Case Study of Addis Ababa LRT IATP Signaling Subsystem RAM Analysis

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This is to certify that the thesis prepared by Worku Mesafint, entitled: *case study of addis ababa LRT IATP signaling subsystem RAM analysis* and submitted in partial fulfillment of the Requirements for the Degree of Master of Science (Electrical and Computer Engineering) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Declaration

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

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Date of submission: _____

This thesis work has been submitted for examination with my approval as a university advisor.

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Abstract

With the growing interest in the railway sector, mainly because of energetic reasons (electrified railway), there is a need to increase the efficiency of the railway lines. One way to optimize this sector, signaling system plays an important role for safe running of trains. Railway signaling systems ensure the safe operation of the railway network, and their reliability and maintainability directly affect the capacity and availability of the railway network, in terms of both infrastructure and trains. As most of its subsystem and components are working in open atmospheres, its operations are sometimes very difficult to monitor. In this context, proper and efficient maintenance activities can be useful to its effective operation.

This thesis seeks to study the reliability, availability and maintainability of a signaling system with failure and repair data by Markov modeling. Then reliability and maintainability of every sub systems are evaluated and graph is plotted for different time intervals. Moreover, maintenance intervals at different reliability values are also evaluated. Steady state reliability of different subsystems is also calculated. The model is verified with simulation of Addis Ababa LRT signaling systems with different scenarios.

The analysis from this thesis shows that reliability of rail signal and switch machine are the lowest among six subsystems, hence it is required more attention than other subsystems and maintainability of onboard IATP equipment, beacon (balise), LEU, CBI, and rail signal is almost good except onboard IATP, switch machine and CBI which is lowest. So onboard IATP, switch machine and CBI are needs special consideration.

Keywords: *railway, signaling system, avaliability,reliability, maintenability,markov*

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I would also like thank Ethiopian Railways Corporation (ERC) for giving me the chance to pursue my graduate study in Electrical Engineering for Railway Systems.

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Lists of abbreviations and Symbols

λ	repair rate
μ	failure rate
A	Availability
AA-LRT	Addis Ababa light rail transit
AB	Active balise
ATC	Automatic train control
ATP	Automatic train protection
ATS	Automatic train supervision
CC	Carbone controller
CBI	Computer based interlocking
CENELEC	European Committee for Electro technical Standards
CTMC	continuous time Markov chain
DCS	Data Communication System
DMI	Driving Monitor Interface
DTMC	Discrete Time Markov Chain
EN	Europe Standard
ERC	Ethiopian rail corporation
ERTMS	European Rail Traffic Management System
FMEA	Failure Mode Effet Analysis
FTA	Fault Tree Analysis
GPS	Global positioning system
LEU	Line Encoder Unit
MDBF	Mean Distance Between Failure
MDTF	Mean Distance To Failure
MMS	Maintenance monitoring system
MSS	Maintenance support system
MTBF	Mean time between failure

MTIB	Moving train initialisation beacon
MTTF	Mean time to failures
MTTR	Mean time to repair
ODEs	Ordinary differential equations
PB	Passive balise
PRAM	Project RAM assuration manager
R	Reliability
RAM	Reliability availability maintainability
RAMS	Reliability availability maintainability and safty
RB	Relocation Beacon
RBD	Reliability block diagram
RC	Railway corridor
RCM	Reliability Centered Maintenance
SPN	Stochastic Petri net
TBF	Time between failure
TS	Track section
TTR	Time to repaire

Chapter 1: Introduction

1.1 Background

The railway network is a complex and distributed system with several technologies working together to fulfill the demands on capacity, speed and mobility to transport goods and passengers. The railway system can be divided into different systems depending on functionality, such as the rolling stock, the track, the power supply, the signaling system, etc. Railway infrastructure managers need maintenance analysis and planning tools that enable them to systematically analyze and optimize budget needs, minimize the total costs for the required reliability, availability, maintainability and safety (RAMS) level, and guarantee the quality of the railway assets in the long run [1]. Systematic maintenance management of the railway assets is required to deal with short-term costs and performance demands and to guarantee RAMS in the long term [2].

The managers responsible for determining maintenance actions face an abundance of data and have a complicated task transforming these data into information that will support maintenance actions [3]. During the operation and maintenance of the railway infrastructure, lots of data are collected and managed. The purpose is to control and analyze the current state of the system. The data include the system architecture, maintenance reports, work orders performed, etc. If up-to-date documentation is lacking, maintainers have serious problems [4]. In addition, confusing data/remarks in the databases often lead to misinterpretations. Structured databases containing the complete information are required to identify where failures are located and the dominant factors causing them, [5]. Without properly functioning maintenance, the railway infrastructure would soon become inefficient. Signaling systems are complex combinations of software and hardware; they play an important role in the control, supervision and protection of rail traffic and their availability affects the performance of the whole system. Further complicating the issue is the fact that signaling systems are composed of several different systems; each has its own purpose, but the main functionality of the overall system is determined by the interoperability between them. Railway managers need to have a holistic view of the various railway systems (especially signaling systems which must be interoperable) to optimize maintenance. When performing the maintenance of a system which is a combination of software and hardware, as for example, a signaling system, and the maintainer must understand how changes will affect the

system, how the system is built, what role the different parts play and how they are interconnected. The development of signaling is closely linked to the development of railways. It began as a manual system determining access to a line, but the growing demand for transportation and the increasing number of trains made this system inadequate. Advanced technologies were implemented to supervise and control railway lines. These were mainly analogue systems, based on relay technology (e.g. track circuit, axle counter, relay interlocking). Today these systems are being replaced by digital control systems based on electronics (e.g. balise, electronic interlocking, line side electronic unit – LEU), but both systems coexist in most of the railway network. Over the years, many signaling and train control systems have evolved, creating a highly technical and complex industry. Every country has developed different solutions over the years. The operation of trains must not be country-dependent, however, and the creation of a unified signaling system would prevent the need to make changes between countries.

There are a number of items within the larger category of signaling systems [6]. For example, track circuits, axle counters and GPS-based Systems can be used to locate a train. Track circuits and signals can help to control the traffic on the railway line to prevent collisions. Balises and radio based systems allow the train control centre to restrict the movement of trains, and advanced systems i.e. European Rail Traffic Management System (ERTMS) or Automatic train control system (ATC), supervise and control the railway network. They interpret the inputs from the other systems, creating restrictions on the train route to ensure safe operation.

Signaling system is an integral part of Addis Ababa railways so it should be very reliable and should be maintained effectively and efficiently. This thesis seeks to study the reliability, availability and maintainability of a signaling system with failure and repair data. Reliability of different subsystems and steady state reliability of different subsystems will be calculated with the help of Markov chain process so that rail maintenance cost can be decreased and also danger of accidents can be reduced. These subsystems can be brought back into serviceable condition after repair or replacement. It is interesting to note that the failure of subsystems and their units can never be predicted precisely as they depend upon the operating conditions, environment, and repair policy used.

1.2 Problem and Research Issues

The main problem is to make the railway-RAMS processes more cost effective and streamlined in a way that satisfies requirements of main stakeholders. Stakeholders are the authorities, the railway companies, and finally, the customers who are going to use the railway system.

Railway signaling system is the major part of railways, so it was the part of research from many years. Many works have been done in this field for the safety and maintenance of railway signaling system. When such a system fails, a maintenance work is carried out to restore the system back to its state just before the occurrence of its failure. As the frequency of failure of subsystems and/or components increases over time, a corrective maintenance action is performed to improve the conditions of subsystems and components, thereby reducing the probability of failure in subsequent time-interval. The use of such a reliability model would help an analyst identify the problem causes and suggest remedial measures so as to continually improve its reliability. This would in effect ensure a consistent performance of the system as a whole. A study, therefore, will be conducted for analysis of reliability, availability and maintainability (RAM) of Addis Ababa LRT signaling system and improvement of it by proper inspections.

1.3 Purpose and Objectives

The purpose of this thesis is to explore the areas that could improve the performance of railway signaling systems during the operation life cycle phase, by enhancing their dependability.

1.3.1 General objective

The main objective of this paper is to suggest improvements of the RAMS process as it is conducted in railway signaling system.

1.3.2 Specific objective

Mathematical model of system to determine the RAM performance, and comparing with RAM contract requirements.

- To analyse RAM of IATP subsystem of AA-LRT;
- To develop markov mode for the analysis;
- To estimate reliability and maintainability pattern of different signaling subsystems at different time intervals and

- To compare the result with the contract;
- Identify the subsystem which needs more focuse.

1.4 Methodologies

This thesis use a case study of Addis Ababa railway signaling system; it use a sub case for the exploratory analysis and to validate the developed methods. This research is focused on operational or field data, collected under actual operating conditions. The data are appropriate for reliability assessment since they realistically represent the whole of the operational conditions of the particular case. When studying maintenance records, it is necessary to establish boundaries on the research due to limitations of time.

The literature review implemented throughout the whole thesis to obtain the source of knowledge of the research topic and to continuously improved and updated to help the research to obtain the quality of the results. Interview surveys is conducted to get more information about railway operations.

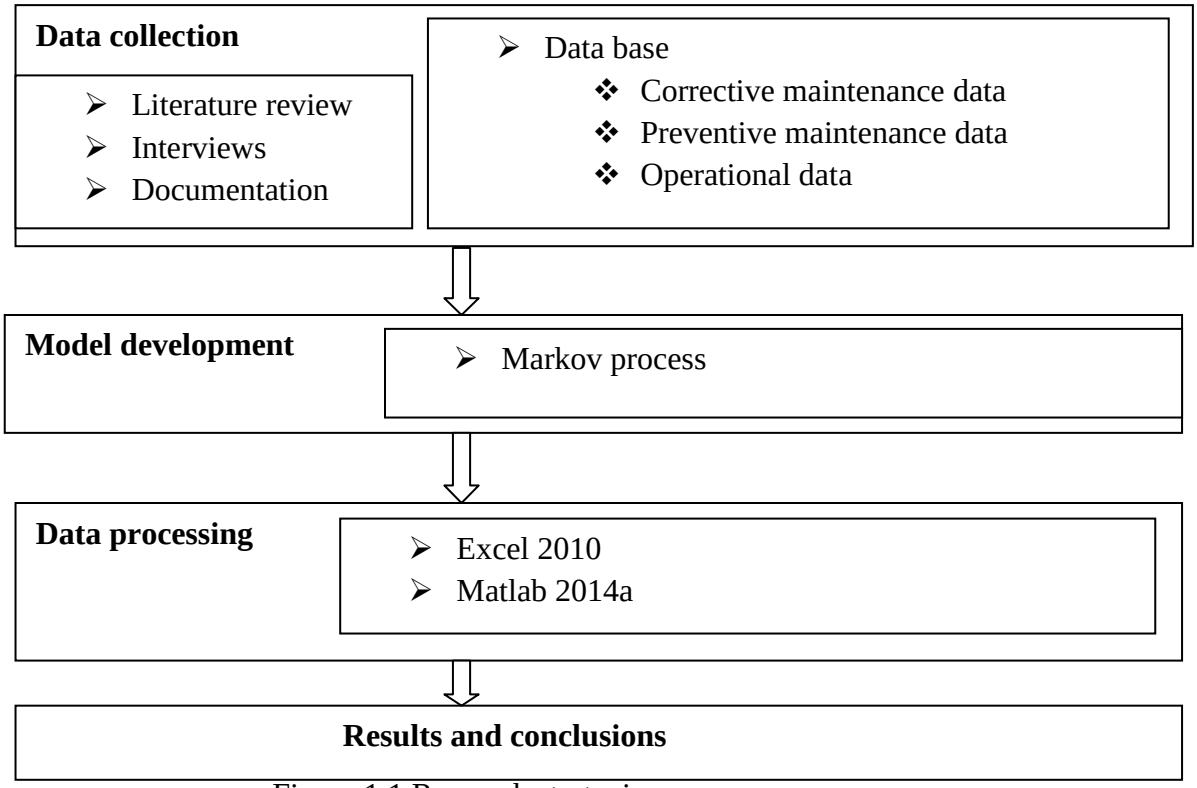

Figure 1.1 Research strategies

1.5 Beneficiaries

This thesis directly or indirectly will benefit the following members of the society to have safest, efficient, reliable and sustainable railway system:

- The Researcher (student)
- Ethiopian Railway Corporation (ERC)
- The Government of Ethiopia
- Railway infrastructure managers;
- Train and station operators; etc…..

1.6 Scop of the Study

The scope of this research is to perform an exploratory analysis which will provide visibility to the best areas to consider improving the reliability, availability, and maintainability of railway subsystems of intermittent automatic train protection (IATP) signaling subsystems. The case study of the AA-LRT railway IATP signaling subsystems. This thesis does not cover other subsystems of AA-LRT signaling system except IATP.

1.7 Contribution

This paper contribute to Ethiopian Railway Corporation (ERC) railway infrastructure managers and operators to reducing maintenance and sparing costs while maintaining and/or increasing production, detecting failures in the early part of opration; increasing the effectiveness of the signaling system and to study whether results are in line with set objectives.

1.8 Organization of the thesis

The thesis is organized in six chapters.

Chapter 1, Introduction, introduces the area of research, defines the problem and research issue, and states the main and specific objectives, state the methodology and organization of thesis.

Chapter 2, Theoretical Background and Literature Review, provides the framework used in the research and gives a summary of the different approaches used to deal with the problem statement. Many research works have been done to improve working of signaling systems to make it more reliable. Therefore in this chapter Literature survey is presented.

Chapter 3, The signaling system structure of AA-LRT and its sub-systems. Based on the data obtained from AA-LRT, components employed in the design and their functional interconnection is presented for each subsystem.

Chapter 4, In this chapter Reliability, Maintainability, Availability modeling of differents signaling subsystems is done with the help of markov process. A reliability block diagram (RBD) of the IATP Signaling subsystem has been developed. Markov's transition diagram has been presented, making some assumptions. From the transition diagram state transition linear differential equations are derived for the markov process and then the steady state performance of Signaling system has been discussed.

Chapter 5, It is about rsult and discussion. Depending on the formulas developed in chapter four,different graphs are plotted. After having the graph, we discussed what the graph result is to mean.

Chapter 6, The final chapter is recommendation and conclusion. Here, we conclude our work based on the result obtained and discussed in chapter five. Further recommendation for the development of new model or improvement of the result in this thesis is suggested.

Chapter 2 : Theoretical Background and Literature Review

2.1 Theoretical Background

The Addis Ababa railway is indeed a dynamic, diverse corporatized entity that has the potential to play an important role in the development of a sustainable transportation system in the country. It needs more research to improve working of signaling systems to make it more reliable, to decrease maintenance cost.

Documents are good sources of data for numerous reasons, e.g. accessibility, and they contain information that would take a long time and effort to gather. Documents may be fragmentary, not fit the conceptual framework of the research, or their authenticity may be difficult to determine. Hence, interviews and a literature review are used as a cross-check in this analysis of the signaling systems in the Addis Ababa railway.

2.2 RAM

Reliability, Availability and Maintainability (RAM) is defined to indicate the quality and working performance of a system. It is a system characteristic and can be achieved by the application of some particular methods, tools and techniques which performed through whole lifecycle of the system.

Standards have been developed for the RAM of railway systems (EN 50126), with special focus on the signaling, communications and processing systems used by the railway (EN 50126, EN 50128, EN 50129). These standards aim to enable interoperability of the line without affecting the safety of the system. The railway standard CENELEC EN 50126 is the specification and demonstration of reliability, availability maintainability and safety in the railway applications. This standard defines RAM in terms of reliability, availability, maintainability and safety; it stresses their interaction and defines a process, based on the system lifecycle and tasks within it, for managing RAM [7].

2.2.1 Reliability

Reliability is a characteristic of an item, expressed by the ‘probability that a specified item will perform a specified function within a defined environment, for a specified length of time’. For

complex systems the reliability requirement is normally specified in terms of the mean time between failures (MTBF) or as a failure rate, for example failures per million operating hours.

Mean Time Between Failures (MTBF)

MTBF — expected or predicted average (arithmetic mean) time between failures of a specific system, assuming that the system goes through cyclic periods of failure and repair [8].

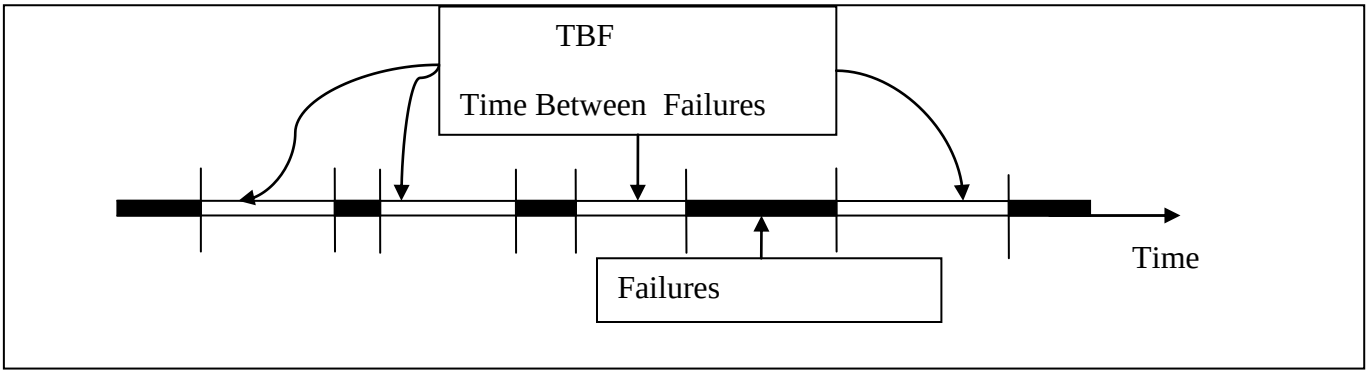

Figure 2.1 state of MTBF [8]

The basic parameter for the reliability study is defined as MTBF.

MTBF = Total operating time/ number of failures

This parameter is used to detect those elements that you should pay more attention. To verify the reliability of the system during its lifetime, it shall prepare a plan for monitoring the reliability, which will form part of the RAMS program to calculate this parameter it will be necessary to have all the design information, configuration of the subsystems and the methodology that it is going to be used. Notice that there are different ways to calculate this parameter.

Table 2.1: Typical reliability parameters that have been used for track

No.	Reliability Parameter	Description
1	Mean Time To Failure (MTTF)	for non-repairable system
2	Mean Distance To Failure (MDTF)	for non-repairable system
3	Mean Time Between Failure (MTBF)	for repairable system
4	Mean Distance Between Failure (MDBF)	for repairable system

Reliability equation for all further analysis has been modeled by exponential failure time distribution as following:

$$R = e^{-\lambda t} \quad (1)$$

Where R is reliability, e is the natural log base, λ is the failure rate and t is the time duration.
With low failure rates and short exposure times, the values for reliability are close to one, since failure rate, λ, is the reciprocal of *MTBF*, the expression for reliability can be rewritten as:

$$\lambda = \frac{1}{MTBF} \quad (2)$$

$$R = e^{-\frac{1}{MTBF}t} \quad (3)$$

2.2.2 Availability

The ability of a product to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval assuming that the required external resources are provided. The number of trains that are available for service without technical restrictions will be checked each day.

Availability is the availability of an item/system is the probability that this item/system will be in a state to perform a required function under given conditions, at a given instant in time or over a time interval, assuming that the given external resources are provided.

$$Availability = 1 - Unavailability/Availability\ max \quad (4)$$

The intrinsic availability facilitates measurement of the availability of an element of a system which indicates the operation of the element depending on the design.

To calculate this parameter it will be necessary to have all the design information, configuration of the subsystems and the methodology that it is going to be used. Notice that there are different ways to calculate this parameter.

For systems without redundancy (simplex), availability is measured as:

$$A = \frac{MTBF}{MTBF+MTTR} \quad (5)$$

Here A is the fraction of total time the system is available, MTBF is its mean time before failure and MTTR is the mean time to repair. For the series of sub systems, there is an equation that puts

this into perspective. It says that the failure rate for the total system λ_T, is the sum of the failure rates, λ_i, for all of the series subsystems.

$$\lambda_T = \lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7 \ldots + \lambda_n \quad (6)$$

Since MTBF is the reciprocal of failure rate, equation (6) can be rewritten as when there is redundancy in the subsystems that can affect positively in the total reliability of system and leads to total reliability improvement. The effect of redundancy on reliability of each redundant subsystem is calculated as the following formula:

$$MTBF_p = \frac{MTBF_i^{(n-1+1)}}{n(MTTR)_i^{(n-r)}} \quad (7)$$

Here , n is the number of parallel elements in the system and, r, is the number that are required for successful operation. As it is conspicuous in the mentioned equation having redundancy can increase the total MTBF of system enormously and this will lead to high reliability of total signaling system, subsequently in the design stage considering redundant subsystems would be much effective method to improve the reliability of signaling system beside other modifications. It follows then for the mean time to repair (restoration) at the system level MTTRs is calculated with following formula.

$$MTTR_s = \frac{\sum_{i=1}^{n} MTTR_i / MTBF_i}{\sum_{i=1}^{n} 1/MTBF_i} \quad (8)$$

Availability of a system composed of two components connected in a serial topology:

$$A = \prod_{i=1}^{n} A_i \quad (9)$$

Parallel topology:

$$A = 1 - \prod_{i=1}^{n} (1 - A_i) \quad (10)$$

2.2.3 Maintainability

The probability that a given active maintenance action, for an item under given conditions of use can be carried out within a stated time interval when the maintenance is performance under stated conditions and using stated procedures and resources.

Maintainability is the probability that a given active maintenance action, for an item under given conditions of use can be carried out within a stated time interval when the maintenance is performed under stated conditions and using stated procedures and resources.

Alternatively Maintainability is a characteristic of design and is essentially a measure of the ease with which the item can be maintained. A more formal definition is 'maintainability is a characteristic of design and installation, expressed as the probability that an item will be restored to operating condition, within a given period of time, using prescribed procedures and resources. The most commonly used measure of maintainability is the mean time to repair (MTTR). Where the logistical delays aren't considered mean down time (MDT).

Among the basic parameters that characterize the maintainability of the elements and systems we have the following:

MTTR (Mean Time to Restore)

MDT (Mean down Time)

Mean Time To Repair (MTTR)

• **MTTR** — the average expected time to restore a unit from a failure condition to a fully working condition.

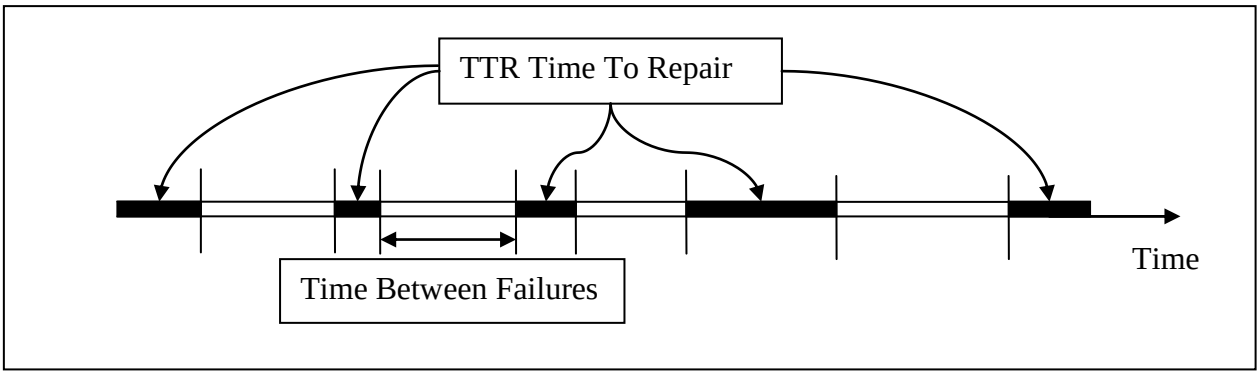

Figure 2.2 state of MTTR [8]

Maintainability will be reviewed to assure maintenance of the elements in each of the systems and subsystems. Maintainability requirements shall be included in the specification either directly in the form of MTTR targets for specific equipment.

Maintainability equation for a system in which the repair times are distributed exponentially is given by:

$$M(t) = 1 - e^{-\mu t} \tag{11}$$

Where μ= repair rate and $\mu = \frac{1}{MTTR}$ (12)

2.3 Methods and tools for RAM analysis

Numerous reliability-availability techniques exist that can be used to provide quantitative performance measures such as system reliability, availability, throughput etc. Reliability availability methods may be used at the design stage for assessing various designs options and/or deriving effective inspection and maintenance policies at the operational stage for any given system configuration, failure and repair data for components, and the interrelationship between them. The various reliability-availability methods can be broadly classified as measurement based and model based methods [9]. Measurement based methods are expensive as they require building a real system or its prototype and taking measurements and then analyzing the data statistically. In the context of process systems, at the design stage where the system or its prototype is not yet been built, the use of measurement technique is not feasible. While at the operational stage it can prove to be very expensive to inject faults into a real system to measure data. Model based methods are much easier to use and are particularly useful at the design stage to screen lots of design alternatives without building the actual system. It is important to mention here that the model-based methods are also subjected to model uncertainty which propagates into RAM performance. Model-based methods can be further categorized into simulation methods and analytical methods, both require a system model to be constructed in terms of random variables for the state of the underlying units [10]. The simulation method uses a probability distribution function for equipment failure and repair actions and uses a simulation engine (usually a Monte Carlo simulation engine) to simulate the detailed dynamic behavior of the system and evaluate the required measures. Analytical methods use analytical models that consist of sets of equations describing the system behavior. For simple systems it is possible to obtain a closed-form solution of the analytical model, but more often numerical methods are used to solve the underlying set of equations. A classification of reliability-availability analysis methods is given in figure 2.3 [11].

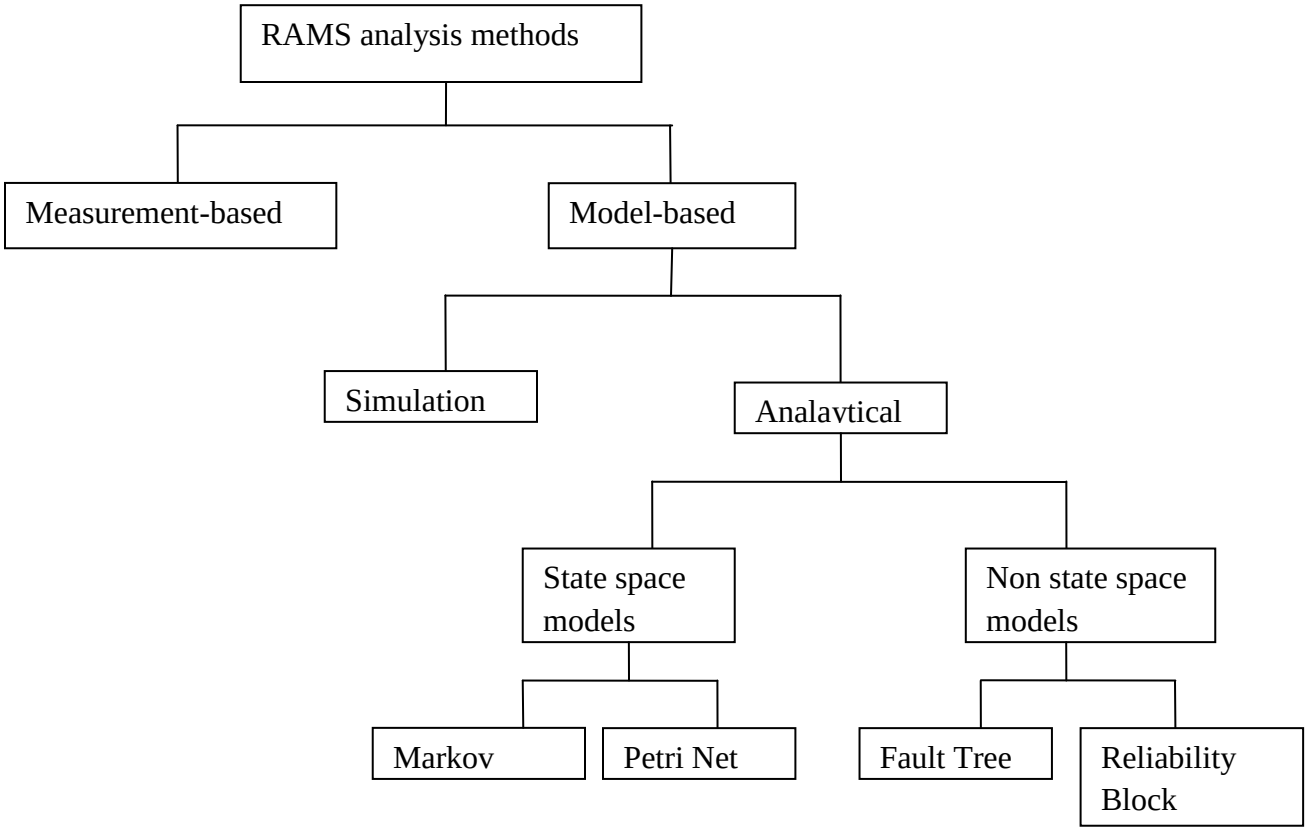

Figure 2.3: Classification of RAMS analysis methods [11]

2.3.1 Analytical methods

Analytical methods are used to calculate the reliability and the availability measures of a system by using structural results from applied probability theory. A number of analytical methods have been developed which can be broadly categorized into state space or non state space modeling techniques [9]. The choice of an appropriate modeling technique to describe the system behavior depends on factors such as

- Measures of interest (steady-state or time-dependent, reliability, availability etc.)
- Level of detail and complexity of the given system (size, structure etc.)
- Available tools to specify and solve the model
- Availability and the quality of data

Before going into details of the different analytical methods, it is useful to understand the meaning of the term state. The term state can be used in reference to a component or a system. For example, in Figure 2.4(a) two possible failure modes for component 1 are described by the up and down states. Now for a system, e.g. a two-component parallel system, as shown in Figure

2.4(b), there are four possible states. The number of total states for a system depends on the total number of components and on the possible failure modes for the underlying components. For instance, considering three failure modes for a component (up, degraded and down), a two-component system will have $2^3 = 8$ possible states [11].

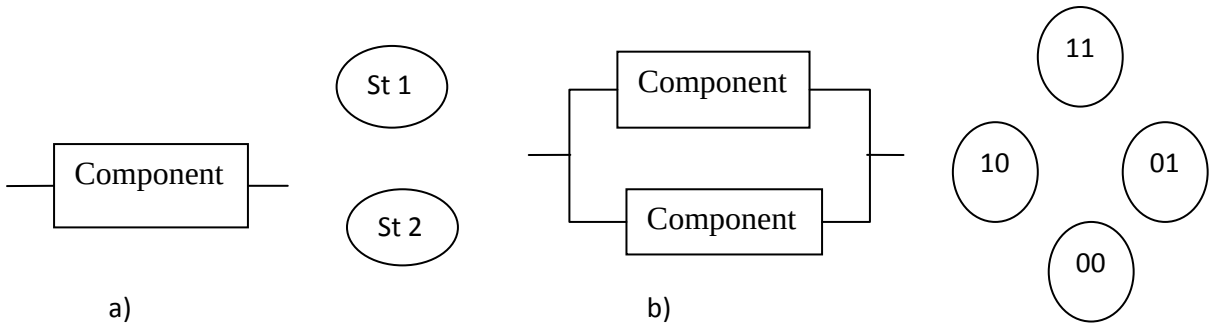

Figure 2.3: Component and system states [11]

Each system state represents a set of local states, meaning that a state can represent when all of the components are functioning, when one specific component has failed, when another has failed, when two have failed, and so on until every possible global state is represented. In addition, there are transitions that exist between many of these states, depending on the nature of the system, and each is given a failure rate that is assumed to be constant.

Non-state space methods

As the name suggests, non-state space models can be solved without generating the underlying state space. These models can be easily used for solving systems with hundreds of components. These models can be applied to fairly large systems to provide performance measures such as a system's steady-state availability, reliability and the mean time between failures (MTBF). The key assumptions used in non-state space models are statistically independent failures and independent repair for components. Two prominent non-state modeling techniques used to evaluate system availability are the fault tree (FT) and reliability block diagrams (RBD) [11].

Fault tree (FT)

Fault tree analysis techniques, first developed in 1962 at Bell Telephone Laboratory, have long been used by a wide range of engineering disciplines as one of the primary methods of predicting system reliability and availability parameters. A fault tree is a pictorial representation of logical

relationships between events and it can be used to represent a combination of events that will lead to system failure, called as top event. However, some of recent developments such as dynamic fault trees [12] which are able to model sequence dependent events have enhanced the capabilities of fault trees. Another limitation is that a manual construction of a fault tree can be time consuming and susceptible to human error. This limitation has been addressed with the development of new sophisticated algorithmic and computational tools for the evaluation and the synthesis of fault trees. Several examples exist in the literature of the successful application of fault tree analysis to industrial process systems [13].

Reliability block diagram (RBD)

A reliability block diagram is a graphical representation of how the components of a system are connected reliability-wise. The simplest and most elementary configurations of an RBD are the series and parallel configurations. In a reliability block diagram each component of the system is represented as a block that is connected in series, and/or parallel, based on the operational dependency between the components [9].

State-space methods

The non-state models described above cannot easily handle more complex situations such as failure/repair dependencies, shared repair facilities, different types of maintenance for different units with different effects and different resource requirements. In such cases, more detailed models such as the Markov chain model and Petri net models can be used. The state space method is a technique that aims to make an exhaustive study of the transition of states of components of a system. This allows for a study of repairable systems, and is often irreplaceable in doing so. It is particularly useful in the study of Markovian processes, and as with any other method, easier to implement with small systems. Non Markovian processes can also be modelled, but calculation becomes harder unless a semi-Markovian process is being studied. Under special conditions, consequence trees can be used as an approximation to semi-Markovian processes [13].

The modelling follows three major steps. The first step is to make an exhaustive list of system states by verifying the combinations of every elementary system or component state (operating, failed, other…). If a system has n components with x possible states for each component then there will be $p=x^n$ possible system states. With two possible states and ten components, a value of $2^{10}=1024$ possible system states is obtained – this number climbs particularly fast with the size

of the system. Failure mode effect analysis (FMEA) can be useful during this stage as an auxiliary method. The second step consists in carrying out a study of the possible state transitions of components or elementary systems accounting the interactions between them. Here, all failures, repair stages and other maintenance procedures must be accounted. Interactions are important for sometimes failures in one component can trigger failure in others. There can also be procedures which return a failed system to the operating state once they are completed. CTM and DTMC can be of assistance during this stage [11].

Finally, the last step is the calculation of the probabilities of being in certain states or of different reliability parameters (MTBF, MTTF, MTTR, failure rate, etc). This can be achieved by calculations applied from the qualitative study done in the last stage, through the transition rate matrix. The qualitative analysis can be represented through a diagram, where every node is a given system state, and every arc linking them represents the transition between states. The transition rates are represented through λ or μ, that is the failure and repair rates of components or elementary systems.

Markov model

Modeling using Markov analysis is widely used in safety and reliability engineering. The reliability behavior of a system is modeled by Markov chains as a state transition net of sequence which consists of a set of discrete states that the system can be in, and defines the speed at which transitions between those states takes place. As such, Markov models consists of representations of possible chains of events that is transition, within systems, which in the case of reliability and availability analysis corresponds to sequences of failures and repair. Markov analysis is technique used to obtain numerical measures related to the probability of a given state concerning availability and reliability of a system or part of a system. Common Markov model is analyzed in order to determine such measures as the probability of certain state at a time, the amount of time a system is expected to spend in a given states, for example representing the rate of failures and repairs [10].

Based on the approximation of the temporality of all stochastic events by the exponential distribution the Markov analysis is well-suited to handle rare events, unlike simulation based analysis, and therefore allows such events to be analyzed within a reasonable amount of time. A Markov model (chain) describes a stochastic process within a number of states in which the

probability of occurrence of future states in conditional only upon the current state; past state are inconsequential (the memory-less property).

A state of Markov chain, represented by a circle or oval (figure 2.3), corresponds to global system state. A change of system states is always stochastic, using the exponential distribution, which is the only one satisfying the memory –less property. It is represented by arc attributed with the parameter λ of the exponential distribution rate [1/time unit], used usually for modeling of failure processes, μ is used for repair actions. The rate corresponds usually to the reciprocal value of mean time to failure MTTF or to repair MTTR assuming that its value is constant during whole system life time. An n-state Markov model leads to system of n-coupled differential equations.

The Markov model provides a powerful modeling and analysis technique with strong applications in time-based reliability and availability analysis. The reliability/availability behavior of a system is represented using a state-transition diagram, which consists of a set of discrete states that the system can be in, and defines the speed at which transitions between these states take place. The transition from one state to the next state depends only on the current state irrespective of how the system has arrived in that state. The Markov models can be classified into continuous time Markov chain (CTMC) and Discrete Time Markov Chain (DTMC). In case of CMTC, the rate of transition between different states is described by ordinary differential equations (ODEs). While in case of DTMC, they are described using a set of algebraic equations [11].

Markov models provide greater modeling flexibility with some of the following advance features

- an ability to model component dependency issue such as cold or warm standby
- an ability to model sequence dependent behavior an ability to handle different types of maintenance

Petri net

Petri net of different statments can be used to evaluate reliability and availability measures for a system at the design stage. A Petri net is a directed-graph (digraph) consisting of places, transitions, arcs and tokens. Tokens are stored in places and moves from one place to another along arcs through transitions. A marking is an assignment of tokens to the places and these may change during the execution of a Petri net. If the transition firing times are stochastically timed, the Petri net is called a stochastic Petri net (SPN). If the transition firing is distributed

exponentially, it is possible to make a statistical approximation of the same availabilities as those of homogeneous continuous Markov chains models [11].

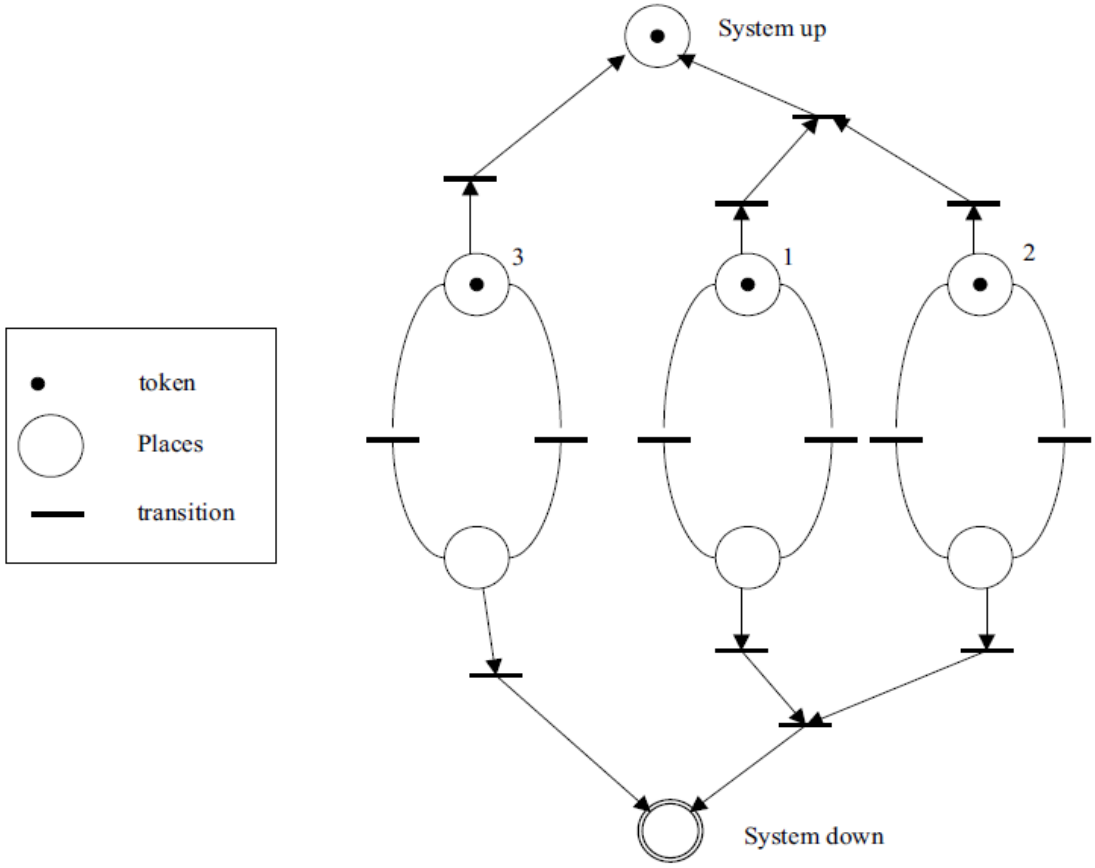

Figure 2.4: Petri net model for an illustrative example [11]

2.3.2 Simulation methods

It is hard (or sometimes impossible) to obtain reliability and availability measures analytically, for modern large and complex systems with equipment that follows different failure and repair distributions. Simulation is used in these cases as an approximation to remedy the limitations of analytical methods. The first step in the simulation method is to construct a system model (FTA, RBD, Markov state-space diagram etc.) describing the interrelations between underlying components. A computer program generates random draws from these distributions to simulate when the system is up and down, stores tables of failure, failure effects, etc. in a log and tracks system or function capability over the considered time horizon. A variety of relevant parameters can then be derived from the log. The number of simulation runs required for accurate

availability measure results will depend on the variation in the output measure at each run. Simulation methods are very flexible and can provide accurate predictions for system perform measures. In particular, they overcome the limitations of the analytical methods and provide time-dependent availability, number of failures and other time dependent measures (cost, throughput etc.) even in cases where non-exponential distributions are used to describe equipment failure and maintenance actions. Therefore, they are well suited for commercially available software used for RAM studies. In the last decade, a numbers of authors have published papers on the successful application of simulation methods for availability analysis of industrial systems [10].

2.4 Comparison of Reliability Analysis Techniques

Table 2.1 shows a comparison of the different approaches to reliability analysis, and a summary of some of the important characteristics of the methods discussed

Table 2.2 Comparison of Reliability Analysis Method Characteristics [24]

Characteristics	FTA	RBD	Markov Chain	Petri Nets
Static	X	X		
Dynamic			X	X
Logic-based	X	X		
State-space			X	X
Top-down	X	X	X	
Variable distribution	X	X		X
Can be used for dependent event			X	X

2.5. Markov Process Model

Markov model is a random process characterized as memory less. The next state depends only on the current state and not on the sequence of events that preceded it. Markov model is a better technique that has constant failure rate and repair rate. Modern probability theory studies chance processes for which the knowledge of previous outcomes influences predictions for future experiments. In principle, when a sequence of chance experiments, all of the past outcomes could influence the predictions for the next experiment. In Markov chain type of chance, the

outcome of a given experiment can affect the outcome of the next experiment. The system state changes with time and the state X and time t are two random variables. Each of these variables can be either continuous or discrete [17]. Various degradations on IATP signaling system can be viewed as different Markov states and further degradation can be treated as the outcome of the present state. In this thesis the IATP signaling subsystem is treated as a discrete state continuous time system with two possible outcomes, namely, S1: Good condition and S2 System completely fails. Partial degradation failures and partially working were not considered. The calculation of the reliability, availability and maintainability of the IATP signaling subsystem is complicated since the system has elements or subsystems exhibiting dependent failures and involving repair and standby operations.

2.6 Advantages of Markov Analysis Model

The advantage of the Markov process is that it neatly describes both the failure of an item and its subsequent repair. It develops the probability of an item being in a given state, as a function of the sequence through which the item has traveled. The Markov process can thus easily describe degraded states of operation, where the item has either partially failed or is in a degraded state where some functions are performed while others are not [24].

1. Simplistic Modeling Approach: The models are simple to generate although they do require a more complicated mathematical approach.

2. Redundancy Management Techniques: System reconfiguration required by failures is easily incorporated in the model.

3. Coverage: Covered and uncovered failures of components are mutually exclusive events. These are not easily modeled using classical techniques, but are readily handled by the Markov mathematics.

4. Complex Systems: Many simplifying techniques exist which allow the modeling of complex systems.

5. Sequenced Events: Often the analyst is interested in computing the probability of an event resulting from a sequence of sub -events. While these types of problems do not lend themselves well to classical techniques, they are easily handled using Markov modeling.

2.7 Literature Review

Railway is playing a very important role in the transportation, hence work is being done in this field from many years. Many research works have been done to improve working of signaling systems to make it more reliable, to decrease maintenance cost, to make it working efficiently so that accidents can be stopped by minimum effort. Some of the researches conducted on the area of railway signaling and related to this work are briefly reviewed below:

[16] A case study on Swedish railway signaling systems with different scenarios. The results show that the probability of being in a state where operation is possible in a degraded mode is greater than the probability of not being operative at all, which reduces delays but requires other risk mitigation measures to ensure safe operation.

[17] A case study on indian railway signaling systems reliability and inspection modeling study the reliability, availability and maintainability of a signaling system with failure and repair data by Markov modeling. The signaling system is classified in different subsystems like track circuit, signal unit and point and point machine.

[18] Propose a Markov Reliability model for a transporter based fail safe and fault tolerant node for use in a network of distributed safety critical railway signaling systems. Using the Markov model they quantify the reliability and safety in terms of Probability of being in unsafe state, probability of safe shutdown during the useful life period and last phase of bath-tub curve.

[19] Studied the analytical probability models for an automated system that consists of n-machines in series with common transfer mechanism and control system is developed. The models assume both failure and repair rates to be exponentially distributed.

[20] Sets out the requirements for specifying of Reliability, Availability and Maintainability (RAM) as well as requirements for designing to achieve specified RAM targets.

[23] The Reliability Centered Maintenance (RCM) approach for the infrastructure and logistics of railway operation‘ aimed to study the application of reliability centered maintenance

techniques to the railway infrastructure. In this RCM was applied to large scale railway infrastructure networks for achieving an efficient and effective maintenance concept.

[21] Proposed tools to assess the dependability and safety of signaling systems during the operation and maintenance phase to facilitate continuous improvement of dependability and safety of signaling systems leading to risk reduction in railway operation by the use of field data.

[22] The main strategy in this paper was to introduce closer follow-up activities towards the later project phases in engineering. Es-pecially, this is true valuable regarding the final-design decisions. At this stage, most of the system details and characteristics are known, and the RAMS analyses and evaluations would be more accurate and applicable.

[24] Analyses of the reliability, availability and maintenance of AA-LRT railway level cross signaling system with initial design failure and repair rate data used to estimate the reliability, availability and maintenance for each subsystem.

[25] Failure propagation models for the subsystems of AA-LRT signaling system are modeled on Matlab-Simulink, where signaling equipments in a main station are represented. Functional interactions between those equipments are also represented.

From above literature review we have got that work is being done in this and related field from many years. Many research works has been done to improve working of safety critical systems to make it more reliable. The above experiences are motivating for going into the problem in order to analayis railway signaling system on more effective RAM implementation.

CHAPTER 3: Addis Ababa Railways Signaling System

3.1 Overview of AA-LRT

Currently AA-LRT project has two lines, the east-west line and the south-north line. About 3 km is the sharing section for both E-W route and N-S route, which has the greatest passenger current [15]. The east-west line phase I project starts from Ayat and ends at Torhailoch. The total length is 17.4km. There are 22 stations, among which 5 are elevated stations, 1 underground station and 16 ground stations. The depot locates at the west ends of the project.The south-north line phase I project starts from Menelik II Square and ends at Kaliti. The total length is 16.97km. There are 22 stations, among which 9 are elevated stations (5 common stations at the common line), 2 underground stations and 11 ground stations. The depot locates at the south end of the project.

Signaling system of railways consists of a group of devices and methods with which the movement of a train is controlled on the flanged steel rails so as to prevent the occurrence of accidents, ensuring the safety of the passengers, the operating personnel, and the rolling stock. A **'**signal**'** is defined as a medium, which conveys a particular pre-determined meaning in non verbal form.

Signals are used to indicate one or more of the following:

1. That the line ahead is clear (free of any obstruction) or blocked.
2. That the driver has permission to proceed.
3. Which way points are set?
4. The speed the train may travel.
5. The state of the next signal.

3.2 Addis Ababa railway signaling system

The research is based on data obtained from the Addis Ababa railway signaling PRAM (Project RAM assuration manager). PRAM is responsible for RAM activities of the project, to ensure the system RAM level meets the requirement of the contract [14].

The duty of PRAM:

- Define and implement RAM plan;
- The RAM requirements assigned by the system level to sub-system level;
- Tracking system design of RAM activities;
- Define and implement system level failure mode effect analysis FMEA;
- Define and implement the system level RAM prediction, evaluation, analysis and validation.

The Addis Ababa railway signaling system is composed of the following subsystems

- iTC subsystem(IATP subsystem);
- iLock subsystem(CBI subsystem);
- iTC subsystem(ATS subsystem);
- DCS subsystem;
- MSS subsystem.

3.2.1 ATS subsystem

The automatic supervise system (ATS) is the core of supervise system. It acquires and processes the information from trackside and equipment centralization stations in real time and provides a human-machine interface. The graphical model illustrations are adopted. It also provides a set of alarm management system for online analysis and postmortem investigation and establishes history records of relevant events [14].

One set of central ATS equipment is configured in the operation control center to complete monitoring functions for the signaling system of East-west Line/South-north Line.

3.2.2 CBI subsystem

The basic interlocking functions of CBI ensure the operational safety of train. It is interfaced to the trackside signaling equipment via safe relay to realize the correct interlocking relationship among track sections, points and signals in train routes as well as the route control. At the same time, it is responsible to be interfaced to line encoder unit (LEU). In the intermittent ATP mode, trains obtain the relevant information of trackside signals and points via the active beacon corresponding to the signal [14].

3.2.3 IATP subsystem

The IATP subsystem consists of trackside equipment and onboard equipment. The iCC onboard equipment mounted in each train is able to realize the following ATP 12 functions [14]:

- Over speed protection;
- Restrictive signal overrun red light protection;
- Rollback protection;
- Spacing protection;
- Train door monitoring;
- Driving mode switch as well as the train control in different modes;
- Assisting drivers in operating trains via the human-machine interface driving monitering interface (DMI).

The onboard iCC system obtains trackside variable information via European beacon and train-ground wireless communication. It obtains train position information via relocalization beacon and realizes intermittent ATP protection controls.

3.2.4 DCS subsystem

The DCS wired network is the transmission platform of the whole signaling system. The ATS network is used for connecting the ATS equipments located in operation control center, stations, depot and etc. The CBI network is used for connecting the CBI equipments of stations and depot. The DCS wireless network provides a reliable, continuous and stable bi-diretional communication channel for trackside CBI and onboard CC systems and realizes intermittent-continuous type IATP functions [14].

3.2.5 MSS subsystem

The IATP, CBI, ATS, DCS, level crossing signaling equipment and power supply equipment have self-diagnosis and monitoring alarm functions. The maintenance support subsystem (MSS) acquires the alarm information of CBI, ATS, DCS and power supply equipment and realizes remote centralized monitoring and alarms [14].

3.3 General principles for equipment configuration

The signaling system equipment in this project (including main line, auxiliary line, level crossing, depot, test track, transfer track and etc.) is equipped mostly includes [14]:

- The main line (including crossover, turn-back line and etc.) and transfer track in this project are equipped with signaling system, included the CBI equipment in trackside and stations, IATP trackside equipment and station ATS equipment, intermittent (continuous) ground-train communication equipment and level crossing signal system equipment;
- All operating trains are equipped with IATP onboard equipment and ground-train communication equipment;
- The operation control center is equipped with high-efficiency train operation management system – ATS subsystem;
- The depot, mainline, operation control center, maintenance center, driver dispatch room, test track and etc. are equipped with power supply equipment;
- The depot is equipped with microcomputer monitoring system(MMS) equipment and the same CBI equipment as mainline;
- The test track of depot is equipped with the same IATP trackside equipment and intermittent (continuous) ground-train communication equipment as the mainline in order to complete the testing of all functions of IATP onboard signal equipment;
- Configured the signaling maintenance and diagnosis equipment;
- The network switch equipment is set up in the corresponding equipment rooms at 2 depots, 8 equipment centralization center and operation control center and the corresponding network equipment and interfaces such as photoelectric converter and etc. are set up at the maintenance center, depot driver dispatch room and test track;
- The configuration of system equipment shall facilitate the installation, commissioning and maintenance of equipment under the precondition of compliance with operational requirements;
- Make sure that the interfaces between individual systems including ATS, IATP, CBI, level crossing signal system and etc., the interfaces between individual subsystems and the basic equipment including signal, point machines and etc. and the interfaces between signaling system and other systems are safe, correct and reliable, and ensure the safety, integrity and overall performance of whole signaling system.

3.4 Overall composition of system

The system structure of signaling system is shown as the following figure:

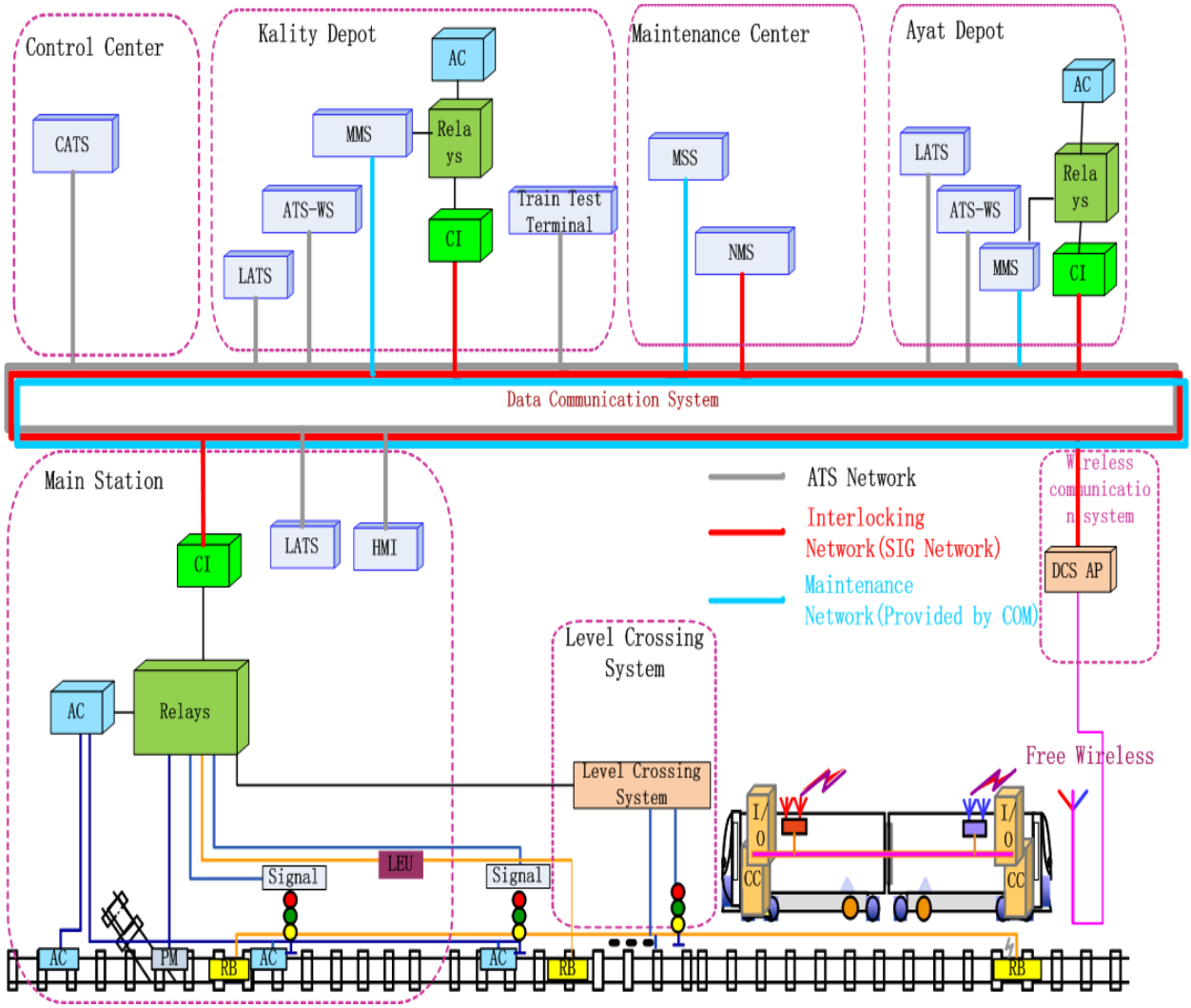

Figure 3.1 System structure sketch map [14]

3.5 Overview of AA-LRT ITAP subsystem

3.5.1 IATP Subsystem Composition

The IATP subsystem is based on trackside equipment and on on-board equipment.

Trackside equipment includes:

- Beacon (balise)
- LEU (Line Encoder Unit or Line side Electronics Unit)
- Trackside radio equipment

On-board equipment includes

- Carbone controller
- Odometer
- Beacon antenna
- DMI
- On-board radio equipment
- On-board switch

3.5.1.1 Trackside IATP equipment

1) Beacon (balise)

For beacon, it is applied for several functionalities:

- RB-Relocation Beacon: The Relocation Beacon is used to ensure that the train, running over it and get beacon message. The stored message includes the beacon identification which must be unique for one beacon on the line, which can check and correct train position, the train localization can still be ensured.
- MTIB-Wheel diameter calibration beacon: it consists of two RB separated by the very precise distance of 21 m. When the train runs over them, the wheel is automatically calculated and calibrated.
- The switchable beacons: are used to provide trackside variants such as signal and switch to CC when train run over it.

Active Balise (AB): the component that embeds the aspect of a signal. When the train passes, the Antenna placed below the train can read the information concerning the signal aspect from the AB.

Passive Balise (PB): the component that embeds absolute position information with respect to the beginning of the line. When the train passes, the Antenna placed below the train can read the information concerning its current location from the PB. Therefore, the position computed onboard through the ODO can be adjusted according to the information received.

The relationship between beacon and other equipment is shown below

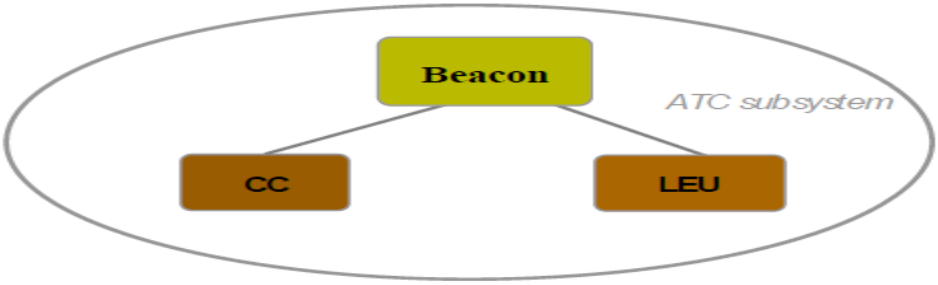

Figure 3.2. The relationship between beacon, CC and LEU [14]

2) LEU (Lineside Electronic Unit)

controls the Active Balises (AB) to embed the aspect of the signal (e.g., red, green, yellow). Information on the signal aspect are received from the CBI. LEU acquires trackside equipment status such as signal and switch, and provides to active switchable beacon. Knowing the permissive or restrictive status of signal and position of switch, train can get movement authority when running over the switchable beacon.

The relationship between LEU and other equipment is as below

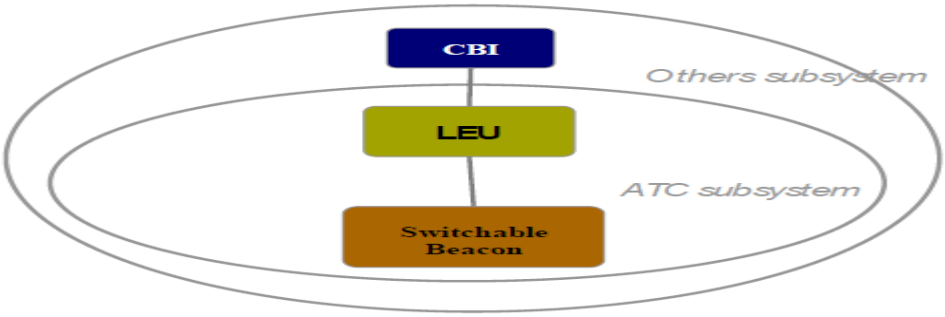

Figure 3.3. The relationship between LEU, beacon and CBI [14]

3) Trackside radio equipment

Bi-direction trackside radio equipment is set in route signal which have IATP protection function. The area covered by trackside radio equipment is not less than train safety braking distance. Details refer to DCS chapter.

3.5.1.2 On-board equipment

The Onboard ATP (OATP) is the core component of the onboard equipment, This component requires additional devices to properly implement its functionalities:

1) Onboard controller CC

On-board equipment of each end includes: one CC, one On-board equipment, two on-board switch, one set driver console, one odometer and one beacon antenna, as figure below:

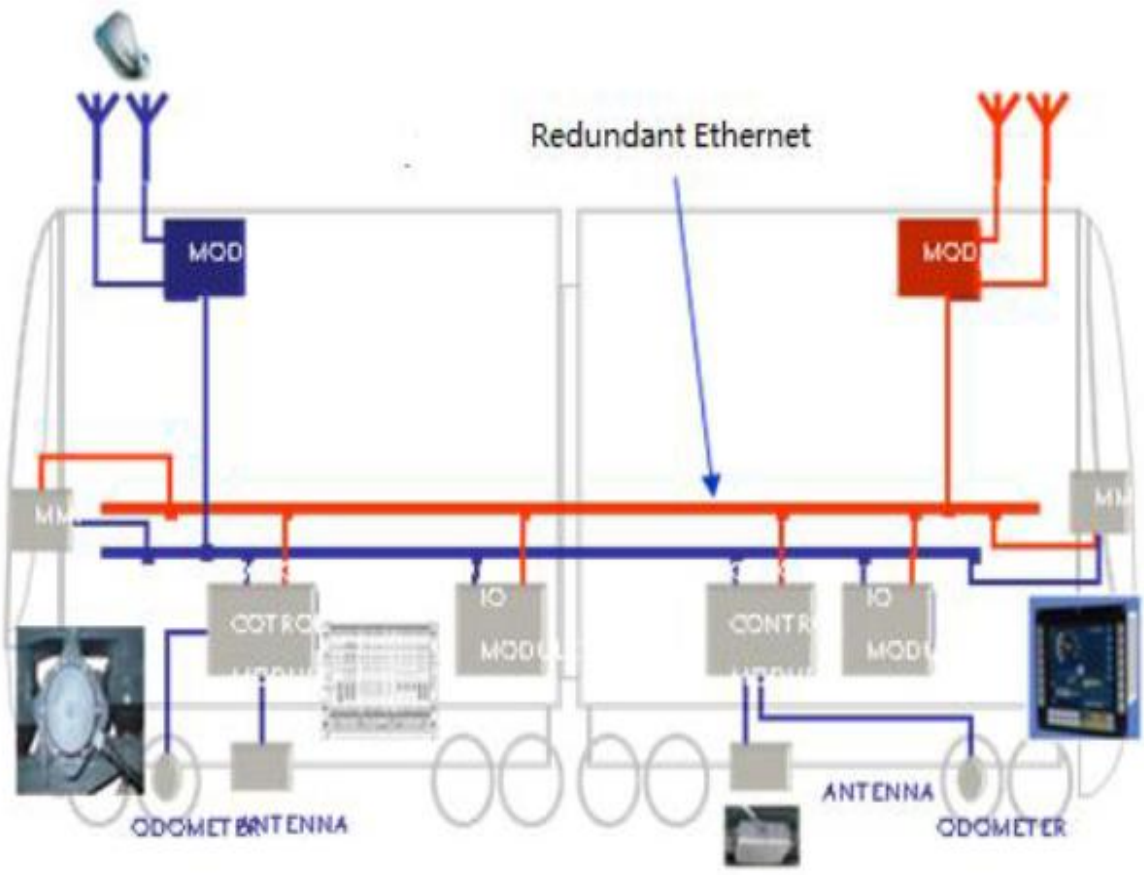

Figure 3.4. The sketch map of onboard equipment structure [14]

The communication between train head/tail and trackside is redundancy structure, which is blue/red redundant network. The CPM and VIOM are also redundant equipment, as figure below:

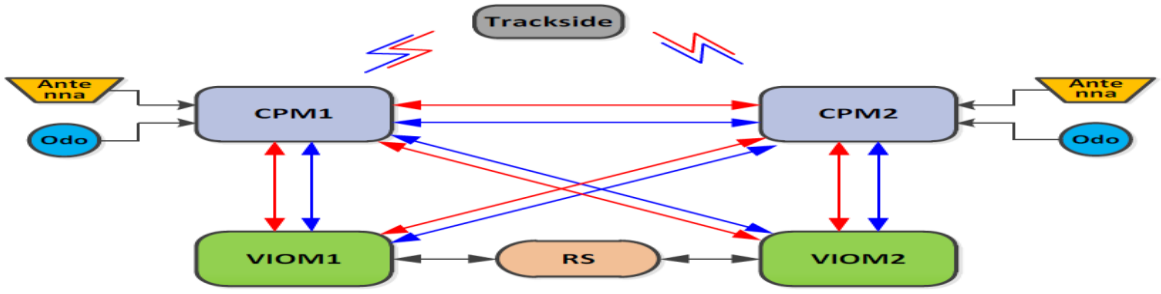

Figure 3.5. Onboard controller structure [14]

2) Odometer

The component includes the sensors and the board that are used for the determination of the train speed and location; A coded odometer is set on each end of the train for train speed and 6 displacement acquisitions by IATP.

3) Beacon Antenna

A beacon antenna is set on each end of the train for data transmission between trackside beacon and core processing unit.

4) Driver console

DMI, push button and indicator are set on each end of the driver desk for driver interface. DMI is integrated with screen and CPU, the size of the screen is 10.4 inch. The picture of DMI as follows:

Figure 3.6. DMI [14]

5) On-board radio equipments

It includes onboard modem and onboard wireless antenna, and adopts to communicate with trackside wireless unit in order to realize intermittent-continuous IATP function. The detailed equipment configuration referred to DCS subsystem chapter.

6) On-board switch

Two switches are set on each end of the train for construction of redundancy onboard network.

3.6 System RAM Assurance Plan

In order to ensure the project signal system meet the contract RAM requirements, RAM plan is written and used to guide the project RAM activities at different phase. The RAM assurance plan defines the RAM organization, method of RAM, the RAM activities and RAMS files needed to delivery according to the CENELEC- EN 50126.

3.6.1 RAM organization

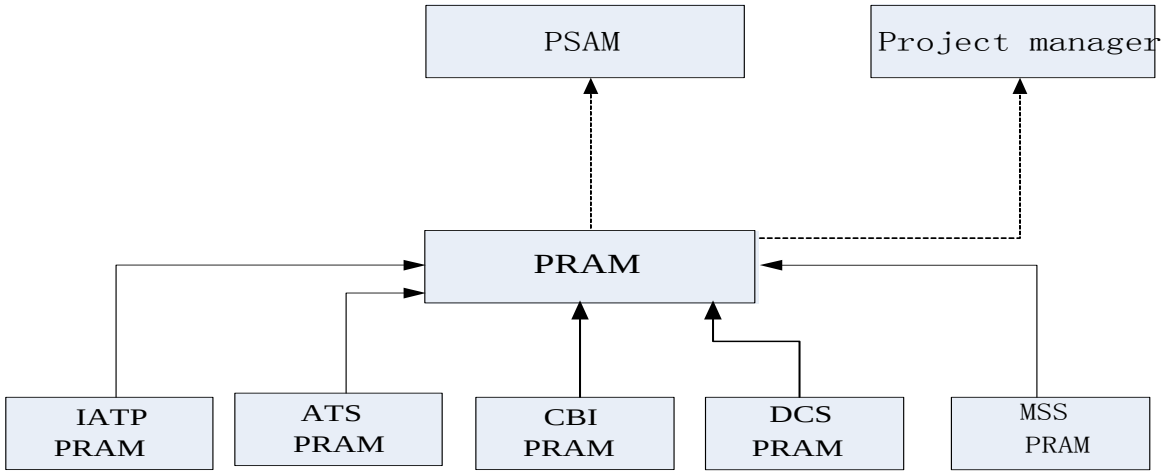

Figure 3.7. RAM organization [14]

PRAM (Project RAM assuration manager) is responsible for RAM activities of the project, to ensure the system RAM level meets the requirement of the contract.

The duty of PRAM:

- Define and implement RAM plan;
- The RAM requirements assigned by the system level to sub-system level;
- Tracking system design of RAM activities;
- Define and implement system level FMEA;
- Define and implement the system level RAM prediction, evaluation, analysis and validation.

CHAPTER4: RAM Modeling of ATP Signaling System

In this chapter it is tried to go through the quantitative calculation of reliability, maintainability and availability of the system. First brief definition about the basic concepts of RAMS analysis has been given in the previous chapters. In the second step quantitative calculations is included, eventually with the conclusion part this chapter and this thesis has been closed.

RAM studies generate sufficient data to base decisions for possible systems changes that may increase system efficiency and hence project profits. The application is relatively inexpensive but powerful RAM forecasting tools can provide a number of benefits to the Signaling system. RAM modeling assesses a production systems capabilities, whether it be operation or still in design phase. The results from RAM modeling will identify possible causes of production losses and can examine possible system alternatives. The application of relatively inexpensive but powerful RAM forecasting tools can provide a number of benefits to the Signaling system.

Those benefits can include

- Reducing maintenance and sparing costs while maintaining and/or increasing production levels.
- Optimizing capital investment for reducing the cost of production.
- Alignment of maintenance resources based on the criticality of equipment to production revenue.
- Detecting failures in the early part of design;
- Optimizing maintenance schedules;
- Adequately allocating the spares inventory;
- Increasing the effectiveness of the signaling system

4.1 IATP control principle

IATP protection function is based on the subsystem below:

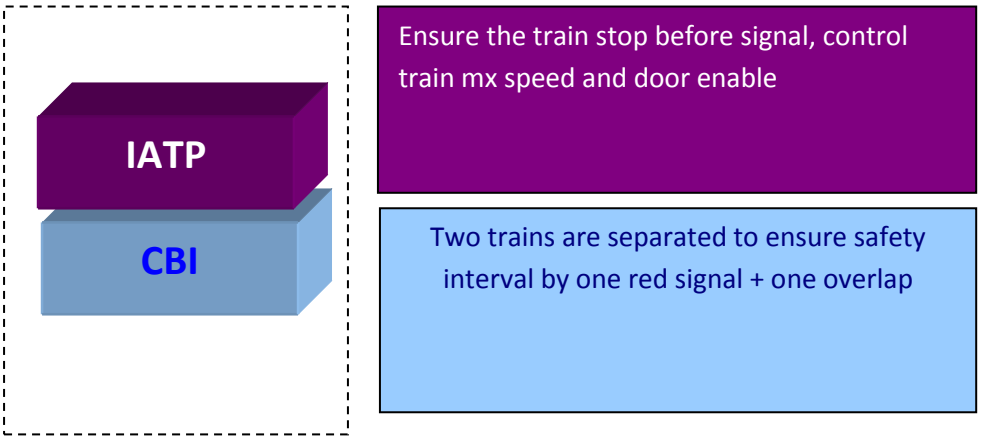

Figure 4.1: IATP subsystem principle [14]

4.2 System control levels

The system control levels are classified as:

- IATP control level;
- CBI control level.

The IATP control level is the normal control level of system and the CBI control level is the degraded control level of system.

4.2.1 CBI subsystem

The basic interlocking functions of CBI ensure the operational safety of train. It is interfaced to the trackside signaling equipment via safe relay to realize the correct interlocking relationship among track sections, points and signals in train routes as well as the route control. At the same time, it is responsible to be interfaced to LEU. In the intermittent ATP mode, trains obtain the relevant information of trackside signals and points via the active beacon corresponding to signal.

4.2.2 IATP subsystem

The IATP subsystem consists of trackside equipment and onboard equipment. The iCC onboard equipment mounted in each train is able to realize the following ATP functions:

- Over speed protection;
- Restrictive signal overrun red light protection;

- Rollback protection;
- Spacing protection;
- Train door monitoring;
- Driving mode switch as well as the train control in different modes;
- Assisting drivers in operating trains via the human-machine interface DMI.

The onboard iCC system obtains trackside variable information via European beacon and train-ground wireless communication. It obtains train position information via relocalization beacon and realizes intermittent ATP protection controls.

DCS wireless network provides a reliable, continuous and stable bi-diretional communication channel for trackside CBI and onboard CC systems and realizes intermittent-continuous type IATP functions.

IATP subsystem will obtain the signal status and switch position from LEU via CBI, and send this information to train by beacon, the principle is as below:

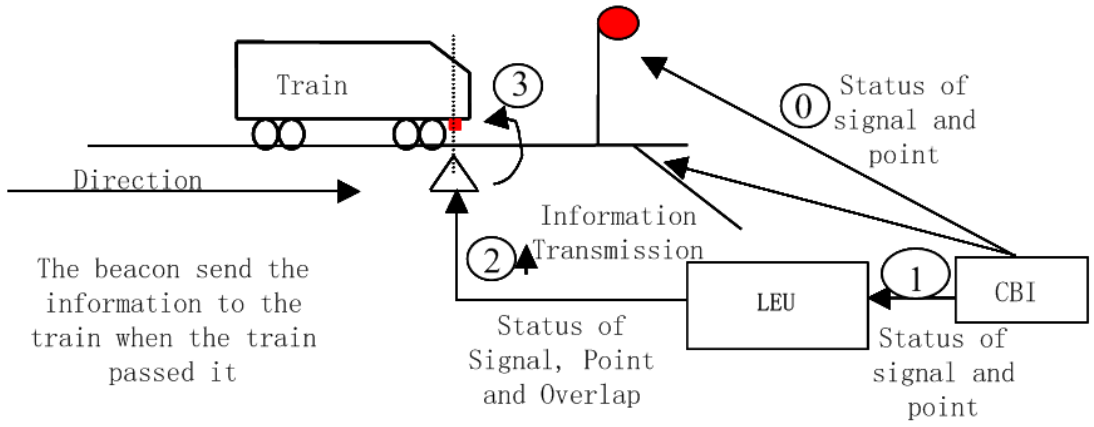

Figure 4-2： IATP subsystem message exchange [14]

The message exchanged is as below

0: CBI collects signal and switch status by relay

1: CBI sends signal and switch status to LEU by relay

2: LEU sends signal and switch status to switchable beacon

3: Switchable beacon sends signal and switch status to train

When the train runs over switchable beacon, on-board ATP shall get signal status for block protection, and react as below:

If the signal is restrictive, train will apply EB immediately to stop the train and prevent the train overrun the overlap.

If the signal is permissive, the train will run until the next signal and get the status of next signal by the corresponding beacon.

4.3 Train operations in case of failure

4.3.1 Failure of IATP trackside equipment

If the trackside IATP equipment in an area is failed, the onboard equipment will generate an alarm and apply emergency braking to trains. Drivers change over the driving mode to the restricted manual driving mode (RM) and manually operate trains for operation according to the states of trackside signal and the commands of central dispatcher;

When a train in the restricted manual driving mode (RM) runs to the IATP initialization area, the onboard equipment receives valid IATP information. The onboard system allows the driving mode exchange to the IATP driving modes without stopping of train.

4.3.2 Failure of onboard equipment

If the onboard ATP equipment is failed, the onboard equipment will generate an alarm and apply emergency braking to stop the train. The driver manually operates the train according to the states of trackside signal.

4.4 Data collection

This thesis deals with reliability, availability, maintainability modeling and performance analysis of AA-LRT ATP signaling system failure and repair data analysis using a Markov model. The failure data of 1 year and 6 months of signaling system of Addis Ababa LRT is taken as our maintenance study. Total numbers of failures from starting operation up to now are taken for the analysis. Gathered data in Table 4-1 are covering some major elements of IATP subsystem. As we get from an interview of signaling and communication maintenance personnel of AA LRT, Mentioned data's, accumulated over 1 year and 6 months of IATP operations. The data that are demonstrated in the table have some inaccuracy and it would be doubtful in some elements however they can give good aspect about MTBF of whole system and would be reliable source for the total reliability calculation of IATP subsystem.

To understand the following calculation we have to draw some kinds of time line. This time line will have two possible states i.e time between failure (TBF) and time to repair (TTR) and from this two states we have got MTTR and MTBF.

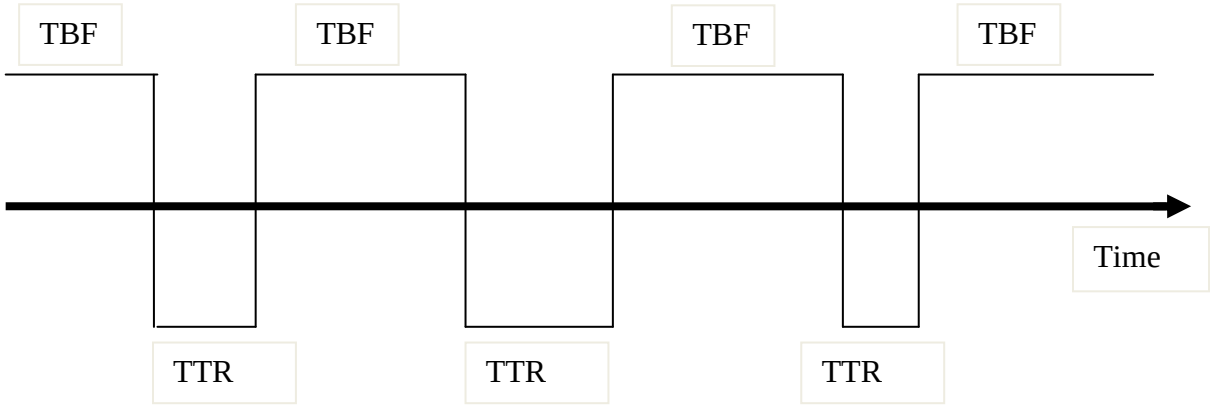

Figure 4-3 : TTR and TBF

Therefore MTBF is the average of the individual TBF and MTTR is also the average of the individual TTR.

IATP signaling

Total TTR = (90+70+50+45+75) minutes =330 minutes

Change minutes into hours 330/60 =5.5 hrs

MTTR= total TTR/ number of failures = 5.5/5 = 1.1 hrs

The total time line is 1 year and six months which is equal to

Total time = (365 + 180) days = 545 days

Change days into hours 545*24 =13,080 hrs

Total time line minus total TTR will give total TBF

Total TBF= 13,080 - 5.5 = 13,074.5 hrs

MTBF = total TBF/(number of failures + 1) = 13,074.5 /6 = 2179.083 hrs

Rail signal

Total TTR = 30+25+45+35+40+30+25+45+40+25+35+28+33+41+29+34) (minutes) = 540

Change minutes into hours 540/60 = 9 hrs

MTTR = total TTR/ number of failures = 9/16 = 0.5625 hrs

The total time line is 1 year and six months which is equal to

Total time = (365 + 180) days = 545 days

Change days into hours 545*24 = 13,080 hrs

Total time line minus total TTR will give total TBF

Total TBF = 13,080 - 9 = 13,071 hrs

MTBF = total TBF/(number of failures + 1) = 13,071/17 = 768.88235 hrs

CBI

Total TTR =(50+45+60+55+80+65+75) minutes = 430 minutes

Change minutes into hours 430/60 = 7.17 hrs

MTTR= total TTR/ number of failures = 7.17/7 = 1.024 hrs

The total time line is 1 year and six months which is equal to

Total time = (365 + 180) days = 545 days

Change days into hours 545*24 = 13,080 hrs

Total time line minus total TTR will give total TBF

Total TBF= 13,080-7.17 = 13,072.83 hrs

MTBF = total TBF/(number of failures + 1) = 13,072.83 /8 = 1634.103 hrs

LEU

Total TTR = (35+50+45+38+57+47+32+42+39+33+43)(minute) = 461 minutes

Change minutes into hours 461/60=7.68 hrs

MTTR= total TTR/ number of failures = 7.68/11=0.7 hrs

The total time line is 1 year and six months which is equal to

Total time = (365 + 180) days = 545 days

Change days into hours 545*24 = 13,080 hrs

Total time line minus total TTR will give total TBF

Total TBF= 13,080 - 7.68 = 13,072.32 hrs

MTBF = total TBF/(number of failures + 1) = 13,072.32 / 12 = 1089.36 hrs

Beacon

Total TTR = (35+28+43+55) minutes = 161 minutes

Change minutes into hours 161/60 = 2.68 hrs

MTTR= total TTR/ number of failures = 2.68/4 = 0.67 hrs

The total time line is 1 year and six months which is equal to

Total time = (365 + 180) days = 545 days

Change days into hours 545*24 = 13,080 hrs

Total time line minus total TTR will give total TBF

Total TBF = 13,080 - 2.68 = 13,077.32 hrs

MTBF = total TBF/(number of failures + 1) = 13,077.32 / 5 = 2615.464 hrs

Switch machine

Total TTR = (60+62+58+63+70+65+73+68+55+49+59+71+67+53+61) minutes = 934 minutes

Change minutes into hours 934/60 = 15.57 hrs

MTTR = total TTR/ number of failures = 15.57/15 = 1.038 hrs

The total time line is 1 year and six months which is equal to

Total time = (365 + 180) days = 545 days

Change days into hours 545*24 = 13,080 hrs

Total time line minus total TTR will give total TBF

Total TBF = 13,080 - 15.57 = 13,064.43 hrs

MTBF = total TBF/(number of failures + 1) = 13,064.43 / 16 = 816.530 hrs

Table 4-1: MTBF and MTTR for the case study

Component	MTTR-hrs	MTBF-hrs
IATP onboard equipment	1.100	2179.083
Beacon(balise)	0.670	2615.464
LEU	0.700	1089.360
CBI	1.024	1634.103
Rail signal	0.563	768.882
Point switch machine	1.038	816.530

4.5 IATP signaling subsystem reliability block diagram

The reliability block diagram of IATP signaling system is shown in Figure 4-3. Therefore, the simplified reliability block diagram of AA-LRT IATP signaling subsystem using only six main subsystems are selected for this paper.

Figure 4-3 ITAP signaling subsystem reliability block model

4.6 State Transition and Mathematical Analysis of Markov Model

Markov model is widely used method to perform reliability analysis of several engineering systems including railways. Generally, it is used to model repairable systems with constant failure and repair rates. Markov models can be defined for continuous and the discrete time. For a given system, a Markov model consist of a set of all possible states, transitions between those states and the conditions described for the transitions. Conditions of the transitions are generally consisting of failures and repairs in reliability analysis.

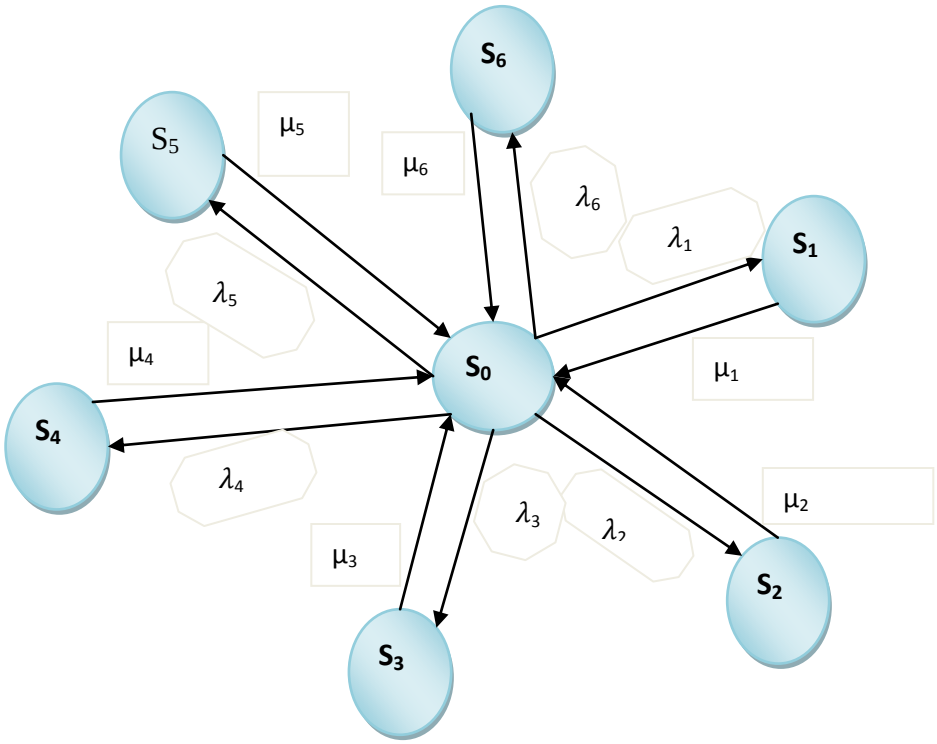

Figure 4.4: Transition diagram for ATP signaling system and subsystems.

4.7 MODEL DESCRIPTION

There are many mathematical models that can be used to perform reliability-related analysis in various railways signaling system. The transition diagram describes the signaling system model for analyzing the reliability of the railway signaling system. The model assumes that it represents the process of IATP signaling subsystem function the alternation between the following seven states:

S_0 – system is in active (operating) state at the moment of time t;

S1 – when onboard equipment fail;

S2– when beacon fail

S3– when LEU fails

S4 – when CBI fail

S5--when rail signal fail

S6--when point switch fail

The methodology of Markov process of reliability modeling of AA-LRT IATP signaling sub system is shown as follows.

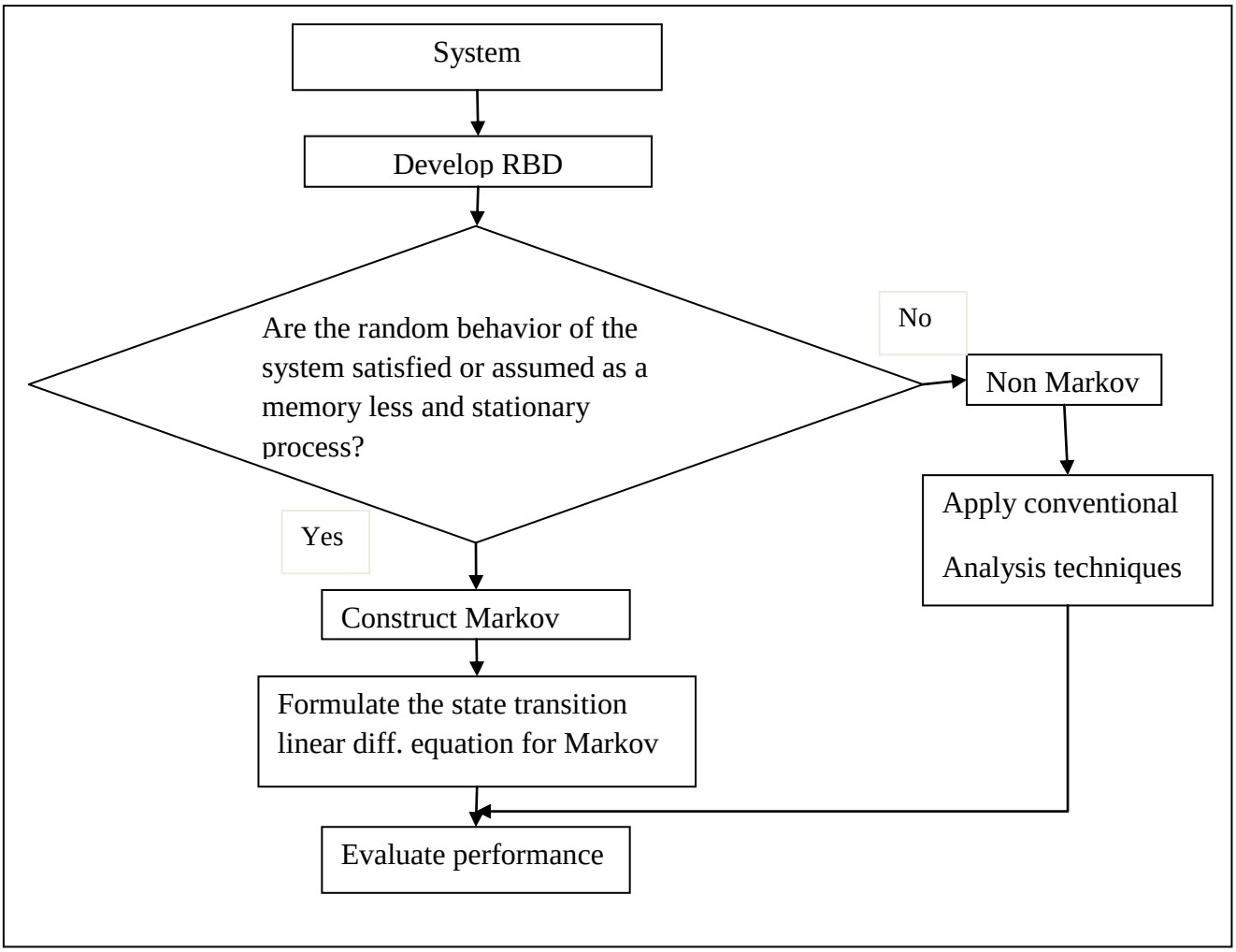

Figure 4.5 Reliability modeling by markov process formulation [17]

The transition probabilities Pij of a homogeneous Markov process form an n x n matrix, called a transition matrix which is:-

$$[pij]=\begin{bmatrix} p11 & p12 & . & . & p1j & . & p1n \\ p21 & p22 & . & . & p2j & . & p2n \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ pi1 & pi2 & . & . & pij & . & pin \\ pn1 & pn2 & . & . & pnj & . & pnn \end{bmatrix} \quad (13)$$

The formula used are shown below. From transition diagram presented in Figure: 4.5 and Markov equations can be derived. The probability that the system is in the operating state after time interval Δt i.e. at time (t+Δt) is given by:

P_{S0} (t +Δt) = [Probability of being in operating state at time t) and (Probability of not failing between t+Δt] + [Probability of being failed states at time t) and (Probability of being repaired between t and t+Δt).

Probabilities of failure between t and Δt are λiΔt and Probabilities of not failing between t and Δt are (1- λiΔt). Similarly the probabilities of repair are μiΔt. Using the addition and multiplication rule for probabilities gives:

$$p_{s0}(t+\Delta t) = p_{s0}(t)[1-(\lambda_1\Delta t +\lambda_2\Delta t +\lambda_3\Delta t +\lambda_4\Delta t +\lambda_5\Delta t+\lambda_6\Delta t)]+\mu_1\Delta t p_{s1}(t)+\mu_2\Delta t p_{s2}(t)+ \mu_3\Delta t p_{s3}(t)+ \mu_4\Delta t p_{s4}(t)+ \mu_5\Delta t p_{s5}(t)+ \mu_6\Delta t p_{s6}(t) \quad (14)$$

And which is equal to

$$p_{s0}(t+\Delta t)- p_{s0}(t)= [-(\lambda_1\Delta t -\lambda_2\Delta t -\lambda_3\Delta t -\lambda_4\Delta t -\lambda_5\Delta t -\lambda_6\Delta t)]\, p_{s0}(t) +\mu_1\Delta t p_{s1}(t)+ \mu_2\Delta t p_{s2}(t)+ \mu_3\Delta t p_{s3}(t)+ \mu_4\Delta t p_{s4}(t)+ \mu_5\Delta t p_{s5}(t)+ \mu_6\Delta t p_{s6}(t) \quad (15)$$

Rearranging

The equations for the Markov model shown in Fig.4.5 can be written as

$$\frac{[p_{s0}(t+\Delta t)- p_{s0}(t)]}{\Delta t}= (-\lambda_1- \lambda_2- \lambda_3- \lambda_4- \lambda_5- \lambda_6)\ p_{s0}(t)+ \mu_1 p_{s1}(t)+ \mu_2 p_{s2}(t)+ \mu_3 p_{s3}(t)+ \mu_4 p_{s4}(t)+ \mu_5 p_{s5}(t)+ \mu_6 p_{s6}(t) \quad (16)$$

Similarly for other states will be

$$\frac{[p_{s1}(t+\Delta t)- p_{s1}(t)]}{\Delta t} = \lambda_1 p_{s0}(t)- \mu_1 p_{s1}(t) \quad (17)$$

$$\frac{[p_{s2}(t+\Delta t)- p_{s2}(t)]}{\Delta t} = \lambda_1 p_{s0}(t)- \mu_2 p_{s2}(t) \quad (18)$$

$$\frac{[p_{s3}(t+\Delta t)- p_{s3}(t)]}{\Delta t} = \lambda_1 p_{s0}(t)- \mu_3 p_{s3}(t) \quad (19)$$

$$\frac{[p_{s4}(t+\Delta t)- p_{s4}(t)]}{\Delta t} = \lambda_1 p_{s0}(t)- \mu_4 p_{s4}(t) \quad (20)$$

$$\frac{[p_{s5}(t+\Delta t)- p_{s5}(t)]}{\Delta t} = \lambda_1 p_{s0}(t)- \mu_5 p_{s5}(t) \quad (21)$$

$$\frac{[p_{s6}(t+\Delta t)- p_{s6}(t)]}{\Delta t} = \lambda_1 p_{s0}(t)- \mu_6 p_{s6}(t) \quad (22)$$

Taking the limit as Δ*t* approaches zero, we obtain the following differential equations.

$\Delta t \rightarrow 0$

$$\frac{dp_{s0}(t)}{dt} = - p_{s0}(t)((\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6) + \mu_1 p_{s1}(t) + \mu_2 p_{s2}(t) + \mu_3 p_{s3}(t) + \mu_4 p_{s4}(t) + \mu_5 p_{s5}(t) + \mu_6 p_{s6}(t) \quad (23)$$

$$= \sum \mu i \, p_i(t) - p_{s0}(t) \sum \lambda i \quad (24)$$

Similarly for other states will be

$$\frac{dp_{s1}(t)}{dt} = \lambda_1 p_{s0}(t) - \mu_1 p_{s1}(t) \quad (25)$$

$$\frac{dp_{s2}(t)}{dt} = \lambda_2 p_{s0}(t) - \mu_2 p_{s2}(t) \quad (26)$$

$$\frac{dp_{s3}(t)}{dt} = \lambda_3 p_{s0}(t) - \mu_3 p_{s3}(t) \quad (27)$$

$$\frac{dp_{s4}(t)}{dt} = \lambda_4 p_{s0}(t) - \mu_4 p_{s4}(t) \quad (28)$$

$$\frac{dp_{s5}(t)}{dt} = \lambda_5 p_{s0}(t) - \mu_5 p_{s5}(t) \quad (29)$$

$$\frac{dp_{s6}(t)}{dt} = \lambda_6 p_{s0}(t) - \mu_6 p_{s6}(t) \quad (30)$$

We can write the above differential equations in the following form

$$\frac{d}{dt} p(t)^T = p(t)^T M \quad (31)$$

Where $p(t)^T = (p_{s0}(t), p_{s1}(t), p_{s2}(t), p_{s3}(t), p_{s4}(t), p_{s5}(t), p_{s6}(t))$

T= transpose

And

M is the transition matrix which is

$$\mathbf{M} = \begin{bmatrix} -(\lambda 1 + \lambda 2 + \lambda 3 + \lambda 4 + \lambda 5 + \lambda 6) & \lambda 1 & \lambda 2 & \lambda 3 & \lambda 4 & \lambda 5 & \lambda 6 \\ \mu 1 & -\mu 1 & 0 & 0 & 0 & 0 & 0 \\ \mu 2 & 0 & -\mu 2 & 0 & 0 & 0 & 0 \\ \mu 3 & 0 & 0 & -\mu 3 & 0 & 0 & 0 \\ \mu 4 & 0 & 0 & 0 & -\mu 4 & 0 & 0 \\ \mu 5 & 0 & 0 & 0 & 0 & -\mu 5 & 0 \\ \mu 6 & 0 & 0 & 0 & 0 & 0 & -\mu 6 \end{bmatrix}$$

Matrix M is square, of dimensions 7 x 7. The terms in each row of the matrix sum up to 0, which means matrix M is a singular matrix, i.e. its determinant is equal to zero. This will allow for the solution to be found if a distribution – normally the initial distribution Mi (0) – is known.
The equilibrium distribution is found using

$$\frac{d}{dt}\,p^{T} = p^{T}M=0 \tag{32}$$

$$-\,p_{s0}\left(\sum_{i=1}^{6}\lambda i\right) + \mu_1 p_{s1} + \mu_2 p_{s2} + \mu_3 p_{s3} + \mu_4 p_{s4} + \mu_5 p_{s5} + \mu_6 p_{s6} = 0 \tag{33}$$

$$\lambda_1 p_{s0} - \mu_1 p_{s1} = 0 \quad \rightarrow \quad p_{s1} = \frac{\lambda 1}{\mu 1} p_{s0} \tag{34}$$

$$\lambda_2 p_{s0} - \mu_2 p_{s2} = 0 \quad \rightarrow \quad p_{s2} = \frac{\lambda 2}{\mu 2} p_{s0} \tag{35}$$

$$\lambda_3 p_{s0} - \mu_3 p_{s3} = 0 \quad \rightarrow \quad p_{s3} = \frac{\lambda 3}{\mu 3} p_{s0} \tag{36}$$

$$\lambda_4 p_{s0} - \mu_4 p_{s4} = 0 \quad \rightarrow \quad p_{s4} = \frac{\lambda 4}{\mu 4} p_{s0} \tag{37}$$

$$\lambda_5 p_{s0} - \mu_5 p_{s5} = 0 \quad \rightarrow \quad p_{s5} = \frac{\lambda 5}{\mu 5} p_{s0} \tag{38}$$

$$\lambda_6 p_{s0} - \mu_6 p_{s6} = 0 \quad \rightarrow \quad p_{s6} = \frac{\lambda 6}{\mu 6} p_{s0} \tag{39}$$

The steady state probabilities are the following at ($t \rightarrow \infty$)

$$p_{s0} = \frac{\mu 1 p_{s1} + \mu 2 p_{s2} + \mu 3 p_{s3} + \mu 4 p_{s4} + \mu 5 p_{s5} + \mu 6 p_{s6}}{(\lambda 1 + \lambda 2 + \lambda 3 + \lambda 4 + \lambda 5 + \lambda 6)} \tag{40}$$

$$p_{s1} = \frac{\lambda 1}{\mu 1} p_{s0} \tag{41}$$

$$p_{s2} = \frac{\lambda 2}{\mu 2} p_{s0} \tag{42}$$

$$p_{s3} = \frac{\lambda 3}{\mu 3} p_{s0} \tag{43}$$

$$p_{s4} = \frac{\lambda 4}{\mu 4} p_{s0} \tag{44}$$

$$p_{s5} = \frac{\lambda 5}{\mu 5} p_{s0} \tag{45}$$

$$p_{s6} = \frac{\lambda 6}{\mu 6} p_{s0} \tag{46}$$

And the sum of all probabilities is equal to one.

$$p_{s0} + p_{s1} + p_{s2} + p_{s3} + p_{s4} + p_{s5} + p_{s6} = 1 \quad (47)$$

Substituting the value of $p_{s1}, p_{s2}, p_{s3}, p_{s4}, p_{s5}$ and p_{s6} in equation (47) we get

$$p_{s0} + \frac{\lambda 1}{\mu 1} p_{s0} + \frac{\lambda 2}{\mu 2} p_{s0} + \frac{\lambda 3}{\mu 3} p_{s0} + \frac{\lambda 4}{\mu 4} p_{s0} + \frac{\lambda 5}{\mu 5} p_{s0} + \frac{\lambda 6}{\mu 6} p_{s0} = 1 \quad (48)$$

At time t=0,

$p_{s0}(0)=1, p_{s1}(0)=0, p_{s2}(0)=0, p_{s3}(0)=0, p_{s4}(0)=0, p_{s5}(0)=0, p_{s6}(0)=0$

Rearranging

$$p_{s0}(1+\sum \frac{\lambda i}{\mu i}) = 1 = \frac{1}{(1+\sum \frac{\lambda i}{\mu i})} \quad (49)$$

$$\text{therefore} \quad p_{s0} = \frac{1}{(1+\sum \frac{\lambda i}{\mu i})} \quad (50)$$

Hence, the steady-state availability of the IATP signaling system will be

$$A = p_{s0(\infty)} = \frac{1}{(1+\sum \frac{\lambda i}{\mu i})} \quad (51)$$

Where (i=1,2…..6)

Unavailability of the IATP signaling system is found as:

$$UA = p_{s1} + p_{s2} + p_{s3} + p_{s4} + p_{s5} + p_{s6} \quad (52)$$

Where

$$p_{s1} = \frac{\lambda 1}{\mu 1(1+\sum \frac{\lambda 1}{\mu 1})} \quad (53)$$

$$p_{s2} = \frac{\lambda 2}{\mu 2(1+\sum \frac{\lambda 2}{\mu 2})} \quad (54)$$

$$p_{s3} = \frac{\lambda 3}{\mu 3(1+\sum \frac{\lambda 3}{\mu 3})} \quad (55)$$

$$p_{s4} = \frac{\lambda 4}{\mu 4(1+\sum \frac{\lambda 4}{\mu 4})} \quad (56)$$

$$p_{s5} = \frac{\lambda 5}{\mu 5(1+\sum \frac{\lambda 5}{\mu 5})} \quad (57)$$

$$p_{s6} = \frac{\lambda 6}{\mu 6(1+\sum \frac{\lambda 6}{\mu 6})} \quad (58)$$

The reliability of different subsystems are :

$$R_1(t)=e^{-\lambda 1t},\ R_2(t)=e^{-\lambda 2t},\ R_3(t)=e^{-\lambda 3t},\ R_4(t)=e^{-\lambda 4t},\ R_5(t)=e^{-\lambda 5t},\ R_6(t)=e^{-\lambda 6t} \quad (59)$$

Where R(t) is reliability of the IATP signaling subsystem

λ failure rate

As subsystems are connected in series, so the reliability of the signaling system will be the product of the individual subsystem reliabilities.

$$R(t)=\prod Ri=R_1R_2R_3R_4R_5R_6= e^{-\lambda 1t}e^{-\lambda 2t}e^{-\lambda 3t}e^{-\lambda 4t}e^{-\lambda 5t}e^{-\lambda 6t} =e^{-\sum \lambda it} \quad (60)$$

The maintainability of different IATP signaling subsystems are as follows**:**

$$M_1(t)= 1- e^{-\mu 1t} \quad (61)$$

$$M_2(t)= 1- e^{-\mu 2t} \quad (62)$$

$$M_3(t)= 1- e^{-\mu 3t} \quad (63)$$

$$M_4(t)= 1- e^{-\mu 4t} \quad (64)$$

$$M_5(t)= 1- e^{-\mu 5t} \quad (65)$$

$$M_6(t)= 1- e^{-\mu 6t} \quad (66)$$

Where μ is the repair rate

Mean time to failure MTTF = $\frac{1}{\sum \lambda i}$ (67)

For steady state availability (A) = $\frac{\text{MTTF}}{(\text{MTTF} + \text{MTTR})}$ (68)

Now mean time to repair MTTR = $\text{MTTF x} \sum \frac{\lambda i}{\mu i} \Rightarrow \text{MTTR} = \frac{\sum_{i=1}^{n} MTTR_i/MTBF_i}{\sum_{i=1}^{n} 1/MTBF_i}$ (69)

System repair rate (μs) = 1/MTTR = $\frac{1}{\text{MTTF x} \sum \frac{\lambda i}{\mu i}}$ (70)

maintainability Ms(t) = 1– $e^{-\mu st}$ (71)

Again, R (t) = $e^{-\sum \lambda it}$ where i=1,2….6 (72)

CHAPTER 5 Results and Discussions

This chapter summarizes the results obtained during the validation of the methods described in the previous chapter, using corrective maintenance data from a specific railway line during a limited period of time. The failure data of 1 year and 6 months of IATP signaling subsystem of Kality to Menlik is taken as our maintenance study. Total numbers of failures from starting normal operation up to now are taken for the analysis. Failure and maintenance data of the subsystems of IATP signaling systems for this study were obtained from an interview from signaling and communication maintenance personnel's and site assessment. But signaling and communication maintenance personnels are not willing to give the real failure data which is logged by maintenance log book system. However, with the help of approximate data repair and failure rate is calculated for the purpose of this thesis, the different probabilities are calculated assuming the same probabilities for all track sections (otherwise, a Markov model must be performed for each track section). Then after reliability and maintainability of six main subsystems and the entire IATP system versus time at different intervals were calculated. The graphs for reliability and maintainability versus time at different intervals were also plotted to estimate reliability and maintainability of the six main subsystems and the entire IATP system. The failure and repair rate is calculated with the following formula and the result is shown in Table 5-1.

$$\lambda = \frac{1}{MTBF} \qquad \mu = \frac{1}{MTTR}$$

Table 5-1: Repair rate and failure rate of different signaling subsystem

COMPONENTS	FAILURE RATE (λ)	REPAIR RATE (μ)
Onboard IATP equipment	0.0000459	0.909091
Beacon (balise)	0.0000382	1.492537
LEU	0.0000918	1.428571
CBI	0.0000212	0.976563
Rail signal	0.0001301	1.776199
Switch machine	0.0001225	0.963391

From above repair rate and failure rate of different signaling subsystem onboard IATP equipment, beacon (balise), LEU, CBI, rail signal and switch machine. Reliability at different time interval is calculated which is given in Table 5-2.

5.1 Reliability Result

In general, reliability is the ability of a system to perform and maintain its functions in routine circumstances, as well as in hostile or unexpected circumstances.

Reliability of each sub system is shown in Fig 5-1 beacon (balise) system has the highest reliability, and rail signal has the lowest.

$$R(t) = e^{-\lambda t}$$

Table 5-2: Reliability of different signaling subsystem for different time interval

Time (H)	Onboard IATP	Beacon(balise)	LEU	CBI	Rail signal	Switch machine
0	1	1	1	1	1	1
50	0.9977	0.9981	0.9954	0.9989	0.9935	0.9939
100	0.9954	0.9962	0.9909	0.9979	0.9871	0.9878
150	0.9931	0.9943	0.9863	0.9968	0.9807	0.9818
200	0.9909	0.9924	0.9818	0.9958	0.9743	0.9758
250	0.9886	0.9905	0.9773	0.9947	0.9681	0.9698
300	0.9863	0.9886	0.9728	0.9937	0.9617	0.9639

From Table 5.2. Reliability of different signaling sub system is calculated and graph is plotted which is shown in figure 5-1.

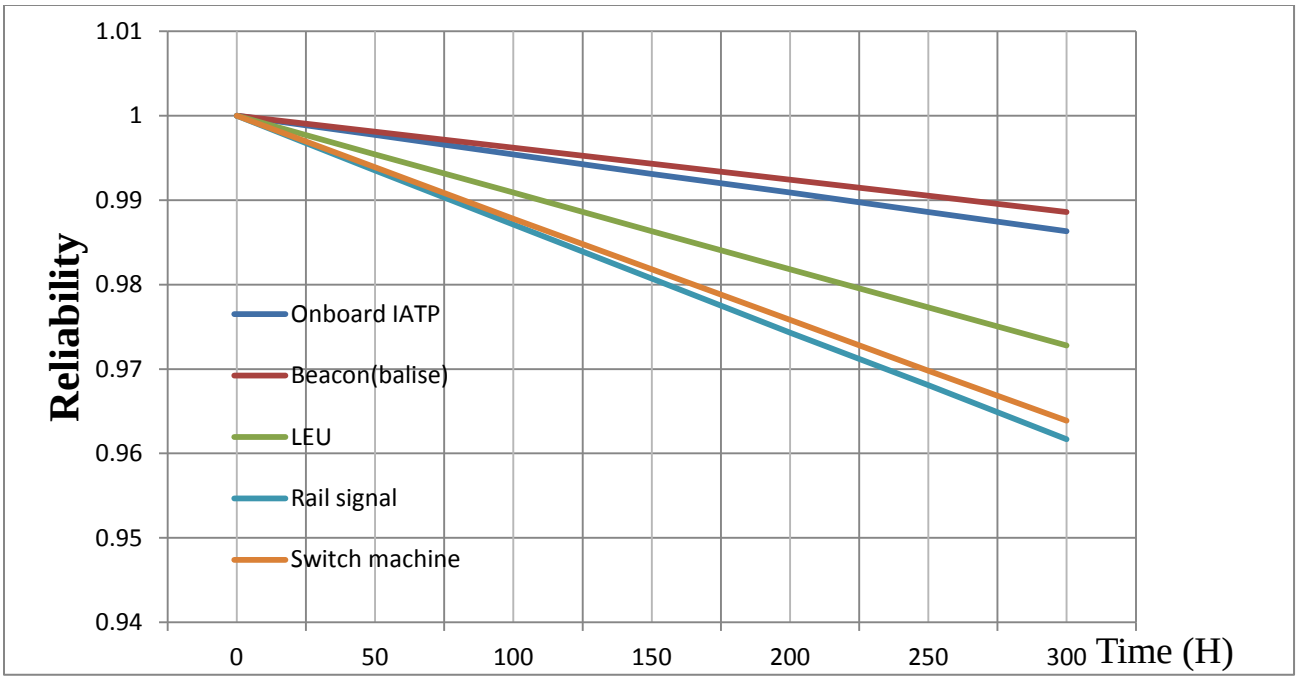

Figure 5-1: Reliability pattern of different signaling subsystems.

It is found that the reliabilities of the different subsystems are different as well as decreasing with time. Reliability of onboared IATP equipment, Beacon (balise), LEU, CBI, Rail signal, and switch machine are respectively 0.9954, 0.9981, 0.9954, 0.9989, 0.9871 and 0.9878 respectively after 50 hours. So reliability of Rail signal and switch machine are the lowest among six subsystems, hence it is required more attention than other subsystems.

5.3 Maintainability Result

Maintainability is defined as the probability of performing a successful repair action within a given time. In other words, maintainability measures the ease and speed with which a system can be restored to operational status after a failure occurs. In Fig 5-2 the relation between the repair rate and maintainability is shown. If the repair rate is high, the maintainability is high, so low repair time can improve the availability of the system.

$$M(t)= 1- e^{-\mu t}$$

Table 5-3 Maintainability of different signaling system at different time interval

Time (H)	Onboard IATP	Beacon(balise)	LEU	CBI	Rail signal	Switch machine
0	0	0	0	0	0	0
0.25	0.2033	0.3114	0.3003	0.2166	0.3586	0.2140
0.50	0.3653	0.4741	0.5105	0.3863	0.5886	0.3823
0.75	0.4943	0.6575	0.6575	0.5193	0.7361	0.5145
1.00	0.5971	0.7752	0.7603	0.6234	0.8307	0.6184
1.25	0.6790	0.8452	0.8323	0.7050	0.8914	0.7001
1.50	0.7443	0.8934	0.8827	0.7689	0.9304	0.7643
1.75	0.7963	0.9179	0.9179	0.8190	0.9553	0.8147
2.00	0.8377	0.9426	0.9426	0.8582	0.9713	0.8544

With the help of data collected and by using mathematical expressions maintainability pattern of six signaling subsystems are calculated as shown in the Table 5-3, and graph is also plotted as shown in Figure 5-2.

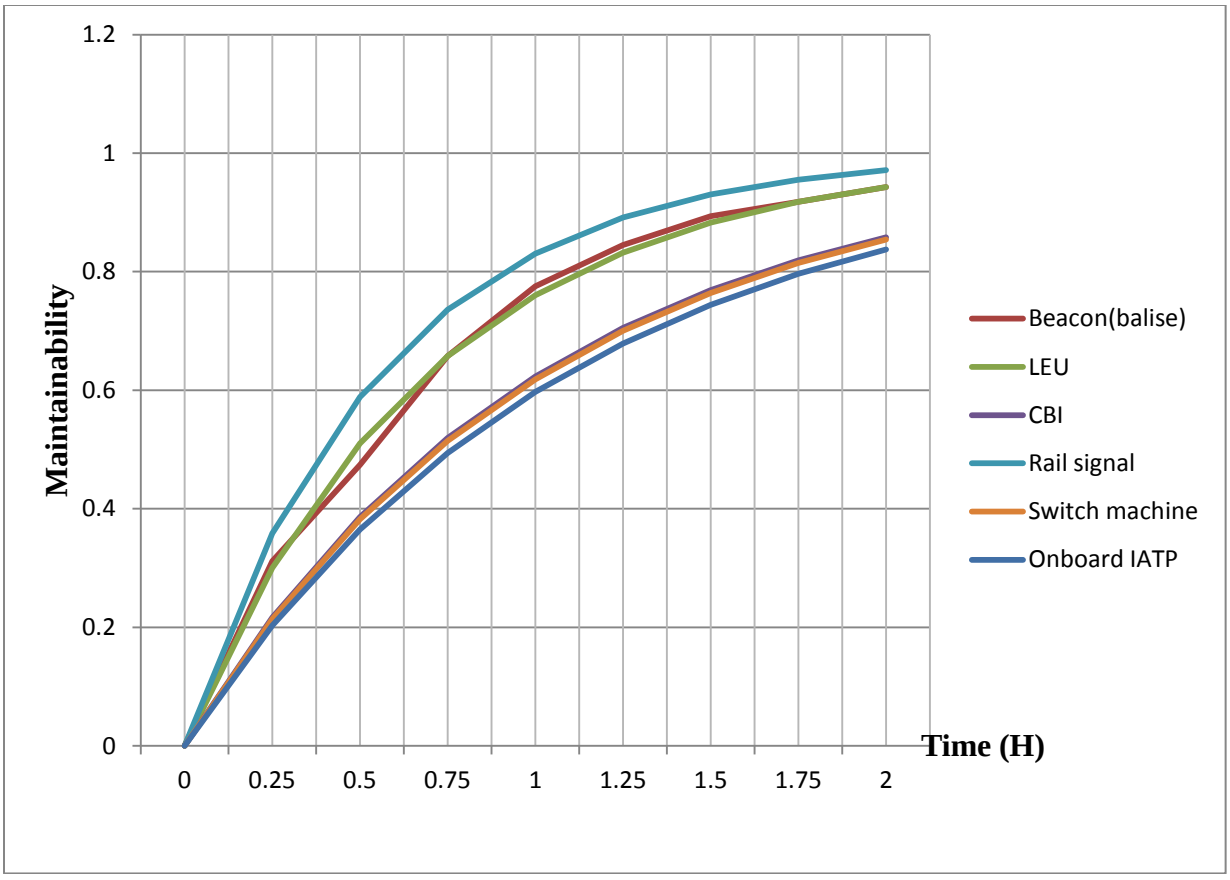

Figure 5-2 Maintainability pattern of different signaling components

From figure 5-2 maintainability of onboard IATP equipment, beacon (balise), LEU, CBI, rail signal and switch machine after one hour and 45 minutes are 0.8377, 0.9426, 0.9426, 0.8147, 0.9553 and 0.8147 respectively. Maintainability of onboard IATP equipment, beacon (balise), LEU, CBI, and rail signal is almost good except onboard IATP, switch machine and CBI which is lowest. So onboard IATP, switch machine and CBI are needs special consideration.

5.3 Availability Result

Availability means the ability of a product to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval assuming that the required external resources are provided.

Now availability of each subsystem can be calculated based on the given failure and repair rate data of the subsystem.

$$Availability\ (A) = \frac{\mu}{\lambda + \mu}$$

Tabele 5-4 Availability of different signaling subsystems

COMPONENTS	FAILURE RATE (λ)	REPAIR RATE (μ)	Availability (A)
Onboard IATP	0.0000459	0.909091	0.99995
Beacon (balise)	0.0000382	1.492537	0.99997
LEU	0.0000918	1.428571	0.99994
CBI	0.0000212	0.976563	0.99998
Rail signal	0.0001301	1.776199	0.99993
Switch machine	0.0001225	0.963391	0.99987

As it is depicted Availability of the system is close to 1. That means IATP signaling subsystem can have acceptable performance during operation.

The availability of each system is shown in Figure 5-3.

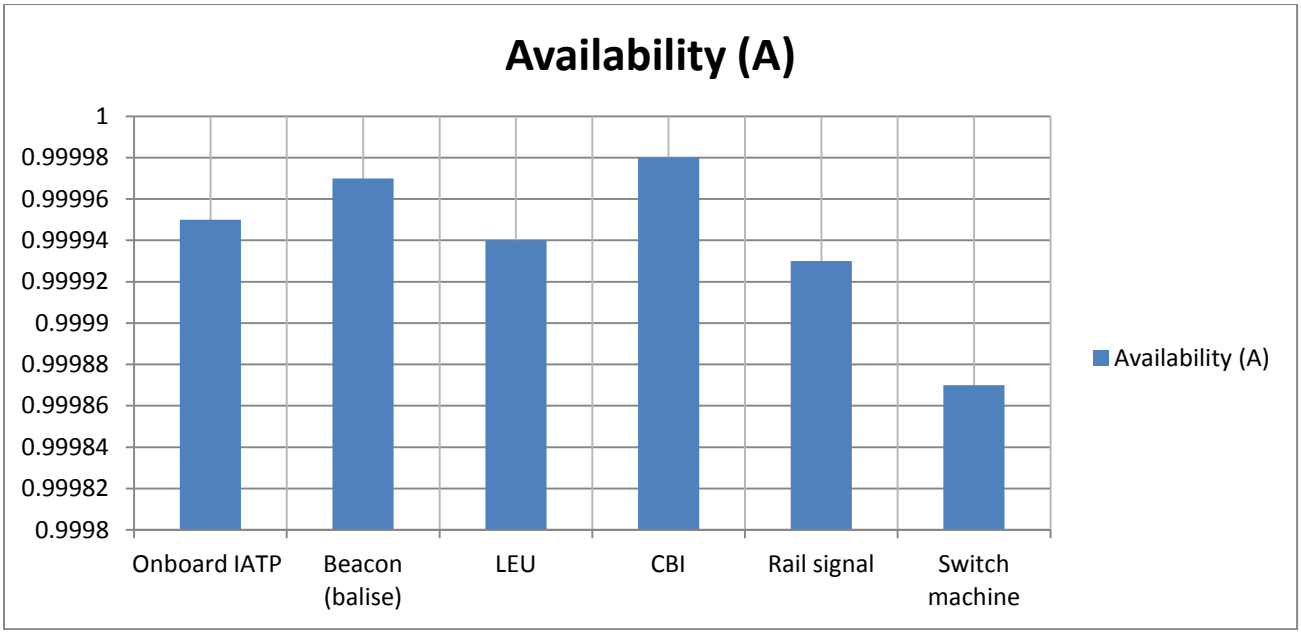

Figure 5-3 Availability pattern of each subsystem

Availability of switch machine are the lowest among six subsystems, hence it is required more attention than other subsystems.

The following table difnes types of availability

Table 5-5 Types of availability [23]

Class	Type of Availability	Availability (%)	Downtimeper Year	Number of Nines
1	Unmanaged	90	36.5 days	1-nine
2	Managed	99	3.65 days	2-nines
3	Well managed	99.9	8.76 hours	3-nines
4	Tolerant	99.99	52.6 minutes	4-nines
5	High Availability	99.999	5.26 minutes	5-nines
6	Very High	99.9999	30.00 seconds	6-nines
7	Ultra High	99.99999	3 seconds	7-nines

Now Reliability, Availability and Maintainability of the total subsystem based on the prescribed formulas calculated.

$$A = p_{s0(\infty)} = \frac{1}{(1+\sum\frac{\lambda i}{\mu i})} = 0.99964 = 99.964\%$$

Again, $R(t) = e^{-\sum \lambda it}$ where i=1,2….6

$$R(t) = e^{-4.497*10^{-4}t}$$

Table 5-6 Reliability of the total subsystem for different time interval

Time (H)	0	500	1000	1500	2000	3500
R (t)	1	0.79864	0.63782	0.50939	0.40681	0.20723

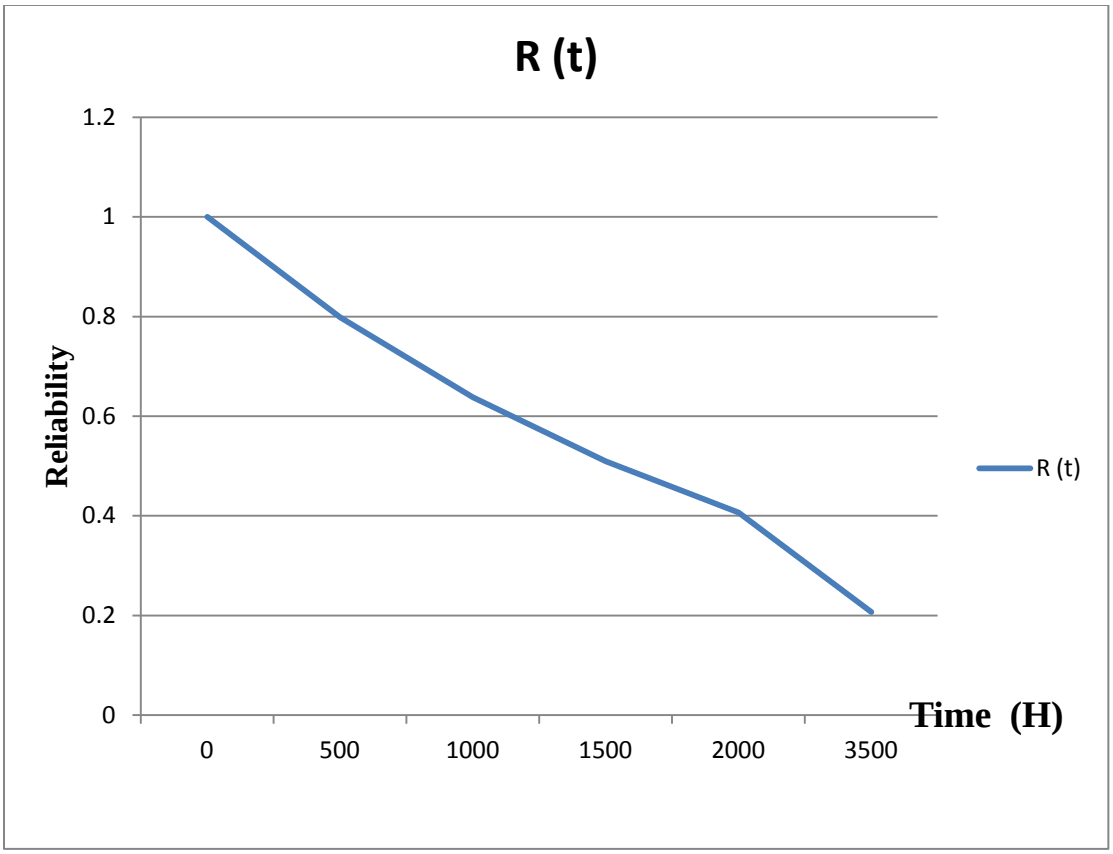

Figure 5-4 Reliability pattern of the total IATP subsystem

MTBFs = $\frac{1}{\sum \lambda i} = \frac{1}{4.497*10^{-4}} = 2.2*10^{3}$ hrs

$$\text{MTTRs} = \frac{\sum_{i=1}^{n} MTTR_i/MTBF_i}{\sum_{i=1}^{n} 1/MTBF_i} \Rightarrow \text{MTTRs} = \frac{3.62454*10^{-4}}{4.497*10^{-4}} = 0.81 \text{ hrs}$$

Now availability of the total subsystem can be calculated based on subsystem mean time between failures and mean time to repairs.

$$A = \frac{MTBFs}{MTBFs+MTTRs} = \frac{4.497*10^{-4}}{4.497*10^{-4}+0.81} = 0.99964 = 99.964\%$$

The result is similar with the result we have got from steady state probablity of state S_0.

Subystem repair rate (μs) = 1/MTTRs = $\frac{1}{0.81}$= 1.2346

maintainability Ms(t) = 1– $e^{-\mu st}$= 1- $e^{-1.2346t}$

Table 5-7 Maintainability of the total IATP subsystem for different time interval

Time(H)	0	0.5	1.0	1.5	2.0	2.5
M(t)	0	0.4606	0.7091	0.8431	0.9154	0.9543

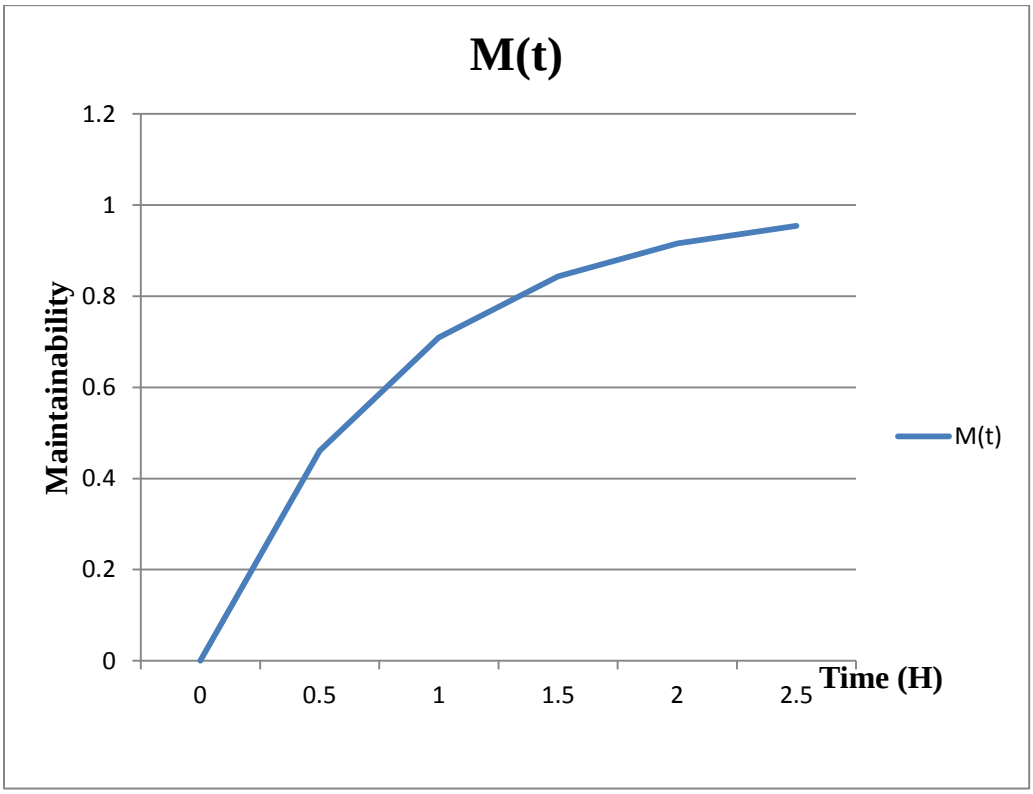

Figure 5-5 Maintainability pattern of the total IATP subsystem

The model developed in this paper is based on the fusion of different types of information obtained from corrective data records, operational data, and railway architecture. The model studies the effect of a failure in the IATP signaling system on the railway operation in terms of reliability, availability and maintainability.

The modeling phase requires understanding of the whole system operation and signaling equipments specific functions. The general topology and equipments localization of signaling system design of AA-LRT is the major input to the modeling phase.

Generally, after identifying each components failure and repair data for all components in the ATP signaling system by employing Markov chain, failure and repair rate of IATP signaling system were obtained. Finally compared the result we have obtained with the quantitative data taken from the signaling system design.

Below are quantitative data taken from the signaling system design [14].

1)Availability

The availability degree of whole signaling system ≥99.99%.

2) Reliability

ATP subsystem: MTBF≥2.0×105h;

3) Maintainability

Electronic and electrical equipment (except switch machine) of trackside equipment: MTTR≤30 minutes;

The result what we have got from the analysis have some varation from the quantitative data taken from the signaling system design.

1)Availability

The availability subsystem: 99.964%.

2) Reliability

ATP subsystem: MTBF = $2.2*10^3$ hrs ;

3) Maintainability

ATP subsystem: MTTR = 48.6 minutes;

Chapter 6 CONCLUSION and RECOMMENDATION

5.1 CONCLUSION

The purpose of this thesis is to ensure that each subsystem design can achieve the reliability, avaliabilty and maintainability (RAM). Determine the reliability avalaibility and maintainability of each device, and compare these values can achieve its allocation of RAM. Markov analysis is a powerful tool in the analyses of dynamic systems such as railway signaling system. Markov techniques decrease the analyst's task by reducing the problem from one of mathematical computation to that of state modeling. Given Markov model breaks the system configuration into seven states. Each of these states is connected to all other states by transition rates as shown in the state transition diagram. First-order differential equations are developed by describing the probability of being in each state in terms of states of the model. The expressions for reliability, maintenability and availability were obtained.

Railway signaling system generally is complex. Therefore, instead of direct implementation and troubleshooting from the beginning it is much easier to once define every equipment, components and subsystems failure data in a model. And test the system with hazards to find how failure propagates and which source is the root cause.

In this thesis, a study is done to calculate RAM corresponding to few subsystems of signaling system of AA-LRT. But, absence of significant data related to failure modes for the equipments used in the design, makes the analysis process difficult. Hence, a number of assumptions and study based data are taken into consideration.

The result outcome of this thesis report is almost comparable to the design data. However, the methodology and approach used in this study is based on interviews, assumptions and study based. It is only serves an academic purpose. Therefore, the results must be carefully checked before any further adoption.

5.2 Recommendation

- Due to lack of real repair and failure data of IATP signaling system from A.A LRT signaling and communocation department, the models developed in this thesis were using design signaling system data, interviews and assesments, there may be some error in the calculated values and simulation. Thus, by considering the actual information we can improve the result obtained in this thesis.

- The models developed for calculating the failure rate and repair rate is taken by considering only north to south line. This result may affect the actual failure and repair rate of the IATP signaling system. Thus, by considering the total line the result may be improved.
- If AALRT signaling division personnels are willing to give each data point consists of a number of information, such as the number of the component, time to failure, repair time, total number of trains delayed due to each failure, delay time for each train, and types of corrective actions taken by the operating and maintenance personnel, The analysis will be perfect.
- Markov process may also be applicable to other signaling subsystems.

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Annex : Technical terms and definitions in RAMS

Availability - A

Ability of a certain entity to be in the state of providing a certain function under certain conditions, at a given time instant.

$$A = \frac{UP\ TIME}{TOTAL\ TIME} = \frac{UP\ TIME}{DOWN\ TIME + UP\ TIME}$$

Corrective maintenance

Operation carried after a component failure is identified intended to restore the component back into a functioning state

Down time

Time interval during which a component is in a failed state, being unable to perform its functions

Failure

Departure of a component's functionality targets from specification. Alternatively, the definition "termination of the ability of an entity to perform a required function under specified conditions"

Failure cause

Events or circumstances that lead to a failure, due to design, manufacturing, or operation

Failure rate

Represented by λ , it is by definition the transition function between a working state and a failed state of a component, sub-system or system. It can be written analytically as the probability of a failure to occur in a time interval given that the component was working up until then. Being a transition function, it deals with short time intervals

Field data

Data obtained during field observations i.e. while the systems are in operation and subject to specific environmental conditions and maintenance policies

Maintainability

Ability of an entity to be restored into or be kept in a condition or state that enables it to perform a required function, when maintenance operations are performed under given conditions and are carried using stated procedures and resources. In short, it is the ability of an entity to be repaired in a given time (deadline). It is normally measured by the probability that the maintenance procedure of a certain entity E performed under certain conditions is finished at time t given that the entity failed at time t = 0.

MDT

Acronym for Mean Down Time. It is the expected value of all experienced component down times. Please refer to the definition of "down time", and of "MTTR".

MTBF (Mean Time Between Failures)

It is the expected value for operating time between the occurrences of two failures.

MTTF (Mean Time to Failure)

MTBF of the first failure. Due to their definition, in non-repairable items MTTF≡MTBF

MTTR (Mean Time to Repair)

Expected value of all the repair times experienced by a component

MUT (Mean Up Time)

Expected value of up (operating) time of a component

Preventive maintenance

Maintenance operations carried out at specified periods (time, cycles, distance, etc.) aimed at reducing the probability of failure of a component

RAMS

Acronym for Reliability, Availability, Maintainability and Safety

Reliability - R(t)

Ability of an entity to perform a required function under given conditions for a given time interval. In other words, an entity is reliable if it hasn't failed – i.e., stayed within the specifications – over a time interval.