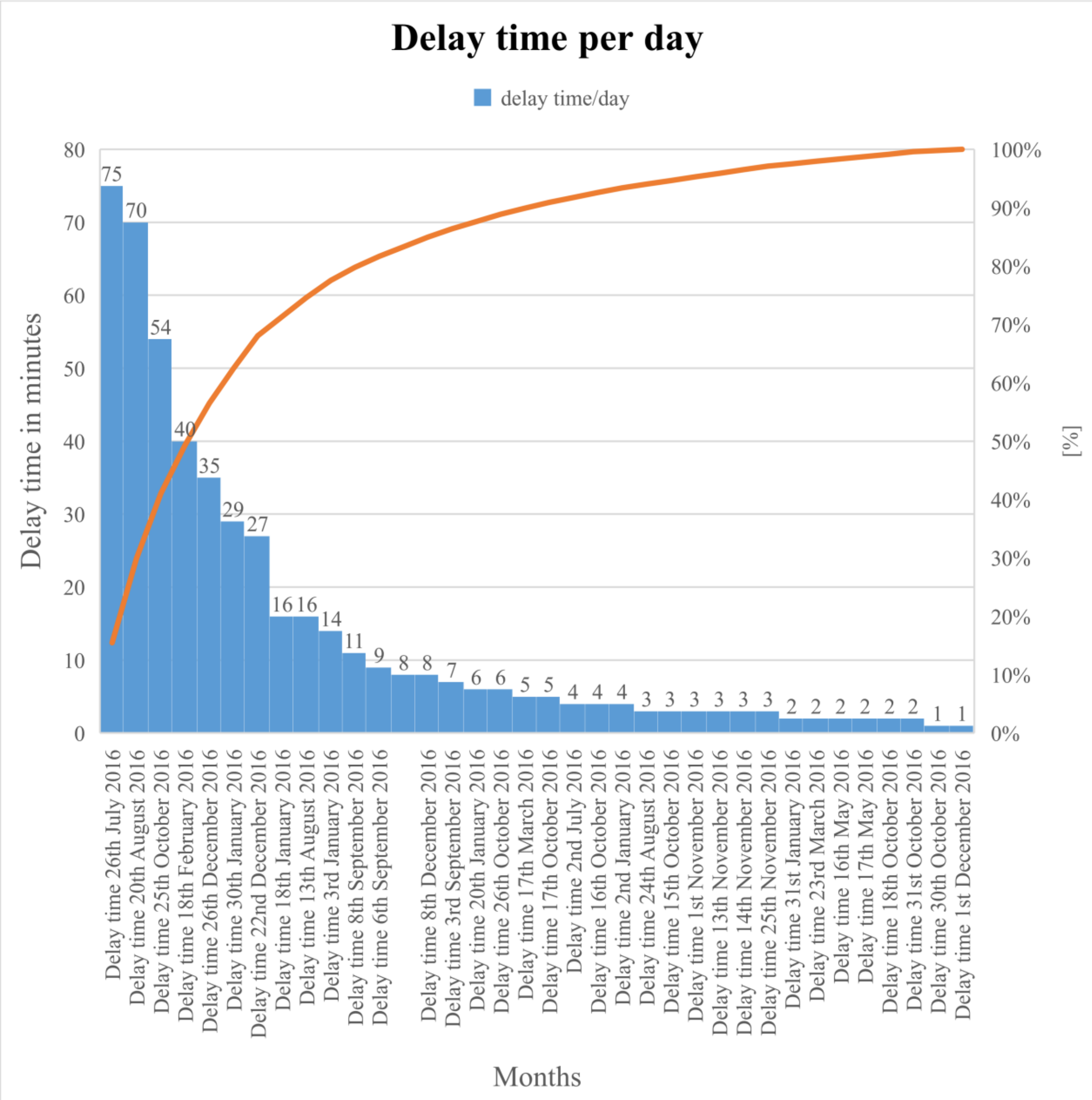


Figure 15: Operation record for train delays 2016

As the availability is of 99.899%, the trains which were operating on the daily basis during the whole year can be said that are of high availability which doesn't have negative impact on the company performance and passenger's satisfaction but positive one.

4.1.4 Operation availability for year 2017

A_O, $=\frac{Uptime}{Uptime+Downtime} = \frac{MTBF}{MTBF+MTTR}$

Mean time to failure, MTBF$=\frac{up\ time}{number\ of\ failures}$

Number of failures. Nf=47

Downtime (DT); Failure time and corrective maintenance time = 263minutes

Total operating time is 12months

Operating time per day is 16 hours; means from 6AM to 10PM

Total operating time =366days *(16hrs*60minutes) = 351,360minutes

Uptime= total operating time (OP) – Downtime (DT)= 351,360minutes - 263minutes=351,097min

MTBF = $\frac{351{,}097}{47} = 7470.148936 min/Nf$

MTTR$=\frac{Downtime}{number\ of\ failures} = \frac{263}{47} = 5.595744681 min/Nf$

A_O, $=\frac{Uptime}{Uptime+Downtime} = \frac{MTBF}{MTBF+MTTR} = \frac{7470.148936}{7470.148936+5.595744681} = 99.925\%$

The better way to present and analyse the result of this simulation of collected data from ERC – AALRT database is to draw a dynamic histogram in Excel following yearly daily records as follow:

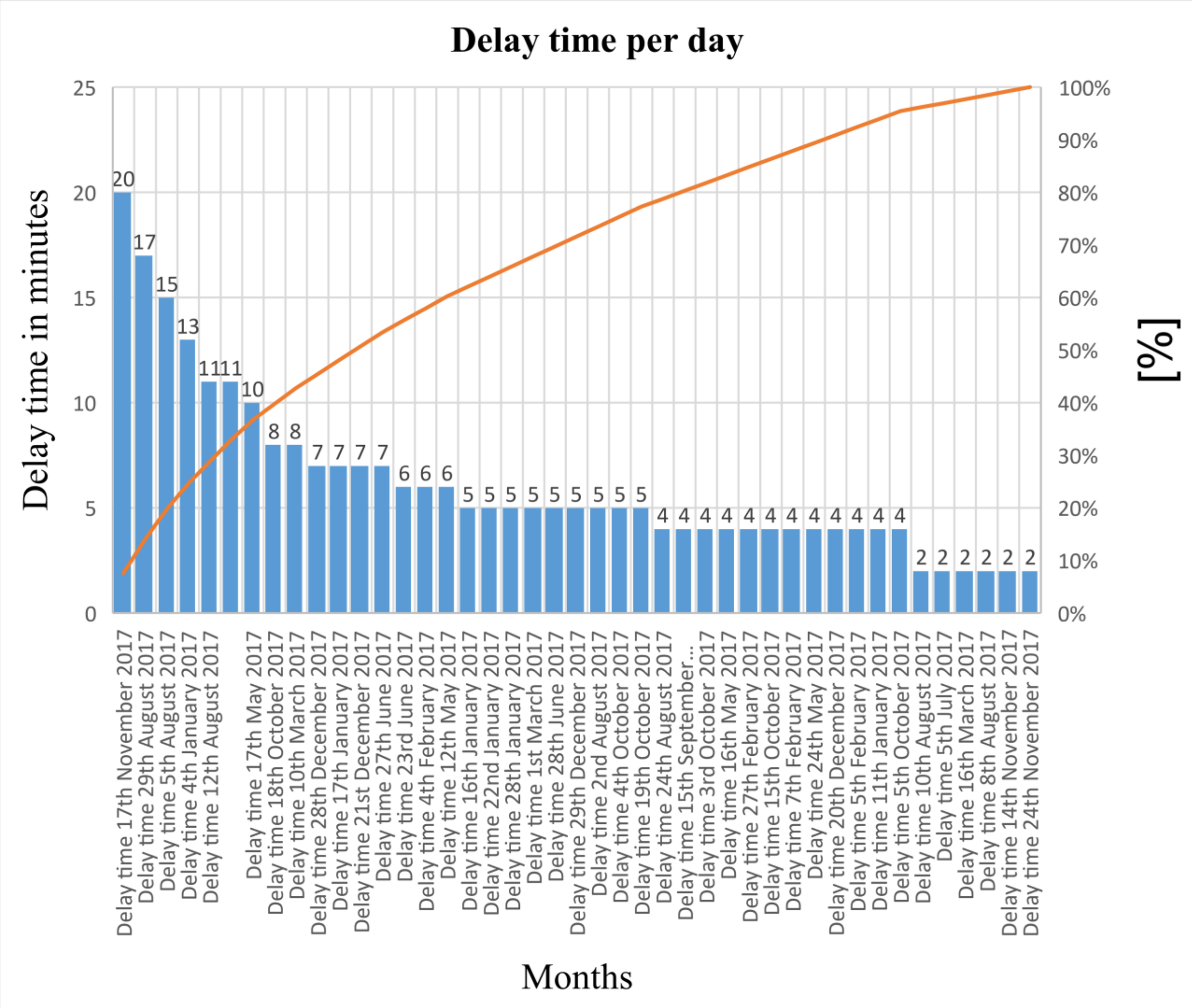


Figure 16: Operation record for train delays 2017

As the availability is of 99.925%, the trains which were operating on the daily basis during the whole year can be said that are of high availability of three nines which doesn't have negative impact on the company performance and passenger's satisfaction but positive one.

4.1.5 Operation availability for year 2018

A_O, $=\frac{Uptime}{Uptime+Downtime} = \frac{MTBF}{MTBF+MTTR}$

Mean time to failure, MTBF=$\frac{up\ time}{number\ of\ failures}$

Number of failures. Nf=38

Downtime (DT); Failure time and corrective maintenance time = 351minutes

Total operating time is 12months

Operating time per day is 16 hours; means from 6AM to 10PM

Total operating time =365days *(16hrs*60minutes) = 350,400minutes

Uptime= total operating time (OP) – Downtime (DT)= 350,400minutes - 351minutes=350,049min

MTBF = $\frac{350{,}049}{38} = 9211.815789 min/Nf$

MTTR=$\frac{Downtime}{number\ of\ failures} = \frac{351}{38} = 9.236842105 min/Nf$

A_O, =$\frac{Uptime}{Uptime+Downtime} = \frac{MTBF}{MTBF+MTTR} = \frac{9211.815789}{9211.815789+9.236842105} = 99.899\%$

As the availability is of 99.899%, the trains which were operating on the daily basis during the whole year can be said that are of high availability which doesn't have negative impact on the company performance and passenger's satisfaction but positive one.

The better way to present and analyse the result of this simulation of collected data from ERC – AALRT database is to draw a dynamic histogram in Excel following yearly daily records as follow:

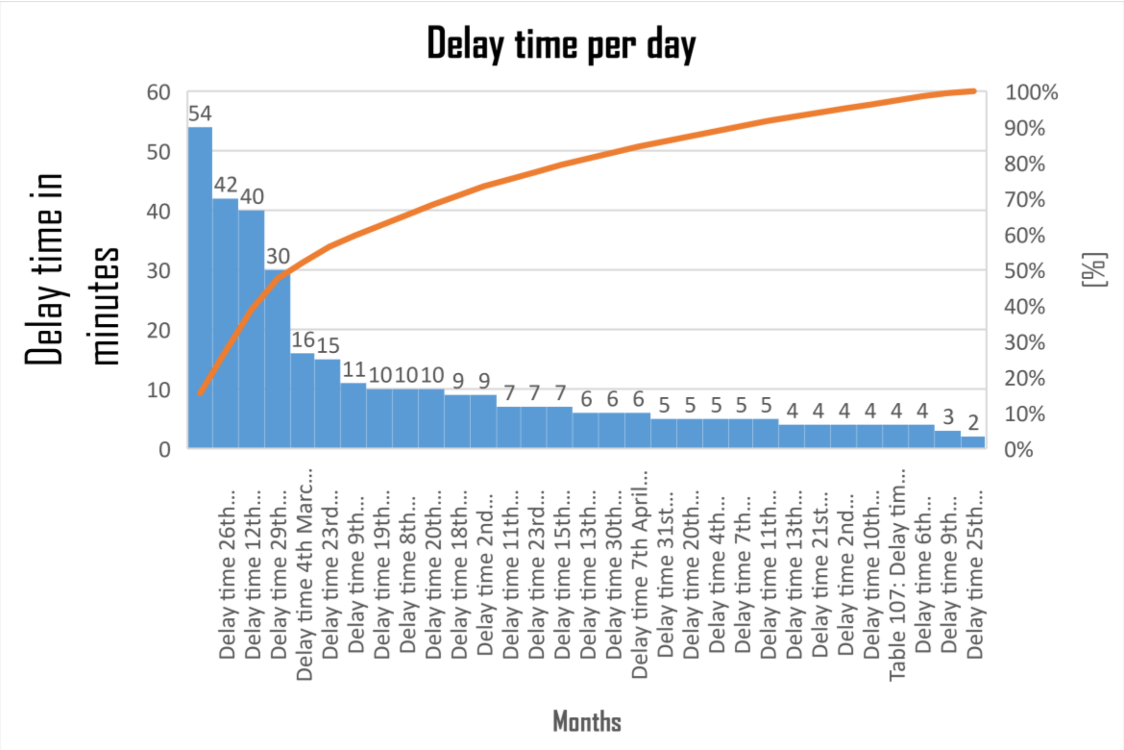


Figure 17: Operation record for train delays 2018

4.1.6 Operation availability for year 2019

A_O, $=\frac{Uptime}{Uptime+Downtime} = \frac{MTBF}{MTBF+MTTR}$

Mean time to failure, MTBF=$\frac{up\ time}{number\ of\ failures}$

Number of failures. Nf=37

Downtime (DT); Failure time and corrective maintenance time = 420minutes

Total operating time is 12months

Operating time per day is 16 hours; means from 6AM to 10PM

Total operating time =365days *(16hrs*60minutes) = 350,400minutes

Uptime= total operating time (OP) – Downtime (DT)= 350,400minutes - 420minutes=349980min

MTBF = $\frac{349980}{37} = 9458.918919 min/Nf$

MTTR=$\frac{Downtime}{number\ of\ failures} = \frac{420}{37} = 11.35135135 min/Nf$

A_O, $=\frac{Uptime}{Uptime+Downtime} = \frac{MTBF}{MTBF+MTTR} = \frac{9458.918919}{9458.918919+11.35135135} = 99.8\%$

The better way to present and analyse the result of this simulation of collected data from ERC – AALRT database is to draw a dynamic histogram in Excel following yearly daily records as follow:

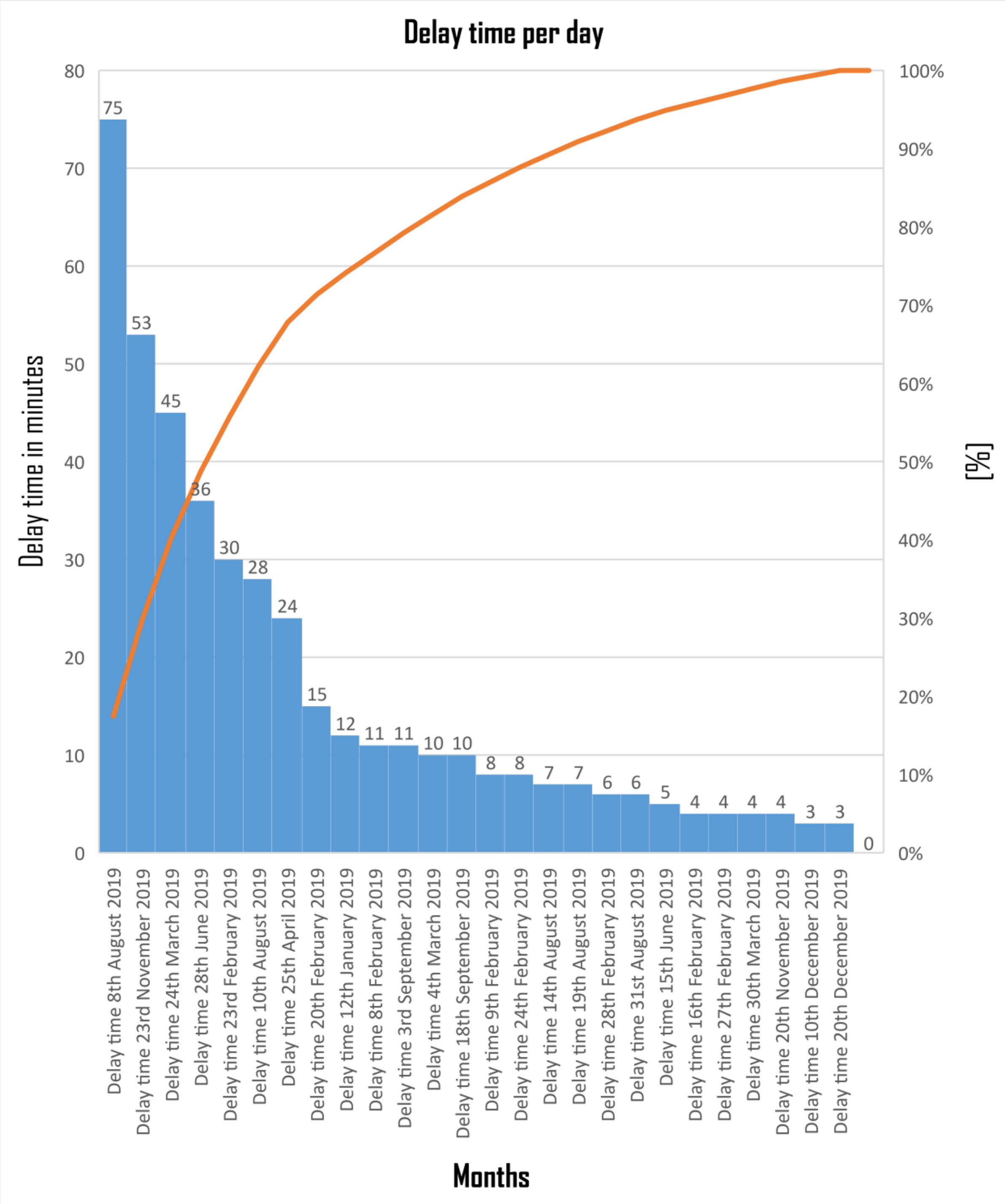


Figure 18: Operation record for train delays 2019

As the availability is of 99.8%, the trains which were operating on the daily basis during the whole year can be said that are of high availability which doesn't have negative impact on the company performance and passenger's satisfaction but positive one.

MTBF (Mean Time between Failures) is the average (expected) time between the two successive failures of a component. It is a basic measure of a system's reliability and availability and is usually represented as units of hours.

"Recovery" is yet another main concern about any service. Having a correct recovery procedure and being prepared to recover from any failure in a defined amount of time via defined amount of energy and resources spent, one may decide not to lower the likelihood of the system to fail, but just simply recover it in case of a failure as soon as possible. All in all, what matters is to have the service do what is it supposed to do at the right time. MTTR (Mean Time to Repair) is the main term when determining how a system would behave in case of recovery. It is another major factor of determining a system "Availability".

Mean Time between Failures is the average (expected) time between two successive failures of a component. It is a basic measure of a system's reliability and availability and is usually represented as units of hours.

- *Mean Time to Repair (MTTR)*

Mean Time to Repair (or Recover) is the average (expected) time taken to repair a failed module.

This time includes the time it takes to detect the defect, the time it takes to bring a repair man onsite, and the time it takes to physically repair the failed module. Just like MTBF, MTTR is usually stated in units of hours or minutes.

4.2 Survey data findings

Research **Question number One**, which explores the types of maintenance applied at AALRT rolling stock workshop, the technic used to collect data was questionnaires with open-ended questions addressing to railway engineers at AALRT, Kality section North-south line as it's the one was the limitation, questionnaires was of nine numbers and all of them gave the same answers which are preventive maintenance and corrective maintenance or breakdown maintenance as it is indicated in the table below:

Table 7: respondent perspectives about types of maintenance AALRT rolling stock

Category	**Volume**	**Percentage**
Corrective	9	50%
Preventive	9	50%
total response category count	18	100%

It can be really seen that the types of maintenance AALRT rolling stock is using are the number of two; preventive maintenance and corrective maintenance or breakdown maintenance.

Research **Question number two** which was about the influences of not having all maintenance machines in the workshop, the technic used to collect data also was questionnaires with open-ended questions addressing to railway engineers at AALRT, Kality section North-south line as it's the one was the limitation, questionnaires and among questions asked some of them obliged the respondents to answer pointing of not having enough machineries and spare parts in the workshop, this causes the low availability.

Table 8: respondent perspectives about influences of not having all maintenance machines in the workshop

Category	Volume	Percentage
availability	6	33%
Safety	4	22%
Reliability	2	11%
downtime reduction	4	22%
Management	2	11%
total response category count	18	100%

Research Question number three which was about outsourcing or subcontracting of maintenance in AARLT, most of the respondents replied yes but there are some who said that they don't have depending on when the contract between Chinese company and AARLT will end but actually there is as it can be seen in the following table:

Table 9: respondent perspectives concerning outsourcing

Category	Volume	Percentage
Yes	7	78%
No	2	22%
total response category count	9	100%

Research Question number four which was about the way they measure the AALRT rolling stock performance, according to the answers given by the respondents the main measurement technic used is the one concerning the operation, that means how the operation takes place as it is all activities you perform to reach business objectives as it is shown by the table below:

Table 10: respondent perspectives concerning AALRT rolling stock performance

Category	Volume	Percentage
Quality	2	15%
Operation	4	31%
Financial	1	8%
Good	1	8%
Availability	3	23%
performance of staff	2	15%
total response category count	13	100%

Research Question number five which was about performance indicators, it is indicated that the one of high percentage is the availability among the indicators; answers given by the respondents about the asked question. As the availability is the he probability that an item will be in an operable and committable state at the start of a mission when the mission is called for at a random time, and is generally defined as uptime divided by total time (uptime plus downtime). The following among others is the efficiency.

Table 11: respondent perspectives concerning AALRT performance indicators

Category	Volume	Percentage
Availability	5	33%
Downtime	2	13%
no standard performance indicator	2	13%
Technicians	1	7%
Efficiency	3	20%
Inventory	1	7%
Cost	1	7%
total response category count	15	100%

Research Question number six which was asking if there was any interruption caused by maintenance, in our thinking we can think that no maintenance can interrupt the operation as maintenance is The work of keeping something in proper condition, care or upkeep including: taking steps to avoid something breaking down (preventative **maintenance**) and bringing something back to working order (corrective **maintenance**) (negitiator, 2020). But among the respondents most of them replied that maintenance interruptions exist at high percentage as it is shown by the records taken like some of them can cause delay or trip cancelation.

Table 12: respondent perspectives concerning maintenance interruption

Category	Volume	Percentage
Yes	6	67%
No	3	33%
total response category count	9	100%

Research Question number seven which was asking if there are breakdown records in order to be sure about secondary data for operation data analysis, the way of collecting this kind of data was questionnaire technic distributed among sample people selected, results got here is that breakdown data is taken every day which helped the researcher to be sure of operation data; 100% yes.

Table 13: respondent perspectives concerning breakdown records

Category	Volume	Percentage
Yes	9	100%
No	0	0%
total response category count	9	100%

Research Question number eight which was asking failures occurred concerning the rolling stock (train door), the technic used to collect data is questionnaires distributed to the respondents; rolling stock engineers and what they answered showed that the highest percentage is the one concerning the opening and closing failures.

Table 14: respondent perspectives concerning failures occurred concerning the rolling stock

Category	Volume	Percentage
V-shape	3	19%
alignment	4	25%
Opening & closing	5	31%
Traction	1	6%
Software	2	13%
non uniform opening and closing	1	6%
total response category count	16	100%

Research Question number nine which was asking How long it took to correct such failure, the technic used to collect data is questionnaires distributed to the respondents; rolling stock engineers and what they answered showed that the highest percentage is of two hours and less which shows that its effect to the operation is not much even if some failures can cause trip cancellation, which is another issue.

Table 15: respondent perspectives concerning the time it took to correct such failure

Category	Volume	Percentage
2hrs and less	6	50%
8hrs and longer	5	42%
it depends	1	8%
total response category count	12	100%

Research Question number ten which was asking the approximation cost of failure correction, the histogram below and the table show that there is no cost as the respondents said that the cost has never calculated and some of them said that it is with no cost.

Table 16: respondent perspectives concerning the approximation cost of failure correction

Category	Volume	Percentage
never calculated	5	56%
no cost	4	44%
total response category count	9	100%

Research Question number eleven about the effect of maintenance practice on LRT performance during that time, it is well seen that the very effect maintenance has on the Addis Ababa LRT is that it causes the delays and sometimes depending on how tough the failure is, the trip can be cancelled even if it occurs rarely.

Table 17: respondent perspectives concerning the effect of maintenance practices on LRT performance

Category	**Volume**	**Percentage**
Delay	8	89%
no effect	1	11%
total response category count	9	100%

To answer the ***Research Question number twelve about how*** *effective maintenance planning is,* it is well seen that according to the respondent answers the service provided by AALRT is very effective.

Table 18: respondent perspectives concerning how effective maintenance planning is

Category	**Volume**	**Percentage**
Excellent	2	22%
effective service	5	56%
Good	1	11%
very good	1	11%
total response category count	9	100%

Research Question number thirteen, the researcher wanted to know if AALRT has enough tools to perform maintenance operations. Actually according to the time research spend there during the practical works or trainings or internship, she can conclude that the answer is yes depending on rolling stock component chosen to be studied on but as she conducted the research using questionnaire, the respondents gave her different answers to analyse using the cited software and come up with conclusion as follow, between the two categories, the one with high percentage is yes which means that AALRT has enough tools to perform maintenance operation about that component.

Table 19: respondent perspectives concerning tools.

Category	Volume	Percentage
Yes	6	67%
No	3	33%
total response category count	9	100%

Research Question number fourteen about the ability of AALRT to repair their own components. In order to repair given component, the company must have all needed tolls to use in repairing; for AALRT some components is difficult to repair as the Chinese company is still under control but for door they are able to repair the occurred failures as it is shown by answers from respondents, among them many replied yes confirming that they have that ability.

Table 20: respondent perspectives concerning AALRT ability to repair their components

Category	Volume	Percentage
No	3	23%
Yes	7	54%
some repaired by only Chinese	3	23%
total response category count	13	100%

But among rolling stock components, some of them are complicated to be repaired by AALRT alone without Chinese involvement like bogie parts that is why the other question which is of number fifteen was asking the major reasons for not repairing some components; as it can be seen well majority of respondents said that the reason is of not having enough machinery like the one dealing with wheel misalignments.

Table 21: respondent perspectives about major reasons for not repairing some components

Category	Volume	Percentage
Skills	**4**	33%
enough machinery	**7**	58%
Manual	**1**	8%
total response category count	**12**	100%

To answer the **last Question of questionnaires** about summary of problems of maintenance in AALRT in order to find out the major ones (vital few problems) as Efficient maintenance is a prerequisite for ensuring economical and secure operations. Both of those two questions had the answers somehow the same about not having enough all maintenance machines or machinery or spare parts in the workshop.

Table 22: problems of maintenance in AALRT

Category	Volume	Percentage
skill gap	4	24%
lack of improvement opportunity	4	24%
shortage of spare parts	6	35%
over-confidence	1	6%
inadequate task instruction	1	6%
software problem	1	6%
total response category count	17	100%

The last research question which was the main focusing on the topic was about studying the effect of maintenance practices to the operation performance. the technic used to collect data was questionnaires with open-ended questions addressing to railway engineers at AALRT, Kality section North-south line and from ERC – AALRT database analysed using Microsoft excel 2013.

For all four years; from 2015 to 2019 the calculated operational availability shows that it is higher than 99.8% which is showing that even if there are failures they didn't have negative impact on the operation as many of them few caused trip cancellation but replaced by the standby trains to continue the cancelled trip for the other train.

All failures occurred did take short time to be repaired as it is said by the respondents and also the cost was not high even it is not calculated, both of the two analyses come up with results showing that the impacts of rolling stock maintenance practices on the LRT operation performance is really positive for saying that maintenance has to be implemented in all transport companies in order to get good performance and customer satisfaction.

4.3 Discussions

The average of operational availability is of 99.8%, which means that trains which were operating on the daily basis during the whole those four years concerned are of high availability; the downtime per year is less than the uptime which doesn't have negative impact on the company performance and passenger's satisfaction but positive one. If the system goes down it will not take a long time to get back into service which implies that the availability will not be hurt also. As of this statement, the researcher may say that rolling stock maintenance practices have positive or good impact on Light Rail Transit operational performance as among failures occurred few of them caused trip cancellation but replaced by the standby trains to continue the cancelled trip for the other train.

All questions asked to the respondents into questionnaires and interviews had the same target of knowing really the impact rolling stock maintenance practices have on LRT operational performance, in order to know the impacts something has on something else, you have first to know it that is why question number one was aiming on knowing all types of maintenance applied at Addis Ababa Light Rail Transit, their costs and time taken using one of them correcting the failed part of train accordingly. Failures occurred did take short time to be repaired as it is said by the respondents and also the cost was not high even it is not calculated, both of the two analyses come up with results showing that the impacts of rolling stock maintenance practices on the LRT operation performance is really positive for saying that maintenance has to be implemented in all transport companies in order to get good performance and customer satisfaction.

As the transportation segment remain to be more effective, among others this is railway transportation one in which maintenance has impact, types of maintenance for rolling stock are preventive maintenance and corrective maintenance or breakdown maintenance which have impact on LRT operation depending on how they are practiced. Lack of enough machineries and spare parts in the workshop causes the low availability of trains, even if sometimes corrective maintenance causes train delay and cancellation, the availability is still high to conclude that maintenance has to continue be implemented in railway transportation.

5 Conclusions and Recommendations

5.1 Conclusions

This study describes the Impact of rolling stock maintenance practices on Light Rail Transit operational performance taking Case of Addis Ababa which is fundamental in achieving operation profitability. Maintenance as a function in an operation system/ an organization can increase operation efficiency, reduce downtime or unwanted stoppages, improve operational performance and consequently, company profitability which is one of the most significant motivations of company's investment.

Maintenance implementation in an operational system can improve operational performance in numerous ways by reducing all process interference. The operation company has to provide service to the passengers and freight from one place to another. In ensuring that expected production or operation, goods are delivered at the right time with the right quality and the lowest possible cost requires optimum availability which can be attain, like passengers have to arrive at their respective destination by efficient maintenance policy.

A proper maintenance practice can keep machines/ equipment (that constitute an operation system) in a reliable component condition, thus, minimizing operational inefficiency, train delay even trip cancellation, downtime, etc. thus, an hour spent not working as a result of unwanted stoppages or machine defect can be costly when transferred into financial terms, thereby threatening company's survival to stay in business.

As the transportation sector continue to be more effective, among others this is railway transportation one in which maintenance has impact, types of maintenance for rolling stock are preventive maintenance and corrective maintenance or breakdown maintenance which have impact on LRT operation depending on how they are practiced. Lack of enough machineries and spare parts in the workshop causes the low availability of trains, even if sometimes corrective maintenance causes train delay and cancellation, the availability is still high to conclude that maintenance has to continue be implemented in railway transportation.

5.2 Recommendations

Based on what have been discussed throughout this study which is Impact of rolling stock maintenance practices on LRT operational performance; Case of Addis Ababa, it is clear that maintenance is not just a bout ensuring proper function of rolling stock equipment but also a support function that is indispensable in a transportation organization. Hence, from the study result, it is recommended that the ERC (Ethiopian Railway Corporation) treats maintenance as a core function of company’s business, thus, with a holistic view, its impact on service quality; passenger transportation, availability, environmental and safety requirements can be identified and quantified.

That is being said, having a maintenance organization should be considered in the company to further outline maintenance significant and its role in operational performance. Thus, the implementation of maintenance in the company is inevitable as this study and several others have shown that maintenance is a core function and essential in today’s transportation system in order to reduce failures, train delays as well as sometimes trip cancellation because of downtime to maximize company’s operation performance.

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7 Appendix

AAiT
Addis Ababa Institute of Technology
Addis Ababa University

African Railway Center of Excellence
የአፍሪካ ምድር ባቡር ልሀቀት ማዕከል

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

To: Ethiopian Railway Corporation
Addis Ababa Light Rail Transit Service

Date: 09/01/2020

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 ISHIMWE PASCASIE ,ID No: GSR/ 3981 /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 Rolling Stock Maintenance Practices and LRT Operation 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:

- ✓ Train delays, Corrective and preventive Maintenance
- ✓ Rolling stock maintenance & performance
- ✓ " structure, standards and Manuals

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.

Rolling Stock division
To Maintenance Center

[illegible]
[illegible]

Thank you in advance for your cooperation.

Addis Ababa University
Addis Ababa Institute of Technology
Railway Engineering Centre

Mr. Zewdie Moges
Post Graduate Program Coordinator
AAiT, AAU

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8 Index

MSc thesis data collection

Topic: Impact of rolling stock maintenance practices on Light Rail Transit operation performance

This is where I describe the study and let people know that their participation is voluntary and their data are anonymous and confidential.

Name: DUCA FEKADU — Position: RAILWAY ENGINEER
Division: ROLLING-STOCK — Department: MAINTENANCE

- What is the importance of having a maintenance department?
  - to keep availability trains on operation
  - to keep well-being of the trains
  - to minimize cost of unintended failures &
  - to prevent equipments & train components from failures.
- What types of maintenance do you use?
  - preventive maintenance
  - corrective "
  - break-down "
- Do you have the outsourcing; subcontracting of maintenance?

Yes/no: Yes

- How is LRT rolling stock performance measured?
  - availability of trains in good conditions
  - measuring performance of staff in the division.
- What performance indicators do you use?
  - continuous availability of trains in service ~~on ope.~~ .
- Is there any interruption caused by maintenance?

Yes/no: Yes

- Do you have breakdown records?

Yes/no: Yes

- What failures occurred concerning the rolling stock (train door)?
  - Standard door measurements (V-shape, alignment)
  - door unable to open /close.

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- How long did it take to correct such failure?

  * Usually a day max, Unless further, detailed maintenance is needed.

- What was its cost; approximate?

  * Such failures (door) usually cost nothing unless spare part replacement is needed.

- What was its effect on LRT performance during that time?

  - delay of trains on mainline operation.

- How effective maintenance planning is?

  - it is usually very effective unless ~~fai~~ maintenance time takes a lot longer.

- Do you have enough tools to perform maintenance operations?

Yes/no---Yes---------------

- Are you able to repair your own components?

Yes/no---Yes, atleast most of the time

- What are the major reasons for not repairing some components?

  - limited knowledge in some maintenance
  - some needed equipments are not available.

- Summarize problems of maintenance in AALRT in order to find out the major ones (vital few problems) as Efficient maintenance is a prerequisite for ensuring economical and secure operations?

  - spare part ~~cos~~/availability...
  - limited knowledge on some components of train system...

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Topic: Impact of rolling stock maintenance practices on Light Rail Transit operation performance

This is where I describe the study and let people know that their participation is voluntary and their data are anonymous and confidential.

Name...Girzachew.....Endale Position ..Engineer..............
Division...Rolling...Stock..... Department ....Maintenance...

- What is the importance of having a maintenance department?

To Insure the availability of the train & reduce ~~the downtime~~ Organize, direct & manage the maintenace activity

- What types of maintenance do you use?

Preventive , Corrective , Break down

- Do you have the outsourcing; subcontracting of maintenance?

Yes/no----No-----------------

- How is LRT rolling stock performance measured?

Based on Quality Indicators (reducing downtime,

- What performance indicators do you use?

  - Reducing downtime
  - Quality (Inspection, maintenance Quality)
  -

- Is there any interruption caused by maintenance?

Yes/no----Yes----------

- Do you have breakdown records?

Yes/no--------Yes---------

- What failures occurred concerning the rolling stock (train door)?

  - ~~[illegible]~~ Door Software failure
  -

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- Door mis alligment
- Interuption of input power
-

  - How long did it take to correct such failure?

- Depend on the specific falure type.

  - What was its cost; approximate?

- Based on spare

$\boxed{\text{Spare part cost + Labor Salary/hr * No of labours + Indirect cost}}$

  - What was its effect on LRT performance during that time?

- If ~~most~~ multiple trains are carry out different maintenance program at the same time there will be a operation interruption on mainline.

  - How effective maintenance planning is?

- Since the maintenance plan is planned based on the operational kilometer intervals, categorized as daily, monthly, quarter and annual, it will address the maintenance activity as per standard.

  - Do you have enough tools to perform maintenance operations?

Yes/no----------Yes--------

  - Are you able to repair your own components?

Yes/no----------If ~~you~~ the question meant a modification or sparepart development, yes indeed, but it is limited to simple component

  - What are the major reasons for not repairing some components?

- Lack of advance ~~repairing~~ machinery or tool relevant for repairing ~~repairing~~ purpose

  - Summarize problems of maintenance in AALRT in order to find out the major ones (vital few problems) as Efficient maintenance is a prerequisite for ensuring economical and secure operations?

- Maintenance skill gaps (due to lack of trainings.)
- Unavailability of Machineries (~~the~~ special machines required for Overall maintenance program)

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MSc thesis data collection

Topic: Impact of rolling stock maintenance practices on Light Rail Transit operation performance

This is where I describe the study and let people know that their participation is voluntary and their data are anonymous and confidential.

Name.................................... Position Engineer

Division... Maintenance... Department ...Rolling Stock

- What is the importance of having a maintenance department?

It enables the Campany to perform as much in it's full capacity as possible.

- What types of maintenance do you use?

- periodic Maintenance (preventive maintenance)
- corrective maintenance (Breakdown maintenance)

- Do you have the outsourcing; subcontracting of maintenance?

Yes/no------Yes (on call basis)

- How is LRT rolling stock performance measured?

- By increasing maintenance quality (longer operation duration of maintened parts.
- reducing waiting time

- What performance indicators do you use?

Number of trains available on main line

- Is there any interruption caused by maintenance?

Yes/no----Yes

- Do you have breakdown records?

Yes/no----Yes

- What failures occurred concerning the rolling stock (train door)?

Mostly V-shape of door opening and door distance from body but both problems fixed by adjustment.

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MSc thesis data collection

- How long did it take to correct such failure?

Maximum one hour, but these problems are fixed during night time (off operation) and during periodic inspection

- What was its cost; approximate?

Never calculated

- What was its effect on LRT performance during that time?

Since the problem is fixed during night time I can't see its influence on the LRT performance

- How effective maintenance planning is?

Excellent

- Do you have enough tools to perform maintenance operations?

Yes/no--------With regard to door Yes, with regard to bogie & Wheel No

- Are you able to repair your own components?

Yes/no----No, ------replacement

- What are the major reasons for not repairing some components?

Work shop facility, [illegible]

- Summarize problems of maintenance in AALRT in order to find out the major ones (vital few problems) as Efficient maintenance is a prerequisite for ensuring economical and secure operations?

— Workshop facility
— No need document of Sophisticated components

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Topic: Impact of rolling stock maintenance practices on Light Rail Transit operation performance

This is where I describe the study and let people know that their participation is voluntary and their data are anonymous and confidential.

Name……Henok……………… Position ……Railway Engineer……

Division……Rolling stock…… Department ……Maintenance……

- What is the importance of having a maintenance department?
  - Reduce downtime of the train caused by failure
  - It enhance the train availability
  - It keeps the train safety and Reliability increase
- What types of maintenance do you use?
  - preventive maintenance
  - Breakdown maintenance
  - corrective maintenance
- Do you have the outsourcing; subcontracting of maintenance?

Yes/no------Yes------ the maintenance was given a sub contract to Shenzhen metro, but currently all maintenance activity conducted by us before management including

- How is LRT rolling stock performance measured?
  - Based on train availability
  - Based on mean btn failure
  - Based on frequency of failure
- What performance indicators do you use?

No documented or standard performance indicator

- Is there any interruption caused by maintenance?

Yes/no------Not often

- Do you have breakdown records?

Yes/no------Yes------

- What failures occurred concerning the rolling stock (train door)?
  - Door alignment
  - input power to the door
  - software package
  - unable the door to open or close

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- How long did it take to correct such failure?

  It depend on the failure type. Major failure – 8 hours and longer
  Minor failure – 2 hours less

- What was its cost; approximate?

  [Maintenance crew work/hour * Maintenance duration hour No] + [component cost] + [indirect cost]

- What was its effect on LRT performance during that time?

  Reduce the availability of train on mainline.

- How effective maintenance planning is?

  Positive effect.

- Do you have enough tools to perform maintenance operations?

Yes/no---------Not----enough

- Are you able to repair your own components?

Yes/no------------Yes--- most of it but certain complicated failure may not be repair by own force.

- What are the major reasons for not repairing some components?

  * Due lack of advanced machinery or tool that assist repairing activity
  * Lack some advanced skill gap.

- Summarize problems of maintenance in AALRT in order to find out the major ones (vital few problems) as Efficient maintenance is a prerequisite for ensuring economical and secure operations?

  * The skill gap on advanced maintenance activity) i.e. ~~Test~~ traction control unit
  * Lack of unwheeling (wheel disassembly machinery) limited our maintenance activity on replacing wheel set after wear.
  * Lack of research based maintenance for a problem or failure.

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Topic: Impact of rolling stock maintenance practices on Light Rail Transit operation performance

This is where I describe the study and let people know that their participation is voluntary and their data are anonymous and confidential.

Name..DULA...FEKADU......... Position .RAILWAY ENGINEER

Division..ROLLING STOCK... Department MAINTENANCE....

- What is the importance of having a maintenance department?

  Maintenance department is important in order to maintain the safe of operation of trains on the mainline & to fulfill the demand of trains' transportational service.

- What types of maintenance do you use?

  - corrective maintenance
  - preventive "
  - service "
  - overhaul "

- Do you have the outsourcing, subcontracting of maintenance?

Yes/no---Yes,---

- How is LRT rolling stock performance measured?

  - taking measures (corrective) for critical failures.

- What performance indicators do you use?

  - availability of trains in operation & availability of standby trains (fully working trains with no failures)

- Is there any interruption caused by maintenance?

Yes/no---Yes---

- Do you have breakdown records?

Yes/no---Yes---

- What failures occurred concerning the rolling stock (train door)?

  - Concerning train door, sometimes door not opening or closing
  - train traction failure, (motor failures).

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- How long did it take to correct such failure?

  - For door failures, it is usually solved right way, sometimes it takes a day.
  - For traction failures, if the problem is known right way, otherwise it may take a week.

- What was its cost; approximate?

  - it usually has no cost for train door failures.
  - There are failures the need spare part changes i.e: traction motor board changes.

- What was its effect on LRT performance during that time?

  ~~lesser trains~~ - delay of trains' time on stations.

- How effective maintenance planning is?

  - it can be said that maintenance planning is a very important ~~factor~~ tool for the rolling stock division. Therefore, it has been very effective in general.

- Do you have enough tools to perform maintenance operations?

Yes/no------Yes------

- Are you able to repair your own components?

Yes/no------Yes, but there are components ~~to~~ repaired by the chinese company.

- What are the major reasons for not repairing some components?

  - not having ~~the~~ enough knowledge of how to repair.

- Summarize problems of maintenance in AALRT in order to find out the major ones (vital few problems) as Efficient maintenance is a prerequisite for ensuring economical and secure operations?

  - shortage of spare parts.
  - inadequate knowledge in some areas of trains' maintenance maintenance
  - inadequate knowledge in using some of the equipments in the workshop.

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Topic: Impact of rolling stock maintenance practices on Light Rail Transit operation performance

This is where I describe the study and let people know that their participation is voluntary and their data are anonymous and confidential.

Name.................................... Position .Railway Engineer (Title).
Division. Rolling Stock........ Department .Maintenance...........

- What is the importance of having a maintenance department?

As we know Railway is a safest means of transportation. To insure this, maintenance department involves functional checks, servicing repairing or replacing of necessary devices and components.

- What types of maintenance do you use?

Preventive maintenance
Corrective maintenance

- Do you have the outsourcing; subcontracting of maintenance?

Yes/no---Yes-------------

- How is LRT rolling stock performance measured?

Good

- What performance indicators do you use?

Availability of trains, train performance, skilled maintenance technicians, maintenance management, having full of necessary tools and devices including spare parts, delaying of servicing time,

- Is there any interruption caused by maintenance?

Yes/no---Yes-------------

- Do you have breakdown records?

Yes/no--Yes---------------

- What failures occurred concerning the rolling stock (train door)?

up to now all train doors are work properly. but some times there were a miss alignement and V-shape problems are occured.

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- How long did it take to correct such failure?

Not more than an hour.

- What was its cost; approximate?

- What was its effect on LRT performance during that time?

It delays the opening and closing of the door. i.e. it delays trains ~~departing~~ departing and arriving time.

- How effective maintenance planning is?

In LRT preventive maintenance is the major and main maintenance method and it decreases the unexpected failures and delaying time also it makes gives ~~the~~ effective service.

- Do you have enough tools to perform maintenance operations?

Yes/no--Yes----------------

- Are you able to repair your own components?

Yes/no--Yes----------------

- What are the major reasons for not repairing some components?

On some parts there is shortage of maintenance manual. and also ~~there~~ ~~in~~ some parts needs replacement and repairing devices.

- Summarize problems of maintenance in AALRT in order to find out the major ones (vital few problems) as Efficient maintenance is a prerequisite for ensuring economical and secure operations?

The main problem in AALRT rolling stock is the ~~wheel~~ displacement of the wheel. ~~As a maintain~~ because of this displacement (wheel) the trains may ~~be~~ out of operation for a long time ~~us~~ and it affects the securing of proper operations and ensuring economical growth.

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Topic: Impact of rolling stock maintenance practices on Light Rail Transit operation performance

This is where I describe the study and let people know that their participation is voluntary and their data are anonymous and confidential.

Name.................................... Position ...Railway Engineer.........

Division...Rolling Stock........ Department ....Maintenance.....

- What is the importance of having a maintenance department?

  - Reduce the occurance of breakdown failure by conducting preventive maintenance program and inspection.
  - Reduce the down time of train failure caused train by organizing and planning breakdown / corrective maintenance schedule

- What types of maintenance do you use?

  1. corrective Maintenance
  2. Breakdown Maintenance
  3. preventive Maintenance

- Do you have the outsourcing; subcontracting of maintenance?

Yes/no-----Yes------------

- How is LRT rolling stock performance measured?

  Based on
  - Availablity of train company (total)
  - Reduction of failure frequency
  - Reduction of period for Maintenance period.
  - Reduction of mean b/n failure

- What performance indicators do you use?

  No in general we use or measure the performance based on quality inspection or performance indicator.

- Is there any interruption caused by maintenance?

  - No operational interruption

Yes/no----------------------

- Do you have breakdown records?

Yes/no---------------------- both computer based failure record and Manual and written Document

- What failures occurred concerning the rolling stock (train door)?

  - Misalignment
  - Door closing and opening problems
  - non uniform opening and closing of all door at the same time.

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- As per the standard all door need to close or open at the same time unless it is isolated. so the Different opening and closing time of individual door
- Failure of alarm that indicate fully open or close

- How long did it take to correct such failure? it depend on the failure type
  - ~~[illegible]~~ high maintenance - '
    Medium maintenance - .
    small maintenance . .
- What was its cost; approximate?

  Depend on maintenance type and spare part cost with out in addition to maintenance duration the failure including the downtime for ~~[illegible]~~ maintaining the failure
- What was its effect on LRT performance during that time?
  No interruption as long as we do have a stand by train that can replace the failure train, if not the performance we be disrupted
- How effective maintenance planning is?

  Very good.
- Do you have enough tools to perform maintenance operations?

Yes/no-----------Depend on the job wide scope it is difficult to say we do have enough tools, but it we can say enough for all necessary & ~~the~~ the fix problem experienced.

- Are you able to repair your own components?

Yes/no-------------No] we will Replace the components rather to repair the components

- What are the major reasons for not repairing some components?
  → Lack of necessary machinery or tool required to repair or develop the ~~[illegible]~~ failed component to re-using
- Summarize problems of maintenance in AALRT in order to find out the major ones (vital few problems) as Efficient maintenance is a prerequisite for ensuring economical and secure operations?
  - Lack of well-advance skill particularly on those delicate sub system of train (TCU)
  - Lack of continious training that can improve the skill gap
  - Lack of some software feature (TCU) and unavailability of system manual
  - Lack of advanced tool (that can might serve as conduct condition based maintenance system or usin

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Topic: Impact of rolling stock maintenance practices on Light Rail Transit operation performance

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Name....Alem Behailu...   Position ....Railway Engineer
Division..Rolling Stock Maintenance   Department ..Maintenance.......

- What is the importance of having a maintenance department?

– To have Continouse / Uninterapted / Operation
– To maintain Availability & relaibility
– To give the most Safty & avoide failure

- What types of maintenance do you use?

– Periodic mentainance / preventive
– Corrective
– Risk-based / troubleshooting
– Condition-based

- Do you have the outsourcing; subcontracting of maintenance?

Yes/no-----------------------

- How is LRT rolling stock performance measured?

– Based on job evaluation performance measures. / for Staffs /

- What performance indicators do you use?

– Efficiency Measure

- Is there any interruption caused by maintenance?

Yes/no-----------------------

- Do you have breakdown records?

Yes/no-----------------------

- What failures occurred concerning the rolling stock (train door)?

– Door System, PIS System, TCU System, Bogie System, etc

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- How long did it take to correct such failure?

  Two years

- What was its cost; approximate?

  –

- What was its effect on LRT performance during that time?

  – Can be measured

- How effective maintenance planning is?

  Good

- Do you have enough tools to perform maintenance operations?

Yes/no-----------------------

- Are you able to repair your own components?

Yes/no-----------------------

- What are the major reasons for not repairing some components?

  – lack of Specialized tools

- Summarize problems of maintenance in AALRT in order to find out the major ones (vital few problems) as Efficient maintenance is a prerequisite for ensuring economical and secure operations?

– Spare part availability
– lack of Special tools
–

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