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Failure analysis and improvement of level crossing signaling system of Addis Ababa-Light Rail Transit

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Advisor:

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ADDIS ABABA INSTITUTE OF TECHNOLOGY

FAILURE ANALYSIS AND IMPROVENT OF LEVEL CROSSING SIGNALING SYSTEM OF AA-LRT

BY

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APPROVAL BY BOARD OF EXAMINERS

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Declaration

I certify that research work titled "*failure analysis and improvement of level crossing signaling system of AA-LRT*" is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

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

Mr. Abi Abate __________________________________ Advisor's Name Signature

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I would like to acknowledge Mr. Abi Abate who suggested and advised me on this research, and to all who shared their precious time and ideas with me. Also I am thankful to respective ERC and CREC offices for their collaboration and support.

Abstract

Railway level crossings signalling systems are the most cause of concern for both rail and road authorities. Level crossings are one of the most crucial parts of the railway lines as two different types of transportation intersect at these points. The principle objective of this thesis represents the failure analysis of level cross in Addis Ababa Light Rail Transit signalling system: employing model-based failure analysis methods and system fault tree, causes and effects, major failures investigated. The improvement of the level cross signalling system after doing complete failure model and optimisation, determination of quantitative aspects such as probability of occurrence of hazard, forecasting about the system which is important in expansion and development of system.

First from the current AA-LRT railway level crossing signaling system installation and configuration, feared event model is developed (Collision between train and vehicle) by a Fault Tree. Second, perform in-depth analyses of the reliability, availability and maintenance of AA-LRT railway level crossing signaling system with initial design failure and repair rate data used to estimate the reliability, availability and maintenance for each subsystem. The system is classified in different subsystems in series like barrier, axle counter, rail signal, LC controller and interlocking (CBI).Mathematical model of these subsystems have been developed using Markov modeling. Third, study methodologies selected which are quantitative, analytical data analysis methods are evaluated and graph is plotted for different time intervals. The analysis from this thesis shows that the reliability of barrier, axle counter, rail signal, LC controller and CBI are 0.44, 0.94, 0.98, 0.90 and 0.90 consecutively after 10000, the reliability of the whole level crossing after 10000 hour and maintainability of Barrier, Axle counter, LC controller, rail signal and CBI after one hour are 0.865, .899, 0.926, 0.939, and 0.909 respectively according to the design data.

Keywords: Level crossing, failure propagation, failure modes, modeling based failure analysis, reliability, availability, maintainability (RAM) and Markov modeling.

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I would like to acknowledge Mr. Abi Abate who suggested and advised me on this research, and to all who shared their precious time and ideas with me. Also I am thankful to respective ERC and CREC offices for their collaboration and support.

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List of figure

List of table

ABBREVIATION

AA-LRT: -Addis Ababa Light Rail Transit

CBI: - Computer Based Interlocking

CIP:- Control Indication Panel

ERC: - Ethiopian Railway Corporation

FHA: - Fault Hazard Analysis

FMEA: - Failure Mode Effect Analysis

FMECA: - Failure Mode Effect & Criticality Analysis

FTA: - Fault Tree Analysis

LRT: - Light Tail Transit

MA: - Markov Analysis

MTBF: - Mean Time Between Failures

MTTF: - Mean Time To Failures

MTTR: - Mean Time To Repair

OCC: - Operation Control Centre

RAMS: - Reliability, Availability, Maintainability, Safety

RBD: - Reliability block diagrams

SIG: - Signaling

SIL: - Safety Integrity Level

TTM: - Time To Maintain

TTR: - Time To Repair

WHO - World Health Organization

WO:WorkOrder

Chapter one:

Introduction

1.1 Background

Railway level crossings (RLC) are location where a public or private roadway, footpath, or both, crosses one or more railway/tramway trucks. It provides a means for vehicles, trains to cross over railway lines. They exist in countries all over the world in many different forms. The layout, configurations and use of level crossings vary from location to location, so each one is essentially unique **[1].** The Railway level crossing accidents is one of the major contributing factors of railway related fatality problems in many countries. It considers as a unique intersection as signalling systems are complex and dealing with at least two mode of transport **[2].**

The safety of trains is dependent on the correct and prompt output of the level cross signalling system. The important concern in safety engineering understands the overall emergent the level cross failure behaviour of a signalling system. A signalling system can exhibited the level cross failure behaviour in many ways, including that failure of individual or a small number of components.

The following are some of the major reasons to why it is necessary to make failure analysis **[3]:**

- Insure system quality
- Achieve system reliability
- Prevent safety and environmental hazards
- Prevent customers dissatisfaction
- In addition, for easy visualization of fault propagation in case when it happens.

Failure analysis can do alone with the level cross control system design process or after the level crossing system design puts into its implementation **[4].**The later requires a historical data of the level cross signalling system failure while it is in operation. Based on this data, failure rates and hazards can simply forecasted. However, this approach is of little value as a compared to doing failure analysis prior to implementation, that is a design lifecycle.

1.2 Statement of the problems

The level cross signalling system that proposed for AA-RLT is new design, i.e. there is no failure is available. Therefore without doing failure/safety analysis prior to implementation study faults, their propagations and effects, the operation will exhibit the faults and may cause severe accidents. The lowering of the crossing barrier achieved by manual control of the crossing operator who can adopt two modes for control, i.e. the indoor manual control and the on-site manual operation:

- When a train approaches the level crossing signalling system, the operator has to make sure that the level crossing area cleared then he presses the lowering button of barrier that the train takes away.
- The crossing barrier can lower by on-site manual control in case of power failure or malfunction.

A model based failure analysis method used to study the safety of AA-LRT level crossing signalling system and give suggestion for improvements needed before implementation in this thesis.

In this method, it is also easier to visualize the propagation of the failure from single or multiple components to the whole level cross control system output that caused hazards to train operations service.

1.3 Objective

1.3.1 General objective

The main objective of the thesis is to assess the safety of AA-LRT level crossing signaling system making the analysis of failure data design practice, which includes modeling level cross component failure to the output and generating fault tree related to potential failure and can provide suggestions for improvements needed before implementation and operation of the service.

1.3.2 Specific objective

The specific objectives are:

- To determine failure modes of the level cross control system and investigate their propagation
- Modeling and illustrating the level cross failure behaviour
- Comparing the safety requirements with the results suggesting correction

1.4 Literature review

To scope with the increasing complexity of level crossing signaling system, CELENEC, IEC and many countries have developed several standards and recommendations. Standards like the IEC **[7]** and its railway specific derivative CELENEC [8] highly recommend them for the software development according to higher safety integrity levels (SIL). Common traditional safety and failure analysis methods that recommended in the safety assessment process. The classical inductive methods for hazard analysis are failure mode and effect analysis (FMEA).The failure modes, effects, criticality analysis (FMECA), fault tree analysis (FTA), hazard, operability analysis (HAZOP), cause-consequence analysis (CCA),and its extension failure mode, effects and criticality analysis as standardized in IEC **[6]**: FMEA classifies failures according to the severity of their effects, the occurrence frequency and the detection. Starting from a definition of the system and its boundaries, a functional viewpoint took and each subfunction analyzed with respect to potential fault modes.

FMECA mostly employed from the traditional methods **[11, 12]**. In extreme case, FMECA would be of little value to the design decision process if the analysis is performed after the level cross control system is built. While the FMECA identifies all failure modes, its primary benefit is the early identification of all critical and catastrophic subsystem or system failure modes so they can be eliminated or minimized through the modification at the earliest point in the development effort.

Therefore, FMECA should perform at the level cross signaling system as soon as preliminary design information is available and extended to the lower levels as the detail design progress. Their disadvantage is, they mainly rely on skill and expertise of the safety engineer and their advantage is that mainly analyzed as methods on a model-based level **[10]**. This means, that a model of the level crossing signaling system under consideration as well as its environment is build.

Rail is playing a very important role in the transportation hence work did in this field from many years. Many research works has done to improve working of level crossing signaling systems to make it more reliable, to decrease maintenance cost, to make its working efficiently so that accidents can stop by minimum effort. Some of the researches conducted on the area level cross signaling and related to this work briefly reviewed below:

In **[5]** proposed an original simulation approach to evaluate the availability of systems in the presence of state uncertainty which arises from incompleteness or imprecision of knowledge anddata.

In**[13]** Tsarouhas reviewed the reliability, availability and maintainability (RAM) analysis in the food industries and aims to identify the critical points of the production signaling systems that should be improved by the operational performance and the maintenance effectiveness.

In**[14]**Chen and Yuan presented a method to calculate and estimate the performance indices such as the mean and the variance of the transient throughput and the probability that the total outputs will meet the demand on time for a series of unreliable machines with the same production rates and without intermediate buffers.

In**[15]** Burman, there are several studies to related to reliability, availability and maintainability of manufacturing. The signaling systems with failure repair data by Markov modeling. The signaling system is classified in different subsystems like track circuits, signal unit, point and point machine.

In**[18]** Cockerillhas presented a reliability, availability and maintainability (RAM) analysis of turbine-generator systems.

In**[16, 17]** Kim and Geshwin developed Markov model to study the effects of tool failures on system performance measures for a flexible manufacturing cell with a single machine served by a robot for part loading/unloading and a pallet for part transfers to estimate reliability and maintenance.

From above literature review we have that work is being done in this and related field from many years. Many research works has done to improve working of safety critical systems to make it more reliable.

1.5 Scope

Thescope of this research is the failure analysis that will happen to the actual system and consider improving the reliability, availability, and maintainability of railway subsystem of level crossing signalingsystems. These studies for AA-LRT railway level crossing signaling system chooses as a good presentation:

- Lack of organized maintenance data of AA-LRT level crossing signaling system was big limitation of this thesis.
- Minimize conflict movement of approaching the train and vehicles at the level crossing signaling system.
- Failure that occurs in a system is redundant and thereby continuous to fulfill its objective was not considered

1.6 Contribution

This research lays a baseline for components based safety analysis of AA-RLT level cross signaling system and based RAM analysis. The store failure data of components and failure propagations can be always can check for failure that it happens to the actual system.

So this paper contribute to ERC railway infrastructure managers andoperators to reducing maintenance and sparing costs while maintaining or increasing production, detecting failures in the early part of design; increasing the effectiveness of the LC signaling system and to study whether results are in line with set objectives.

Other contributions of this study includes: suggesting improvement of level cross signaling system after making complete failure model, investigation how to development of the signaling system, predicting the control needs in maintenance or repair processes and potential design modification to ensure a desirable level of the level crossing signaling systems.

The study also initiates the use of modern model based failure analysis methods to any signaling system (Electrical, Mechanical ...). Hence, the same analysis can be employed for others systems of railway which Ethiopia is implementing

1.7Methodology

Initially, literature review is conducted. It is the study of different research works on related topicsare based on an in-depth analyses of reliability, availability, dependability, maintenance and risk evaluations of Level crossing signaling system of AA-LRT. The description of level crossing signaling system of AA-LRT modeled by fault tree to evaluate the occurrence probability of the feared event and Markov process to evaluate failure rate and repair rate at different time interval.

The following methodologies are considered:

- Literature Reviewing: this includes reading books, articles, and simulation tools.
- Model the current AA-LRT level crossing signal installation; how events or errors propagated from the bottom to the top feared events uses fault tree analysis.
- Reliability, availability and maintainability of level crossing signal quantitatively analysis using Markov process based on the design data.
- Evaluate the performance of AA-LRT level crossing signaling system, this will manly focuses on assessing the following aspect of the system :
  - Availability
  - Reliability
  - Maintainability

Analyze the main factors contributing to accidents and increasing the improvement of level crossing signaling system of AA-LRT in basic safety engineering studies beside the efficiency of level crossing signal system. The data analysis methods are qualitative, quantitative and analytical data analysis methods. Presentation of results obtained from analysis of primary data (from field observation) and secondary data (from books, stakeholders inputs and other documented files) sources will be performed graphically, by charts, tabular formation and in words using mat lab simulation.

1.8 Organization of this thesis

The research of the work consists of 6 chapters including this chapter. In this first chapter was the introduction part in which includes background, statement of the problem, objective and literature review, scope of the studies, methodology and applicability of the research are included.

Chapters 2 discuses about the level crossing signaling system. This chapter focuses the failure modes components based safety analysis methods the approaches followed to come up with a good failure model of the level cross control system and it is fault tree.

Chapter 3 is about different qualitative, quantitative reliability, analysis techniques and comparisons of each technique briefly discussed.

Chapter 4is about the RAM modeling level cross signaling system structure of AA-LRT and the failure model for the signaling system are based the data of each components.

Chapter 5 is about the simulations results and discussions based on the models described under four chapters.

Chapter 6 discusses the conclusions and recommendations for improvement and future works.

Chapter two

AA-LRT Level cross signaling system

This case study concerns a decentralized radio based railway level cross control system takes from a realistic specifications of a new radio-based train control system, which developes for the Germany Railways **[22].** This modeling is of a high level of abstraction and does not take into account failures of the system.

Although, simplification makes in the presentation of this example, it remains especially interesting, as it known by the railway specialists, takes into account software and hardware, specification, hybrid dynamic and temporal constraints. Our aim is a completely modeling level cross control system by taken into account hybrid dynamic, temporal constraints and failure. Then, applying the method described above to extract critical scenarios.

2.1.Level cross control system

The radio-based level cross control system used in an intersection area between a single-track railway line and a road. To avoid collision, the trains and the road traffic has not to enter at the same time this crossing zone also called danger zone. The level crossing controlled by means of signals radio communication between a train-borne control system, a level cross control system and an operation center that supervises interactions between the two preceding components. It is important to note that transmission times on the network may vary and radio telegrams maybe lost.

The railway crossing is equipped with half barriers, a red and a yellow road traffic light. Road users shall stop at the level cross signaling system if possible when a yellow light is shown and has to stop when the red light is shown as level cross control system is closed for a road users in this case. The yellow light and the red light have never to shown together and when both are off road users can cross the danger zone. The traffic lights and barriers at the level cross is controlled by the level cross control system that will be activated with the approach of a train to the level crossing signaling system. When level cross control system activated, it carries out a sequence of actions at a specific timing to ensure a safely closing of this crossing, and danger zone to be free of road traffic. If the barriers have completely lowered within this time, the level cross control system signals the safe state of the level cross and the train can cross it. When the train has completely passed the danger zone, the level cross maybe opened for road traffic. In level cross opening phase, the barriers are first opened then the road traffic lights and level cross control system are switched off.

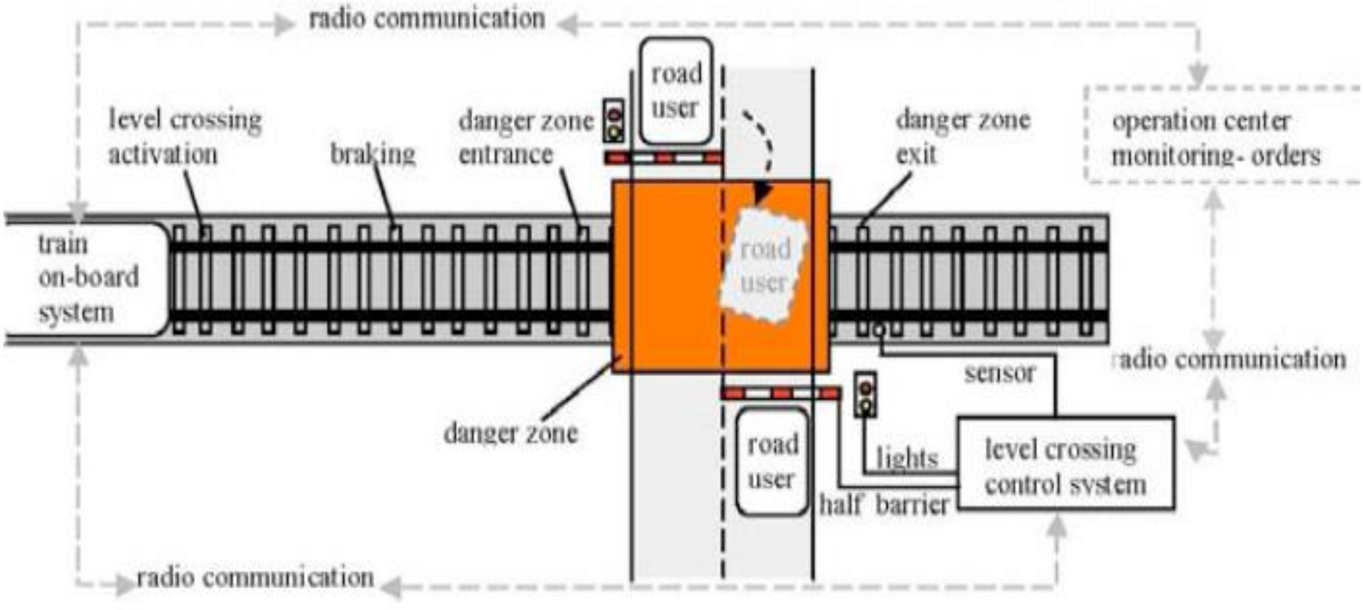

Figure2. 1: Railway of level cross control system [35].

2.2 Failure modes of level cross control system

A main cause of failure is malfunctioning of sensors or actuators. The main physical structures, communication systems and the control systems themselves maybe failed. Failure may occur at any time detective devices will be repaired after some time but will not take place when a train approaching or passing of the level cross in case of non-recoverable failure. In this case, only a limited number of failures are taken into account:

- Failure of the yellow or the red traffic lights
- Failure of the barriers
- Failure of the vehicle sensor
- The delay or loss of telegrams on the radio network

The traffic lights and the vehicles sensors constantly supervised and defect reported to the level cross control system. Failure of the barriers can only detect by time-out when barriers fail to reach upper or lower end position in time and at all.

2.3. The nominal behavior of the level cross control system

The train is equipped on board by a route map which contains the positions of danger points at level crossings and provides information of train when or where to send an activation order to the corresponding level cross control system. The train on-board system sends so a radio message to the level cross control system in order to close the level cross in time and let the train pass through without any delay or braking action. It will also set a breaking curve for speed supervision making the train stop at the danger points in a failure situation. The level cross control system acknowledges receipt of the activation order to the train. After receipt, the acknowledgement the on-board system waits the necessary time for the closing of the level crossing then sends a status request to the level cross control system. If the level cross is in a safe state it will report to the train that allows cancelling the breaking curve and safely pass over the level cross. The vehicle sensor at the rear of the level cross will triggered allowing the opening of the level cross.

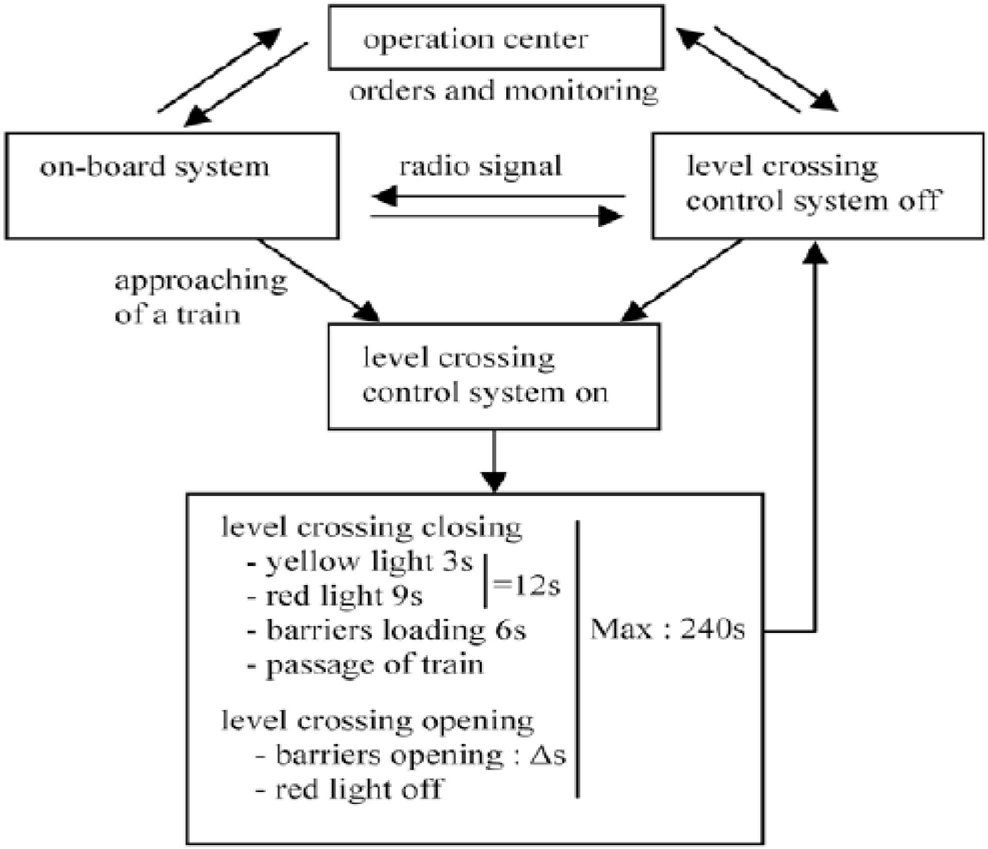

Figure2. 2: General view of the nominal behavior of level cross control system [35].

2.4 Level cross control system failure behavior

The level cross control system detects the occurrence and repairs of the failure of traffic lights and vehicle sensor and immediately reports them as an event to the operations center. Train operation is not suspend on the affected track section until repair. When the train sends a status request, if in the sequel it does not receive the status report with safe state of level cross before entering its breaking curve the on-board system will apply the break until the status report will receive or the train has come to a standstill. If the status report received before the standstill, breaks released and the train can continue its run. If not a request is prompted on the driver's display to make sure that the level cross can be passed safely and to confirm safe state on the display. Otherwise, the driver must to confirm the safe state of the level cross in order to release the breaks and continue its run.

The train supervises a maximum arrival time of 240 seconds to avoid tong waiting times of road users. If the train detects that it cannot arrive at the level cross within a specified time and still is able to stop before the danger point it cancels the activations order by sending a deactivated order to the level cross. In this situation the train discards any information received from the level cross and supervises a breaking curve ending at the danger point. The level cross will open upon receipt of the deactivated order. The driver has to confirm as described above the safe state before passing unclosed level cross.

The level cross control system will not activate if the red traffic lights or the vehicle sensor is defective and it will not send an acknowledgement to the train. If the level cross control system has activated, a minimum green time considered since that last deactivation of the level cross before switching on the yellow light for 3 seconds. If the yellow traffic light becomes defective either before of during the yellow light period, traffic lights switched to red and the red light period of 9 seconds extended correspondingly by the messing time of the yellow light period. If the red traffic light fails after activation of the level cross control the closing procedure has to be cancelled unless the barriers have yet begun to be lowered. The failure state of level cross must reported if the barriers fail to completely lower within a maximum duration of 6 seconds or if in the meantime red traffic light has become defective. The current state of level crossing will report to the train upon request.

However, the level cross control system supervises a maximum closure time starting from the red light be switched on. The exceeding of the maximum closure time will report to the operation center by the level cross control system. The operation center finds out, whether the train has yet passed the level cross or not. In the first case, the operation center sends a deactivation order to the level cross. Otherwise, the train is still approaching or just running on the level cross and rules for the late arrival at the level cross apply as described above.

2.5 Addis Ababa Light Rail Transit signaling system

A LRT system defines as a "specially built line for operation of at 80km/h **[32].** The project is located in Addis Ababa, the capital of Ethiopia, which was the location of the head office of African Union. The altitude of the plateau is 2,400m. With an Urban transportation esp. that of the downtown area, the government of Ethiopia decides to build a light rail in the city of Addis Ababa. Currently this project has planned 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 **[32].**

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 control center (commonly used by both lines) is temporarily **[32]**.

2.6 AA-LRT level crossing signaling system

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.

2.6.1 Composition of level cross subsystem

In the existing system, each of the 12 level crossings for LRT line and highway will be provided with one of set of independent level cross equipment. AA- LRT Level crossing equipment control system is mainly composed of the following equipment indoor unit and outdoor unit equipments:

- Main control cabinet MCC
- Control and indication panel CIP
- Barrier control box
- Barrier and road signal
- Audible warning
- Axle counter
- Rail signal

2.6.1.1Main control cabinet

The level crossing main control cabinet (MCC) consists of main control unit, outdoor equipment interface board and power module. The main control unit adopts PLC technology; except the interlocking system interface. The level crossing subsystem adopts all electronic mode for crossing equipment control and wall mounting.

2.6.1.2 Control and indication panel

Control and indication panel (CIP) integrates on the faceplate of the control cabinet and LCD screen is used for indicating the status of the level crossing equipment.

2.6.1.3 Barrier Control Box

The Barrier Control Box used for the Crossing operator to control the barrier. Two sets (Set A and Set

B) of lifting/lowering buttons are arranged in each Barrier Control Box and one set of lifting/lowering buttons may be shared by two opposite barriers for simultaneous lifting and lowering control[29].

The buttons are non-stick. As soon as the barrier is activated, under automatic mode, it will be lifted automatically till reaching the full-lifting position.

Barrier lifting button - non-stick button adopts, with pressing and times recorded by PLC;

Barrier lowering button -non-stick button adopted;

Barrier bypass switch - two-position switch that can only operate by inserting the dedicated key;

Indoor alarm Acknowledge button-single and non-stick button; indoor audible alarm.

Figure2. 3: level crossing signaling around CMC area[21].

2.6.1.4 Audible Warning

This used in conjunction with mechanized swing gate assemblies and fitted inside the gate mechanism or mounted near the gate mechanism. The audible warning may either produce a different tone in this situation, or stop when the first train passes and resume when the second train approaches **[19].**

Where road traffic light signals provided, the warning sound should begin when the amber lights first show. At all automatic open or half barrier crossings, the warning sound continues until intermittent red lights extinguished. At the barrier crossings operated by railway staff. The warning sound stops when the barriers fully lowered. At automatic open or half barrier crossings where two train can arrive at the crossing without providing the minimum road open time, the character of the warning sound should change distinctively after the first of the trains arrive at the crossings. At simple, un-automated open crossings, the audible warning maybe provided by horns from approaching trains **[20].**

2.6.1.6 Rail signal

Rail signal is one of the trackside signaling equipment used to allow the train to the level crossing area or not allow the train from passing through the level crossing. The composition of signaling system at crossing is shown in following figure:

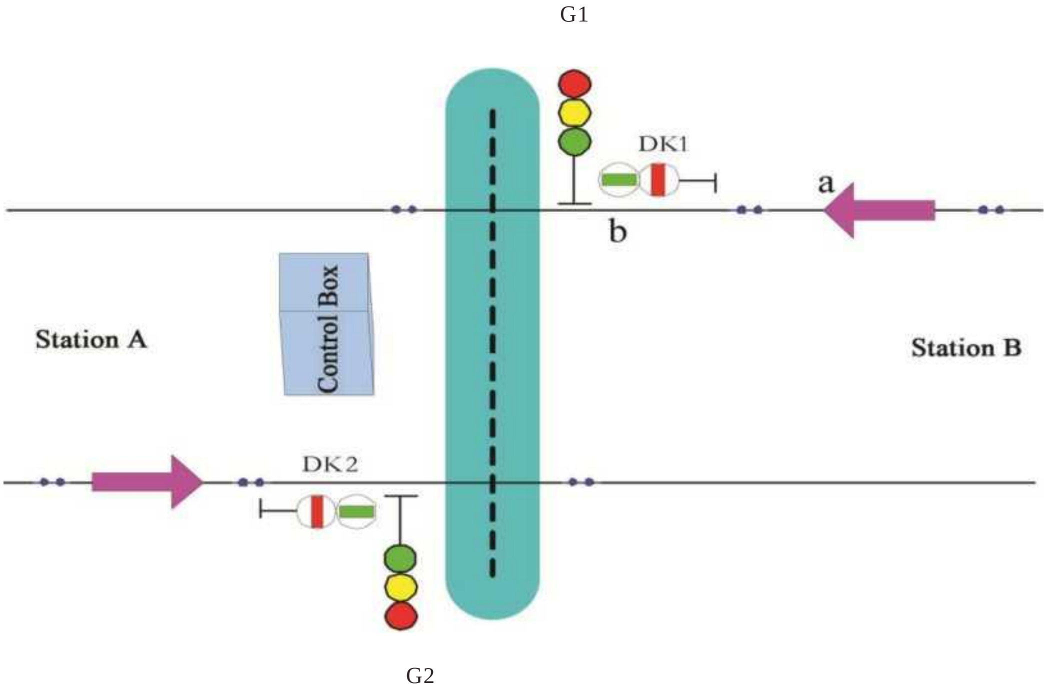

Figure2. 4: Equipment diagram of the crossing signaling control system [21].

Take the train running from Station B to Station A. The control principle is generally described as follows: **[21]**

1) When the train does not occupy the track section A, the road signal G1 and G2 in the signaling system at the crossing indicates a stable green light, which allows the motors and pedestrians to pass through the level crossing. Meanwhile, the signal DK1 indicates a red

light, which prohibits the train from passing through the level crossing.

2) When the train is detected to occupy the track section A, the road signal indicates a yellow light and initiates an acoustic alarm to remind the motors and pedestrians already in the crossing area to pass through the level crossing at a faster speed and to stop the motors and pedestrians that intend to enter the crossing area.

3) When the train occupies the track section B, the road signal G1 and G2 indicates a stable red light, which prohibits the motors and pedestrians to enter the crossing area. Meanwhile, the signal DK1 indicates a green light, which allows the train to pass through the level crossing.

4) After the train passes through the track section B, the road signal resumes the stable green light, which allows the motors and pedestrians to pass through the level crossing. Meanwhile, the signal DK1 indicates a red light, which prohibits the train from passing through the level crossing.

2.6.1.7 Axle Counters

An alternative method of determine the occupied status of a block is used device located at its beginning and end that count the number of axles entering and leaving. If the same number of wheels leave the block as enter it. The block is assumed to be clear. Although axle counters can provide similar functionality to track circuits, they also exhibit a few other characteristics. In a damp environment an axle counted section can be far longer than a track circuit one. The low ballast resistance of very long track circuit reduces their sensibility.

Track circuits can automatically detect some type of track detect such as:

- A broken rail
- In the event of power restoration after a power failure, an axle counter section left in an undetermined state until a train has passed through the level crossing. When a block section has left in an undetermined state, it may worke under pilot working. The first train to pass the level crossing would typically do so a speed no greater than 32km/hr of walking pace in areas of high transition, reverse curvature and may have someone who has a good local knowledge of the area

acting as the pilot man. A track circuit section will detect the presence of a train in section immediately.

- If the part of the train is left in the section, the part will continue to be detected by the track circuit **[25]**

2.6.1.8 Computer Based Interlocking

The computer based interlocking (CBI) is a system that controls railway station signal device by using computer technology to finish transportation tasks. It mainly composed of Man Machine Interface (MMI) & maintenance computer, controller, relay interface circuits and controlled signaling devices, when LRT train approaches the crossing from any direction, the CBI will send the information of train approaching to the level crossing subsystem according to the occupation condition of the approach section to the crossing or the condition of route setting **[21].**

Generally, CBI system ensures the safety train running, and control routes, signals and switches under stipulated interlocking conditions and time sequences to make sure that the interlocking among the signal elements in the route such as track sections, switches and level crossing signals is safe.

2.6.3 Signaling Safety related Data of AA-LRT: Reliability, Availability, Maintainability and safety data

This work details with reliability, availability, maintainability and safety modeling and failure analysis of AA-LRT level crossing signaling system. The failure and repair data analysis using a Markov modeling are given:

- Reliability is the probability that an item can perform a required function under given conditions for a given time interval. Reliability often measured as probability of failure, frequency of failures, or in terms of availability, a probability derived from reliability and maintainability. Maintainability and maintenance are often important parts of reliability engineering.
- Availability is 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 the required external resources are provided.

- Maintainability is the probability that a given active maintenance action for an item under given conditions of use can be carried out within a state time interval when the maintenance is performed under state conditions and using state procedures and resources.
- Safety is the freedom from an unacceptable risk of harm.

To maintain dependable level crossing signaling system and optimize level crossing signaling system performance, factors which could influence the RAMS of the level crossing signaling system needed to be identified, their effect assessed and the cause of these effects managed throughout the lifecycle of the level crossing signaling system by the application of appropriate controls **[23]**. The RAM of the railway level crossing signaling system influenced in three ways: by sources of failure introduced internally within the level crossing signaling system at any phase of the system lifecycle. by sources of the failure imposed on the level crossing signaling system during operation and by sources of the failure imposed on the level crossing signaling system during maintenance activities **[23]**. These resources of failure can interact. Improving the factors influencing RAMS will improve dependability.

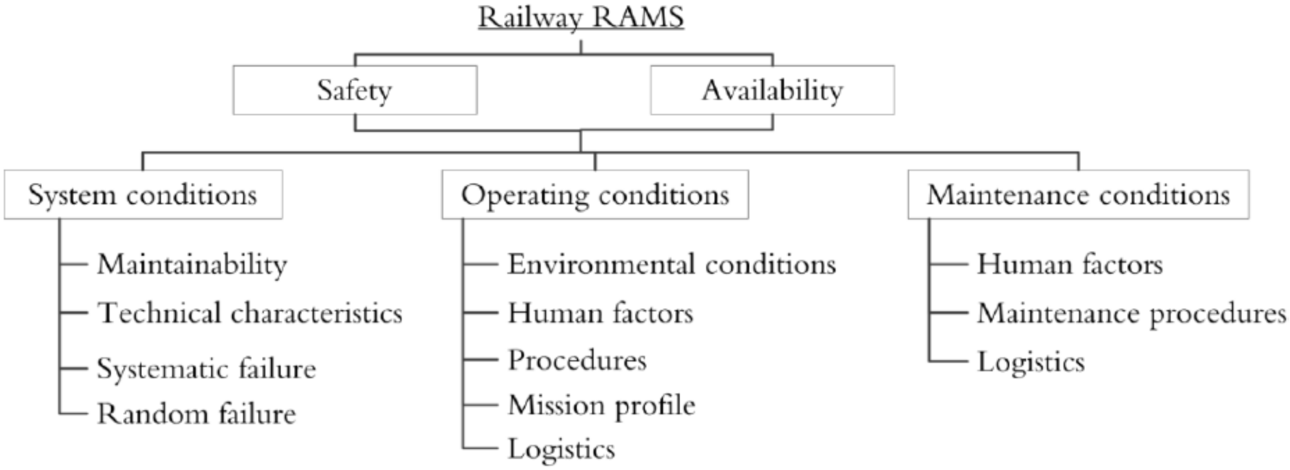

Figure2. 5: Maintenance approaches[23].

There are two types of failure to take into account, sematic and random. Sematic failure are those due to errors in any safety lifecycle activity, within any phase, which cause a system to fail under some particular combination of inputs or under some particular environmental condition **[23]**, e.g. errors in requirements, design and realization inadequacies, manufacturing deficiencies, inherent weakness, software errors, operating instructions deficiencies, etc.

Random failures are those related to such factors as the operating mode, the environment, stress degradation and wear out, etc. while sematic failure can minimize by better maintenance support, random failures are inherent to the system and the operation condition. Both types of failures have to manage to the control and minimize their effects **[24].**

The level crossing signaling system can consider repairable system with non-zero time to restoration and continuously operating item **[27].** RAMS parameters can estimate to study the dependability of the system

Based on these assumptions, the following definitions are given by **[26]:**

- Time between failures (TBF): the time duration between two consecutive failures of a repaired item.
- Operating time between failures: total time duration of operation time between two consecutive restorations.
- Mean operating time between failures (MTBF): expectation of the operating time between failures.
- Time to maintain (TTM): the total downtime (TD) when the system is not available for operation.

It is important to mention the note related to the definitions of mean time between failures on the standards, where it states that the use of the abbreviation MTBF as the mean time between failures are now deprecated **[26].**

Reliability
Mean Operative Time Between Failures (MTBF) = $\frac{total\ Operative\ Time}{Nr.of\ failures}$
Failure rate (λ) = $\frac{1}{MTBF}$
Failure probability F(t)
Reliability R(t) =$\int_{t}^{\infty} f(s)\,ds$
Availability
availability (A) = $\frac{MUT}{MUT+MDT}$
Mean up time (MUT), substitute as appropriate MTBF, MTBSF, etc.

Mean Down Time (MDT), substitute as appropriate MTTM, MTTR, etc.
Operational availability $(A_0) = \frac{MTBF}{MTBF+MTTR}$
Maintainability
Mean Time To Maintain (MTTM)
Mean Time to Restore (MTTR)
Restoration rate (μ)=$\frac{1}{MTTR}$
Operational restoration rate $(\mu_0) = \frac{1}{MTTM}$
MTTR=$\frac{\text{Totsl TTR}}{Nr.of\ failures}$
False Alarm Rate
Safety
Mean Time between Safety System Failures (MTBSF)
Hazard Rate H(t) and Tolerable Hazard Rate (THR)
Time To Return To Safety (TTRS)

Table2. 1: RAMS parameters [23].

Below are quantitative data taken from the signaling system design **[29]:**

1) Availability
   - The availability degree of computer system of individual subsystems shall be>99.998%;
   - The availability degree of completely signaling system shall be >99.99%.
2) Safety

The safety integrity level SIL of safety-related equipment in the signaling system reaches the level 4:

- International Electromechanical Commission’s (IEC) standard IEC 61508 specifies SIL defined as a relative level of risk reduction provided by a safety function or to specify a target level of risk reduction. SIL is a measurement of performance required for a safety-instrumented function. SIL assignment has only 4 levels and SIL level 4 is the highest safety integrity.

Subsystem	Safety integrity level
IATP system	Level 4

CBI system of mainline and depot	Level 4
Train position detection equipment	Level 4

Table2. 2: Safety Integrity levels for signaling equipment [29].

- The wrong side output probability of safety equipment in the whole signaling system is $<10^{-9}$/h.

3) Reliability

ATS system: MTBF>$2.0\text{x}10^{5}$ h;

ATP system: MTBF>$2.0\text{x}10^{5}$h;

CBI system: MTBF>$2.0\text{x}10^{5}$h;

Single outdoor balise beacon: MTBF>10^{6}h;

Onboard DMI: MTBF>$2.0\text{x}10^{5}$h;

Mean correct counts of axle counter is >$1\text{x}10^{9}$ axles;

Axle counter: MTBF>$1.75\text{x}10^{5}$h

4) Maintainability

Onboard equipment: MTTR< 30 minutes;

OCC equipment: MTTR< 30 minutes;

Station equipment: MTTR<30 minutes;

Electronic and electrical equipment (except switch machine) of trackside equipment: MTTR<30 minutes. Level crossing signaling equipment: MTTR<30 minutes

Chapter three

Reliability analysis techniques

For as long as technology has allowed us to create complex and safety critical systems, a challenge inherent to these systems is the problem of analyzing and predicting how reliable they are. In the advancement of technology and the modification and improvement of these complex and safety criticalsystems, one goal has always been to make them safer and more reliable. However, in order to do this we must first understand these systems and find a way to determine which parts contribute the most to the risk involved with their use. For a long time, this was done merely by approximation and use of existing data. However, in recent history many techniques have been developed and refined in order to represent these complex and safety critical systems. Both qualitative and quantitative methods developed to analyze complex and safety critical systems, and there are constantly more researched, especially in the academic community. Some are used more widely than others, while some are developed primarily for one specific application, but all techniques have their advantages and disadvantages.

3.1 qualitative techniques

Qualitative reliability analysis methods have always used to help identify all possible failures that could occur within a system, and the general risks associated with each of those failures. The most widely used qualitative method is failure modes and effects analysis (FMEA), sometimes also known as failure modes, effects and criticality analysis (FMECA). The purpose of FMEA is to review a system in terms of its subsystems, assemblies, and so on, down to the component level, in order to identify all of the causes and modes of failure and the effects of these failures. This does generally by identifying the five following characteristics: how each part can possibly fail, what might produce these failure modes, what could be the effects of these failures, how can the failures detected, and what provisions provided to compensate for this failure in the design **[28].**FMEA can completed either on an existing system or during the design phase, and its application at different phases fulfills various objectives. For instance, when performed during the design phase, it can help to select design alternatives with high safety and reliability potential. It can also assist in developing early criteria for test planning, which can help provide a basis for any quantitative reliability analysis that would perform. No matter when it performed, FMEA ultimately strives to list all potential failures and identify the magnitude of their effects **[28].**

3.2 Quantitative Techniques

There are several methods of quantitative reliability analysis techniques, with various theories behind them. The three that are most widely used are fault tree analysis (FTA), reliability block diagrams (RBD), and Markov analysis (MA). As will be discussed, all three of these methods are best for different situations, and all have their own advantage and disadvantage. Quantitative analysis aims to use knowledge of how a system works, often gained from previously completed qualitative assessments, and apply information about failure rates, probabilities, characteristics, and so on to this knowledge in order to gain more knowledge of subsystems or the system as a whole. The information concerning failure rates, distributions, or probabilities can gained in a variety of ways, but the most accurate is always through test data. However, when this data is not available, or sufficient data does not exist, a variety of theories can apply to hypothesize and predict the failure characteristics of a component or subsystem. Then, depending on which analysis method is used, the outcome is some form of failure data of the system, and can be used to perform a range of tasks, the most obvious being to identify the largest risk contributors in a system in order to improve them and consequently reduce the risk the system undergoes **[28].**

3.2.1 Fault Tree Analysis

The concept of FTA developed in 1962 by Bell Telephone Laboratories for the U.S. Force for use with the Minuteman system. A fault tree is a logic diagram that shows potential events that might affect system performance, and the relationship between them and the reasons for these events. Failure of one or more components of the system is not the only possible causes however. The reasons also include environmental conditions, human errors, and other factors [9]. A fault tree helps to illustrate the state of a system, otherwise denoted as the top event, in terms of the states of the system's components, otherwise denoted as basic events. A top event can connected to lower events through gates. The two gates that form the building blocks for the other (more complicated, less used) gates are the "OR" gate and the "AND" gate. The "OR" gate symbolizes that the output event will occur if any of the input events occur. The "AND" gate means that the output even will occur only if all of the input event occurs. There are the only two gates that were originally used when fault tree were developed, but since then many more types of gates have been created to fit specific needs (such as Inhibit gates, Priority AND gates, Exclusive OR gates, and k-out of-n gates) **[28].**

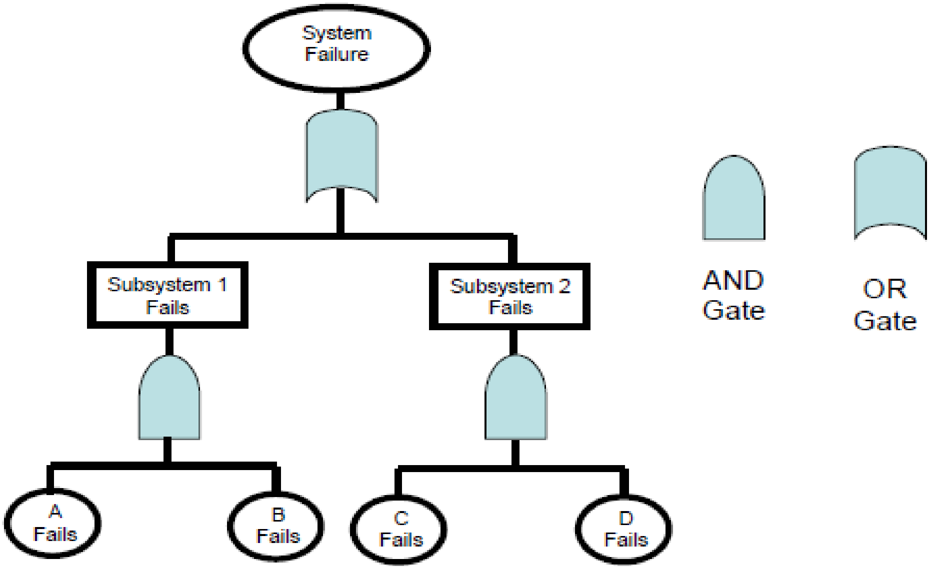

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Figure3. 1: Simple of fault tree analysis[34].

.3.2.1. Reliability Diagram Block

System reliability can predicted by looking at the reliabilities of the components that make up the entire system. In order to do this, a configuration must be predetermined that accurately represents the logic behind the reliability of the system. This action is similar to determining what types of gates to use in a fault tree. However, in the case of RBDs, a top-down approach used as well, so at the end of this composition the sum of the components must accurately represent the whole system. The two basic structures employed in RBD that coincide with the two gates mostly used in FTA are the series and parallel configurations. A sample RBD can see in Figure 3.2. A set of blocks in series is the equivalent of a set of events connected by an “OR” gate, while a set of blocks in parallel is the RBD equivalent of a set of events all under the same “AND” gate. Similarly, just as in FTA, blocks can be connected through sets of series and parallel connections in order to accurately represent a system. In addition, there are many other types of connections (such as the k-out-of-n, or the bridge structure) that can be used to form the block diagrams for mort complex system **[9].**

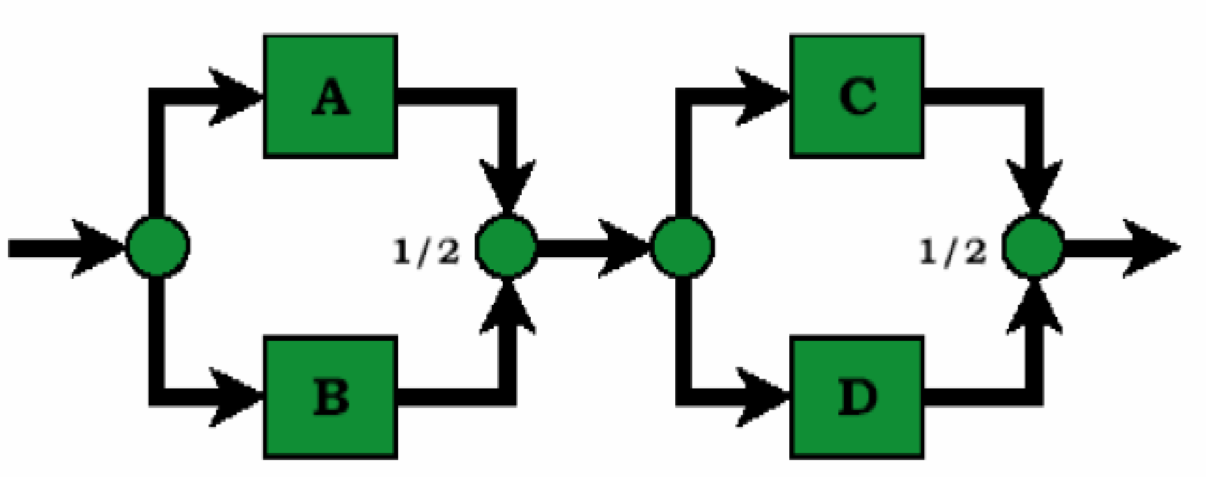

Figure3. 2: Simple RDB of a series of two sets of two parallel gates[34].

.2.3.2. Markov Analysis

Markov analysis is different from the others described previously in that it is a dynamic, state-space analysis. This means that the state of the system is what is model, and not the probability of specific events occurring. 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 represented. In addition, there are transitions that exist between many of these states, depending on the nature of the system, and each gives a failure rate that assumed constant. For instance, Figure 3.3 shows a system of two identical components (A and B), both of which can be functioning or failed at any time, independent of what state each other is currently in, with a failure rate of each component of λ and repair rate of µ. This means that there can be four possible global states: both are working, A is working and B fails, B is working and A fails and both have failed. As can be seen there is then a failure rate associated with each transition between states. Since this is a repairable system there can also transitions from fail states back to working states with given constant rates as well. (There is not transition directly from the state where both are working to the state where both have failed because it is theoretically impossible for two independent components to fail simultaneously**[30].**

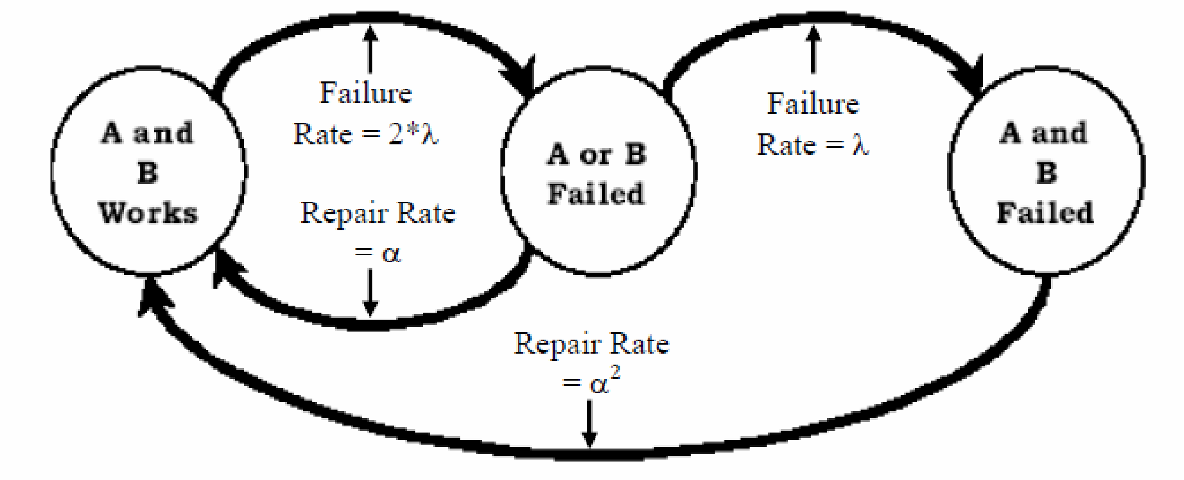

Figure 3. 3: Simple Markov Chain[34].

The qualities inherent to MA give it many distinct advantages and disadvantages. The major advantage comes from it being a dynamic analysis. This allows MA to be representative of the system at any given time using just one model. It also gives an illustration of the state of every component or subsystem at any given time in the analysis. However, since MA is a state-space analysis as opposed to an event-based analysis (like FTA or RBD) the models can get incredibly large very quickly. This is because when developing a MA model, every single possible state must be consider, which makes the model as well as the analysis very complicated. When modeling a very complex system, this can get completely out of hand very quickly, which is one of the large reasons that MA is not commonly used for very complex systems. Another disadvantage is that MA is limited to the use of constant failure rates for the transitions. Although MA is widely used for system where constant rates can apply, this does not accurately represent most components or subsystems and therefore makes the accuracy of the results gained from MA highly questionable **[30].**

2.3.3 Petri Nets

Petri Net is another dynamic method of reliability analysis that is not be use nearly as much as the other methods previously discussed. A Petri Net is actually a general-purpose mathematical tool mostly used for describing relations existing between conditions and events, which are the major reason that it is starting to, lend itself towards reliability analysis. In the case of reliability analysis, there are a number of places representing all of the possible states that whatever is being model could be in. A token, which could represent a number of things (including, but not limited to, a component, assembly, orsubsystem) would be located in any one of these places, which would identify the current state of whatever that token represents. In addition, there are transitions (either instant or timed) between many of these places according to the physics of the system, and a token will move from one place to another according to the transitions connecting the many places represented in the Petri Net. Petri Nets, just like any other reliability analysis technique, have had much more details and options added to them that help to more accurately model a larger range of systems, but those are the basics behind the method. Figure 3.4 is an example of a simple Petri net, with a legend denoting the items involved. One can see how this approach might become complicated rather quickly with a growing model **[31].**

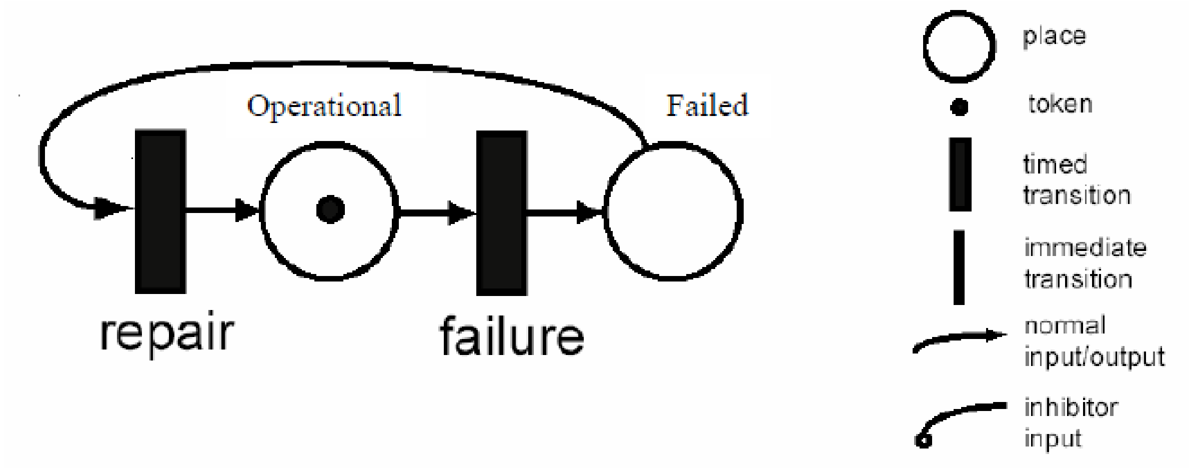

Figure 3. 4: Simple Petri Net[34].

Similarly to MA, the use of Petri Nets is advantageous because it represents the state of one or many components (or systems), and therefore is more representative of what it is modeling over time. In addition, since this method is not limited to constant failure rates, it can sometimes more accurately denote the actions of a system than can MA. However, since it is a state-space analysis, it tends to get incredibly large and hard to work with, as the model it represents gets more complex and complicated. Between this and the fact that it is not very well known to begin with, it is rarely used as a reliability analysis method with the exception of its application to simple models.

Table: 3.1 Shows a comparison of the different approaches to reliability analysis and a summary of some of the important characteristic of the methods discussed.

Characteristic	FTA	RBD	MA	Petri Nets
Static	X	X		
Dynamic			X	X
Logic-based	X	X		
State space			X	X
Top-down	X	X		
Variable distributions	X	X		X

Table3. 1: Comparison of Reliability Analysis Method Characteristics [33].

3.3 Railway Operation Rate

The railway operation can be considered to be in one of three possible states depending on whether operation is possible and whether the level crossing signaling system is operative:

Operative state: In this state, operation is possible and the level crossing signaling system is fully operative.

Faulty state: This is the operational state from when a failure occurs and the operation is stopped until the dispatcher allows continued operation in a degraded mode (40km/h, driver responsible for supervision and protection).

Degraded state: In this state, railway operation is possible in a degraded mode (40 km/h, driver responsible for supervision and protection), but the level crossing signaling system is not operative due to a failure in one of the signaling subsystems.

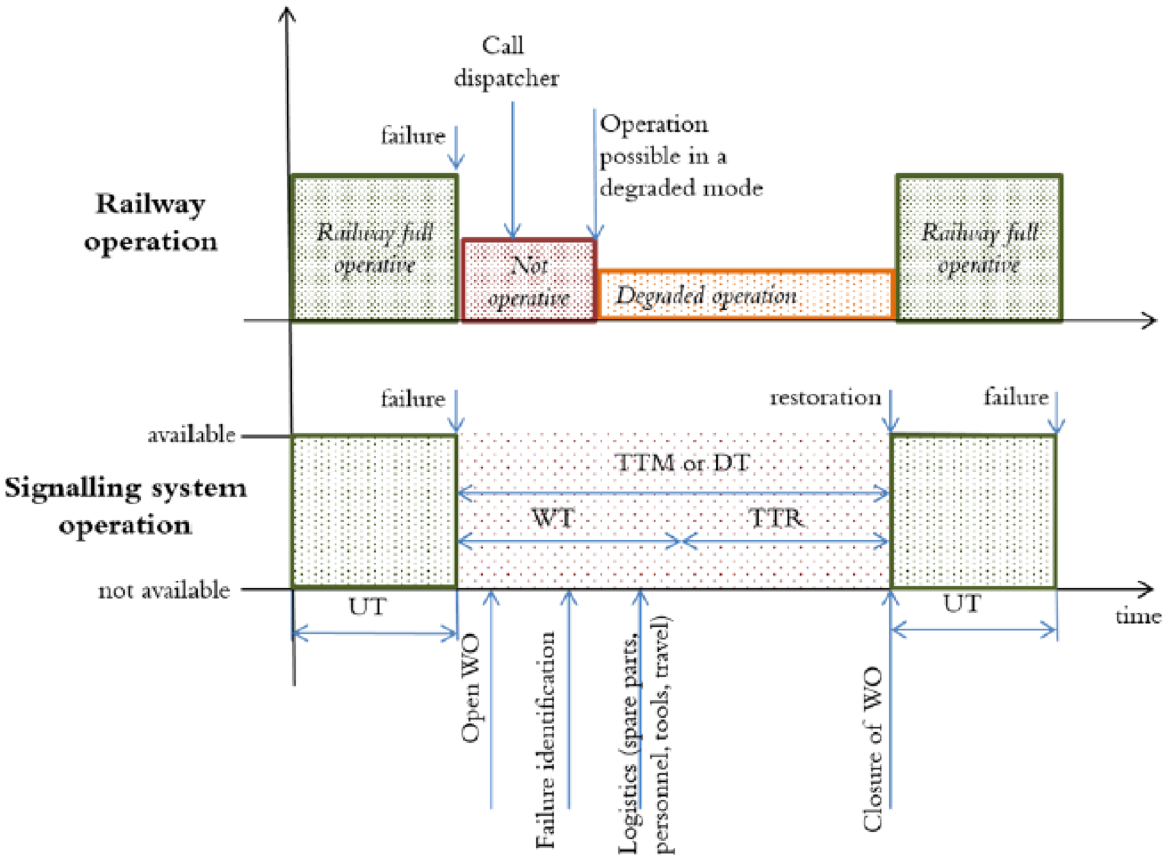

Figure 3. 5: Correspondence between different times[33].

For the level crossing signaling system, three possible states can consider:

- Available state or up time (UT): the system is operative.
- Not available or waiting time (WT): the time between when a failure occurs until the corrective action starts. During the waiting time, the WO (work order) opens, the failure identifies, maintenance personnel are informed, the spare parts and tools needed are gathered and the personnel go where the failure is located.
- Not available or restoration time (RT): corrective actions (repair or replacement)performed and the WO is closed.

To analyses the time data, calculate the total time spent on the corrective action (TTM) given by Equation (4), the time to restore (TTR) given by Equation (5), and the relative restoration time (RRT) against the total time to maintain for each WO given by Equation (6) and analyses the general characteristics of each and the relationship between them. Figure 3.5 shows the correspondence between the different times given above and the signaling system operation.

TTM= t(finish of corrective action) - t(failure identification)……………………………………..…(4)

TTR= t(finish of corrective action) – t(starting of corrective action)……..……………………(5)

RRT (%) = $\frac{TTR(sec)}{TTM(sec)}$…………………………………………………..……………………… (6)

Chapter Four

RAM modeling of AA-LRT level crossing signaling system

4.1 Introduction of the RAM modeling

RAM modeling can simulate the configuration, operation, failure, repair and maintenance of levelcrossing signal equipments. The inputs to RAM modeling will include the physical components andmaintenance schedules in a system and the outputs can determine how effective the system can beover the plant life. RAM studies will generate sufficient data on which to base decisions for possible systemschanges that may increase system efficiency and therefore increase project profits. A well designed and properly implemented asset optimization program can significantly lower costs. RAM modeling assesses a production system's capabilities, whether it is in operation or still design phase. The results from RAM modeling will identify possible of production losses and can examine possible system alternatives.

The key benefits of RAM modeling include:

- Detecting failures in the early part of design,
- Optimizing maintenance schedules,
- Adequately allocating the spares inventors,
- Increasing the effectiveness logistics and
- Identifying of the level crossing signaling system's equipment priorities on failure.

4.2 Modeling of the AA-LRT level crossing

4.2.1 Description of the system

The AA-LRT Railway level crossing signaling system consists of three parts:

- **Rail part**: it consists of a material part (train and road rail) and a human part (the operator of the train).
- **Road part**: it contains a material parts (vehicle and road) and a human part (the driver of the vehicle)
- **Level crossing**: it consists of three main parts:
    - **Power network and communication** of network between the components of the AA-LRT railway level crossing signaling system.

- **Control part**: it consists of programmable logic controller and its program.
- **Operative part**: it consists of sensors (axle counter) and actuators (the road lights, the alarms and barriers).

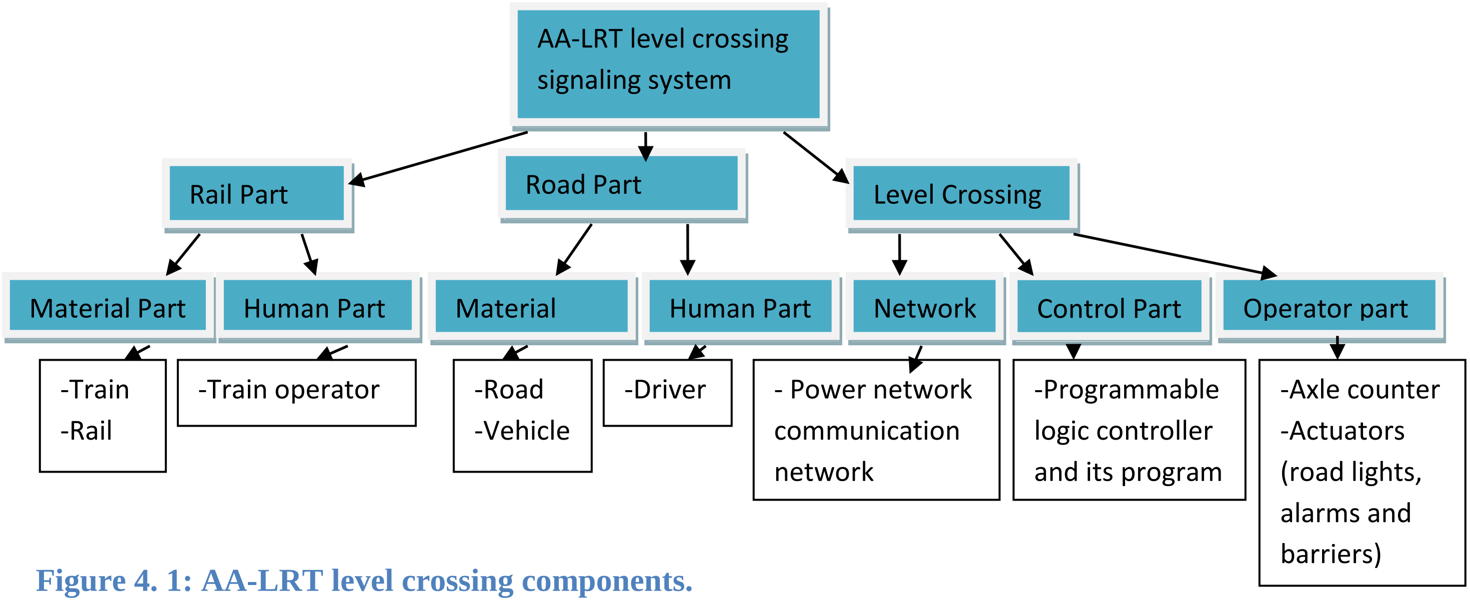

Figure 4. 1: AA-LRT level crossing components.

4.2.2 Modeling of the system

From the description of the AA-LRT railway level crossing signaling in the previous section, we were able to modeling the feared event (Collision between train and vehicle) by Dynamic Fault Tree (DFT) shown in figure 4.1.

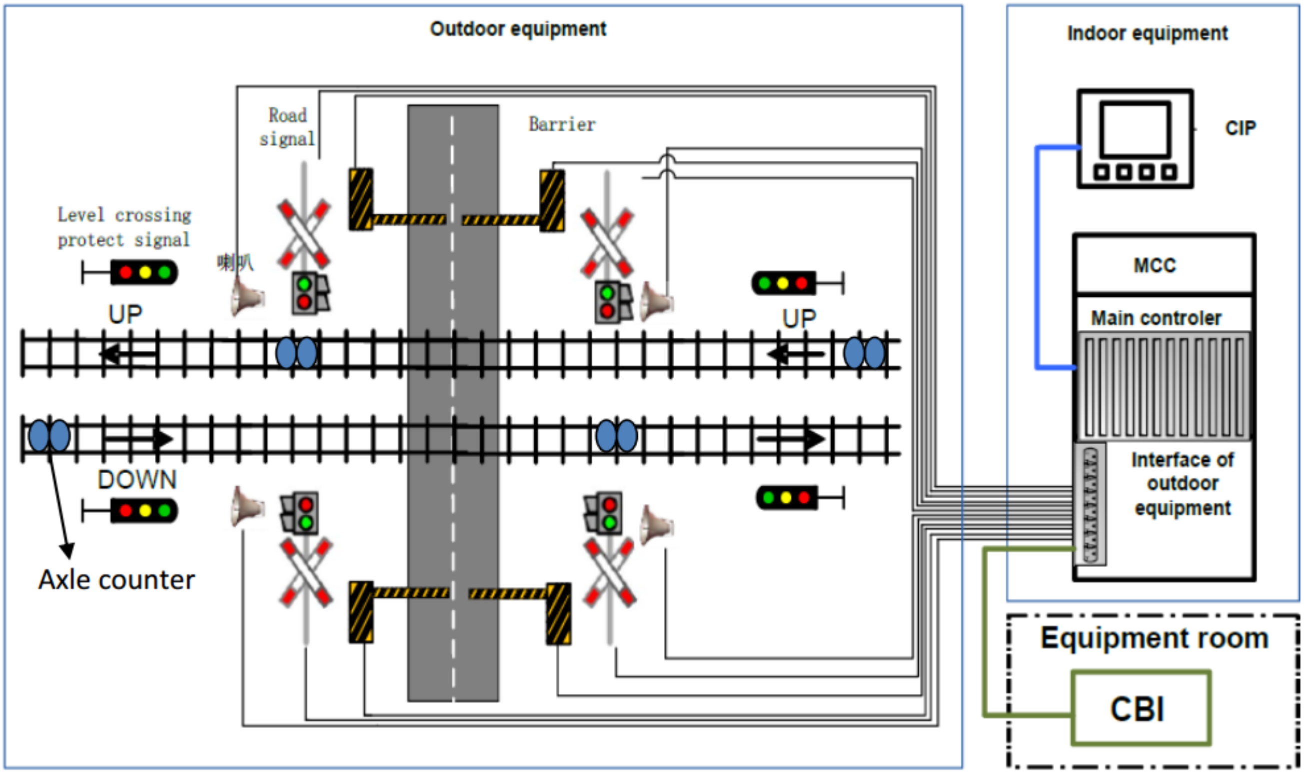

Figure 4. 2: the structure of level crossing signaling system of AA-LRT [21].

From above structure, it is clear that Axle counter, Barrier, rail and LC controller are the measure part of level crossing signaling system of AA-LRT and hence we considered these five subsystems of level crossing signaling system to analyze their failure in this thesis. From the structure of the following fault tree model in figure 4-3 developed and analytically their failures were evaluated using Markov analysis. This would create a visual understanding of level crossing signaling system of AA-LRT.

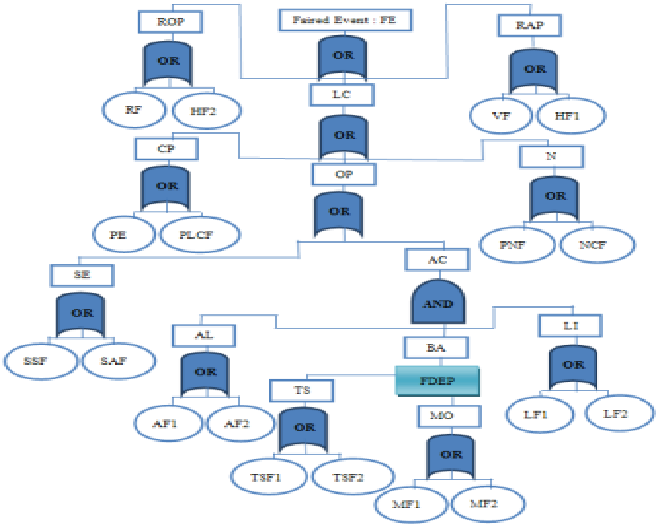

Figure 4. 3: Dynamic fault tree of the AA-LRT Railway level crossing [37].

We supposed that the motors failure depends on the transmission system failure. If the trigger event (transmission system failure) occurs, the dependent event (motor failure) occurs subsequently and output becomes true.

The basic events that produce the feared events are given in the table 4.1.

symbol	Basic events
HF	Human failure
VF	Vehicle Failure
RF	Rail Failure
PLCF	Programmable logic Control Failure
PE	Program Error
NCF	Network Communication Failure
PNF	Power Network failure
SAF	Sensor Ad Failure
SSF	Sensor Surrender Failure
AF	Alarm Failure
LF	Light Failure

MF	Motor Failure
TSF	Transmission System Failure

Table4. 1: the basic event [37].

We supposed that these events follow exponential laws with an imprecise failure rates represented by a fuzzy triangular numbers given in the same table 4.1.

The symbols intermediate events of the fault tree are given in the table 4.2.

Symbols	Intermediate Event
FE	Feared Event
ROP	Road Part
RAP	Rail Part
LC	Level Crossing
N	Network
CP	Control Part
OP	Operative Part
SE	Sensors
CA	Actuators
BA	Barriers
AL	Alarms
LI	Lights
M	Motors
TS	Transmission Systems

Table4. 2: Symbol of Intermediate Events [37].

In figure 4.2 a graphical presentation of the logical relationship between these basic events can be presented. The successive levels in the fault tree depict how the propagation of lower-level events causes the top event to occur. This method is easy to understand computational advantage and hundreds of components can easily solve. However, this method lacks the ability to handle various dependences, such as the failure dependencies, redundancy in repairable system, and shared repair, which are of essential importance for the system level reliability analysis. This method cannot accurately model dynamic system behavior. In these cases, Markov chain method has to be important and we used this method in this research to analysis the failure analysis and improvement of level crossing signaling system of AA-LRT.

4.3. Reliability Analysis Using Markov Modeling

4.3.1 Introduction

Markov Modeling is a reliability analysis tool which in the past few years has become the most prominent method of computing the reliability (or unreliability) of fault tolerant systems. It is an extremely flexible tool which can be used to predict the reliability of in-flight critical digital electronic systems. It has been used on a number of digital electronic engine controls to compute the probability of events such as aircraft loss due to control system failures, mission aborts, inflight shut-down of engines, overspeeding of engines and inadvertent thrust reversal. Markov modeling offers many advantages over other reliability modeling techniques, some of which are:

- **Simplistic modeling approach**: The models are simple to generate although they require a more complicated mathematical approach. This is not a problem, however, because the mathematics are well suited for the digital computer.
- **Redundancy management techniques**: System reconfiguration required by failures easily incorporated in the model.
- **Coverage**: Covered and uncovered failures of components are mutually exclusive event. These are not easily modeled using classical techniques, but are readily handled by the Markov mathematics.
- **Complex systems**: Many simplifying techniques exist which allow the modeling of complex systems.
- **Sequenced events**: Many times the analyst is interested in computing the probability of an event that is the result of a certain sequence of sub-events. As an example, the probability of an engine over speed might desire. This is usually the result of two events, these being loss of over speed protection and an uncommanded high fuel flow. These must necessarily occur in that order. For if the uncommanded high fuel flow precedes the over speed protection failure, an engine shutdown occurs rather than an over speed. While these types of problems do not lend themselves well to classical techniques, they easily handled using Markov modeling.

4.4.2 Markov analysis modeling

Markov modeling can apply to systems that vary discretely or continuously with respect totime and space. In reliability, we are generally concerned with continuous time, discrete state models. These systems characterized by randomly varying stochastic processes. Stochasticprocesses must have two important properties in order to model them with the Markov approach.

These are:

- The process must be memoryless
- The process must be stationary

A memoryless system is characterized by the fact that the future state of the system depends only on its present state. A stationary system is one in which the probabilities which govern the transitions from state to state remain constant with time. In other words, the probability of transitioning from some state i to another state j is the same regardless of the point in time the transition occurs. The states of the model are defined by system element failures. The transitional probabilities between states are a function of the failure rates of the various system elements. A set of first-order differential equations are developed by describing the probability of being in each state in terms of the transitional probabilities from and to each state. The number of first-order differential equations will equal the number of states of the model. The mathematical problem becomes one of solving the following equation: $\frac{\partial P(t)}{\partial t}$= A.P(t)

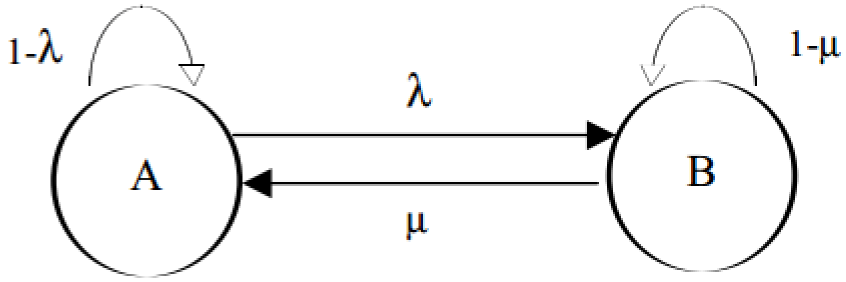

Figure 4. 4: Simple State Transition Diagram [36].

In figure 4.3 shows a simple state transition or bubble diagram (a diagram with two states: A= operational and B= failed) with a failure rate λ and a repair rate μ for the homogeneous case. Movements from the left to right indicate failure rate and movement from right to left indicates recovery.

Where $\frac{\partial P(t)}{\partial t}$ and P(t) are n x 1 column vectors, [A] is an n x n matrix and n is the number of states inthe system. The solution of this equation is:

$P(t)=P(0).e^{At}$

Where exp[A]t is an n x n matrix and P(0) is the initial probability vector describing the initial state of the system. Two methods which are particularly well suited for the digital computer for computing the matrix exp[A]t are the infinite series method and the eigenvalue/eigenvector method.

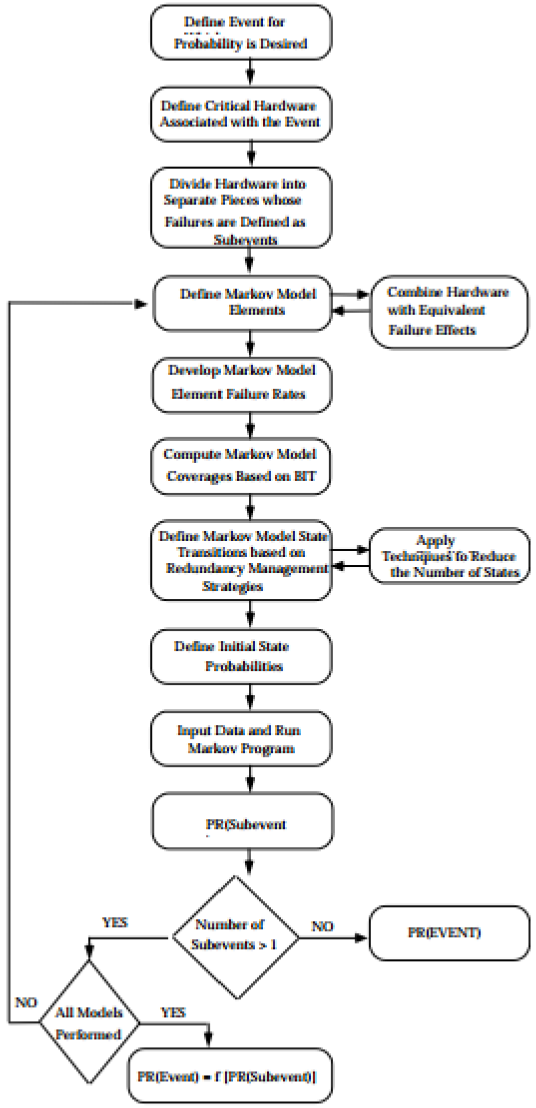

Figure 4. 5: Markov Modeling Process [36].

4.3.3 Development of the Markov Model Equation

In order to illustrate how the Markov model equations are developed, assume we have a system that makes up of two elements. Each element has two mutually exclusive states - a good and failed. The states of the model generated based on the elements being in one of these two states. The probabilities that cause transition from state to state are a function of the element failure rates. An element with constant failure rate has a transitional probability that approximated by $\lambda.\Delta t$. The probability of more than one element failure in Δt considered negligible.

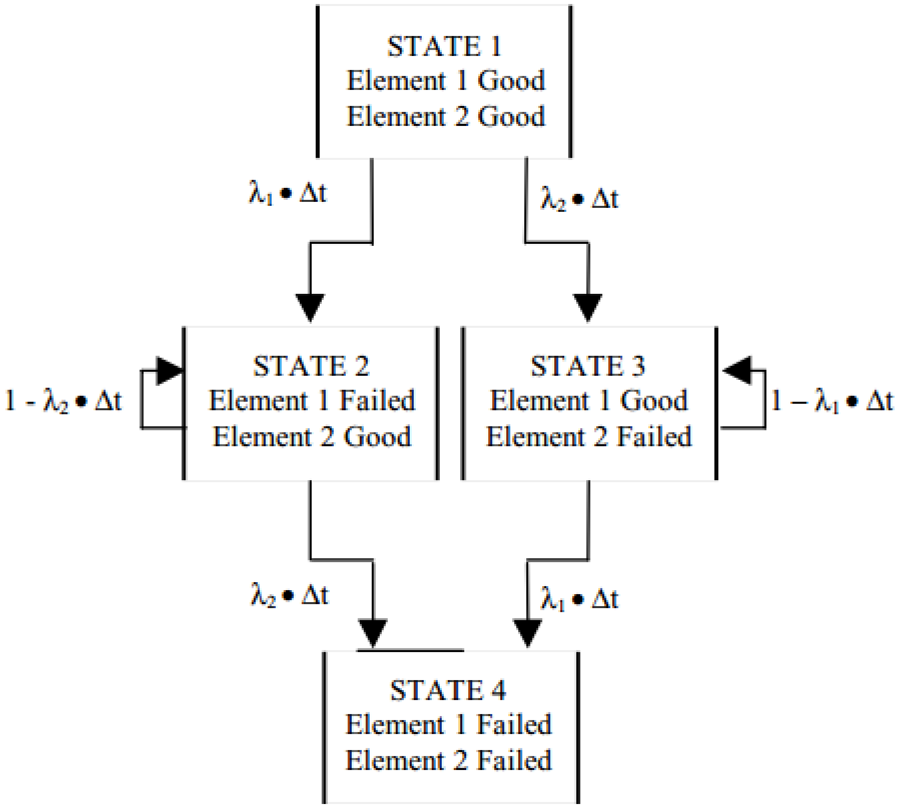

Figure 4. 6: Markov Flow Diagram.

We develop the Markov differential equation by describing the probability of being in each of the states at time t + Δt as a function of the state of the system at time t. The probability of being instate one at some time t + Δt is equal to the probability of being in state on at time t and not transitioning out during Δt. This can be written as:

$$P_1(t+\Delta t) = P_1(t).[1-(\lambda_{1+}\lambda_2).\Delta t]$$

The probability of being in state two at time t +Δt is equal to the probability of being in state one at time t and transitioning to state two in Δt plus the probability of being in state two at time t and not transitioning out during Δt. This can be written as:

$$P_2(t+\Delta t) = P_1(t).\lambda_1.\Delta t + P_2(t)(1-\lambda_2.\Delta t)$$

The other state probabilities generated in the same manner resulting in the following equations:

$$P_1(t+\Delta\mathrm{t}) = P_1(t).[1-(\lambda_{1+}\lambda_2).\Delta\mathrm{t}]$$

$$P_2(t+\Delta\mathrm{t}) = P_1(t).\lambda_1.\Delta\mathrm{t} + P_2(t)(1-\lambda_2.\Delta\mathrm{t})$$

$$P_3(t+\Delta\mathrm{t}) = P_1(t).\lambda_2.\Delta\mathrm{t}+P_3(t)(1-\lambda_1.\Delta\mathrm{t})$$

$$P_4(t+\Delta\mathrm{t}) = P_2(t).\lambda_2.\Delta\mathrm{t}+P_3(t).\lambda_1.\Delta\mathrm{t}+P_4(t)$$

Rearranging:

$$\frac{\partial \mathrm{P}_1(t+\Delta\mathrm{t})}{\partial\mathrm{t}} = -P_1(t)((\lambda_{1+}\lambda_2).\Delta\mathrm{t}$$

$$\frac{\partial \mathrm{P}_2(t+\Delta\mathrm{t})}{\partial\mathrm{t}} = P_1(t).\lambda_2.\Delta\mathrm{t} - P_2(t).\lambda_2.\Delta\mathrm{t} = (P_1(t).\lambda_1 - P_2(t).\lambda_2).\Delta\mathrm{t}$$

$$\frac{\partial \mathrm{P}_3(t+\Delta\mathrm{t})}{\partial\mathrm{t}} = P_1(t).\lambda_2.\Delta\mathrm{t} - P_3(t).\lambda_1.\Delta\mathrm{t} = (P_1(t).\lambda_2 - P_3(t).\lambda_1).\Delta\mathrm{t}$$

$$\frac{\partial \mathrm{P}_4(t+\Delta\mathrm{t})}{\partial\mathrm{t}} = P_2(t).\lambda_2.\Delta\mathrm{t} + P_3(t).\lambda_1.\Delta\mathrm{t} = (P_2(t).\lambda_2 + P_3(t).\lambda_1).\Delta\mathrm{t}$$

Taking the limit as Δt →0:

$$\frac{\partial \mathrm{P}_1(t)}{\partial\mathrm{t}} = -P_1(t)(\lambda_{1+}\lambda_2)$$

$$\frac{\partial \mathrm{P}_2(t)}{\partial\mathrm{t}} = P_1(t).\lambda_1 - P_2(t).\lambda_2$$

$$\frac{\partial \mathrm{P}_3(t)}{\partial\mathrm{t}} = P_1(t).\lambda_2 - P_3(t).\lambda_1$$

$$\frac{\partial \mathrm{P}_4(t)}{\partial\mathrm{t}} = P_2(t).\lambda_2 + P_3(t).\lambda_1$$

The transition rates can be expressed in form of a transition matrix as follows:

$$\begin{vmatrix} \frac{\partial \mathrm{P}_1(t)}{\partial \mathrm{t}} \\ \frac{\partial \mathrm{P}_2(t)}{\partial \mathrm{t}} \\ \frac{\partial \mathrm{P}_3(t)}{\partial \mathrm{t}} \\ \frac{\partial \mathrm{P}_4(t)}{\partial \mathrm{t}} \end{vmatrix} = \begin{bmatrix} -(\lambda_1+\lambda_2) & 0 & 0 & 0 \\ \lambda_1 & -\lambda_2 & 0 & 0 \\ \lambda_2 & 0 & -\lambda_1 & 0 \\ 0 & \lambda_2 & \lambda_1 & 0 \end{bmatrix} . \begin{bmatrix} P_1(t) \\ P_2(t) \\ P_3(t) \\ P_4(t) \end{bmatrix}$$

Equating first order derivative to zero for a steady state these equations will take the following form for the level crossing signaling system. The solution for this equation:

P (t) = P (0).e^{At}

$$\begin{bmatrix} P_1(t) \\ P_2(t) \\ P_3(t) \\ P_4(t) \end{bmatrix} = \begin{bmatrix} e^{-(\lambda_1+\lambda_2)\mathrm{t}} & 0 & 0 & 0 \\ -e^{-(\lambda_1+\lambda_2)\mathrm{t}} + e^{-\lambda_2 \mathrm{t}} & e^{-\lambda_2 \mathrm{t}} & 0 & 0 \\ -e^{-(\lambda_1+\lambda_2)\mathrm{t}} + e^{-\lambda_1 \mathrm{t}} & 0 & e^{-\lambda_1 \mathrm{t}} & 0 \\ -e^{-(\lambda_1+\lambda_2)\mathrm{t}} - e^{-\lambda_2 \mathrm{t}} - \frac{\lambda_2}{\lambda_1} e^{-\lambda_1 \mathrm{t}} + \frac{\lambda_2}{\lambda_1} & 1 - e^{-\lambda_2 \mathrm{t}} & \frac{\lambda_2}{\lambda_1}(1 - e^{-\lambda_1 \mathrm{t}}) & 1 \end{bmatrix} . \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

Where P (0) = $\begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix}$

$P_1(t)$ =$e^{-(\lambda_1+\lambda_2)\mathrm{t}}$…………………………………………………………………………….(4.1)

$P_2(t)$ =$e^{-\lambda_2 \mathrm{t}}$ -$e^{-(\lambda_1+\lambda_2)\mathrm{t}}$……………………………………………………………………..(4.2)

$P_3(t)$ =$e^{-\lambda_1 \mathrm{t}}$-$e^{-(\lambda_1+\lambda_2)\mathrm{t}}$……………………………………………………………………….(4.3)

$P_4(t)$ =$\frac{\lambda_2}{\lambda_1}$-$e^{-(\lambda_1+\lambda_2)\mathrm{t}} - e^{-\lambda_2 \mathrm{t}} - \frac{\lambda_2}{\lambda_1} e^{-\lambda_1 \mathrm{t}}$……………………………………………………………..(4.5)

4.3.4 A series configuration of AA-LRT level crossing signaling system

The simplest and perhaps most commonly occurring configuration in reliability mathematical modeling is the series configuration. The successful operation of the AA-LRT level crossing signaling system depends on the proper functioning of all the subsystem components. A component failure represents total system failure on the AA-LRT level crossing signaling system. A series reliability configuration is represented by the block diagram of AA-LRT level crossing signaling system was represented in figure 4.5with only five main level crossing components. Further, assume that the failure of any one component is statistically independent of the failure or success of any other systems.

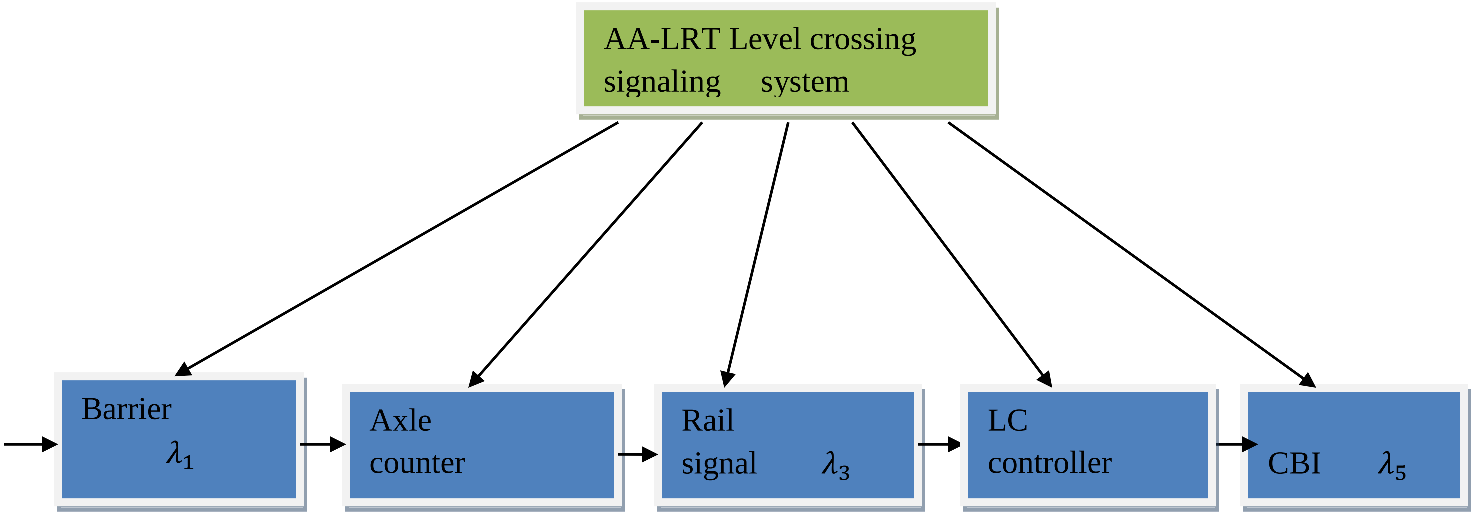

Figure 4. 7: Series Configurations of AA-LRT Level Crossing Reliability Block Diagram.

Thus, for the configuration of Figure 4.5, under the assumptions made, the series reliability is given by:

R(t)=$R(t)_1 R(t)_2 R(t)_3 R(t)_4 R(t)_5$

R(t)=exp (-λ_1t)exp (-λ_2t) exp(-λ_3t) exp(-λ_4t)exp(-λ_5t).

Where : λ_1- The failure rate of barrier.

λ_2- The failure rate of axle counter.

λ_3- The failure rate of rail signal.

λ_4- The failure rate of LC controller.

λ_5- The failure rate of CBI.

Hence R(t)=exp(-λt).

Where λ= $\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5$

Thus, the system failure rate, λ, is the sum of the individual component failure rates.

The maintainability of the different subsystem is given as following:

$$M_1(\mathrm{t}) = 1 - \mathrm{e}^{-\mu_1 \mathrm{t}}$$

$$M_2(\mathrm{t}) = 1 - \mathrm{e}^{-\mu_2 \mathrm{t}}$$

$$M_3(\mathrm{t}) = 1 - \mathrm{e}^{-\mu_3 \mathrm{t}}$$

$$M_4(\mathrm{t}) = 1 - \mathrm{e}^{-\mu_4 \mathrm{t}}$$

$$M_5(\mathrm{t}) = 1 - \mathrm{e}^{-\mu_5 \mathrm{t}}$$

Where : μ_1- The failure rate of barrier.

μ_2- The failure rate of axle counter.

μ_3- The failure rate of rail signal.

μ_4- The failure rate of LC controller.

μ_5- The failure rate of CBI.

Mean time to failure MTTF=$\frac{1}{\sum \lambda_i}$

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

Mean time to repair MTTR=$\frac{1}{\sum \lambda_i} * \sum \frac{\lambda_i}{\mu_i}$

The system repair rate (μ_s)=$\frac{1}{MTTR}$=$\frac{1}{MTTF}$*$\sum \frac{\lambda_i}{\mu_i}$

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

Chapter five

Results and Discussions

The data on failures and repairs improvements of subsystems of level crossing signaling systems for this study got from signaling system detailed design of AALRT Part I technical specification. With the help of these data, the reliability, maintainability of five main subsystems. the overall level crossing system of time-crossings at different intervals were calculated and estimated using the Markov process. The graphs for reliability and maintenance time at different intervals have also been plotted to estimate the reliability and maintainability of the five main subsystems and of the whole system of the level crossing signaling system. The rate of failure and repair of the improvement is shown in the table below.

Components	Failure rate(λ)/hour	Repair rate (μ)/hour
Barrier	0.00008	2
Axle counter	0.000002	2.3
Rail signal	0.000005714	2.8
LC controller	0.000050	2.6
CBI	0.000010	2.4

Table5. 1: Failure Rate and Repair Rate Improvement of the Difference Level Crossing Signaling System.

From the above repair rate and failure rate of different LC components Barrier, Axle counter, rail signal, LC controller and CBI reliability at different time interval is calculated which is given in thetable 5.2.

Time(hour)	Barrier	Axle counter	Rail signal	LC controller	CBI
0	1	1	1	1	1
150	0.9881	0.9991	0.9997	0.9985	0.9985
300	0.9763	0.9983	0.9994	0.9870	0.9970
450	0.9646	0.9974	0.9991	0.9955	0.9955

Table5. 2: Reliability of the different components at the level crossing signaling.

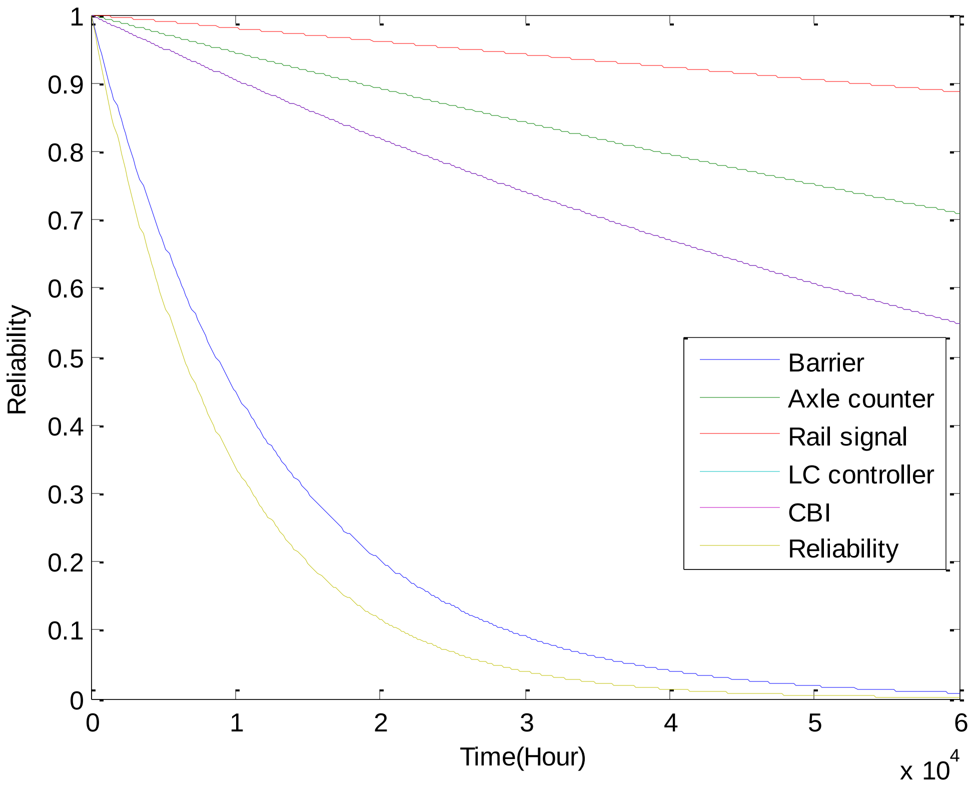

Figure 5. 1: Reliability of the level crossing signaling system.

The diagram of the reliability is the ability of the level crossing system to perform stated condition for a specified period of time. As shown figure 5.1, initially, the rail signal system is of the highest reliability 10000 hours. So that the reliability of barrier, axle counter, rail signal, LC controller and CBI are 0.44, 0.94, 0.98, 0.90 and 0.90 consecutively after 10000. Anyway, the reliability of the barrier system is not good reliability among the five subsystems level crossing system for a lengthy time.

Time(hour)	Barrier	Axle counter	Rail signal	LC controller	CBI
0	0	0	0	0	0
1.5	0.9502	0.9683	0.9850	0.9727	0.9798
3	0.9975	0.9990	0.9998	0.9993	0.9998
4.5	0.9999	1	1	1	1

Table5. 3: Reliability of the different components at the level crossing signaling.

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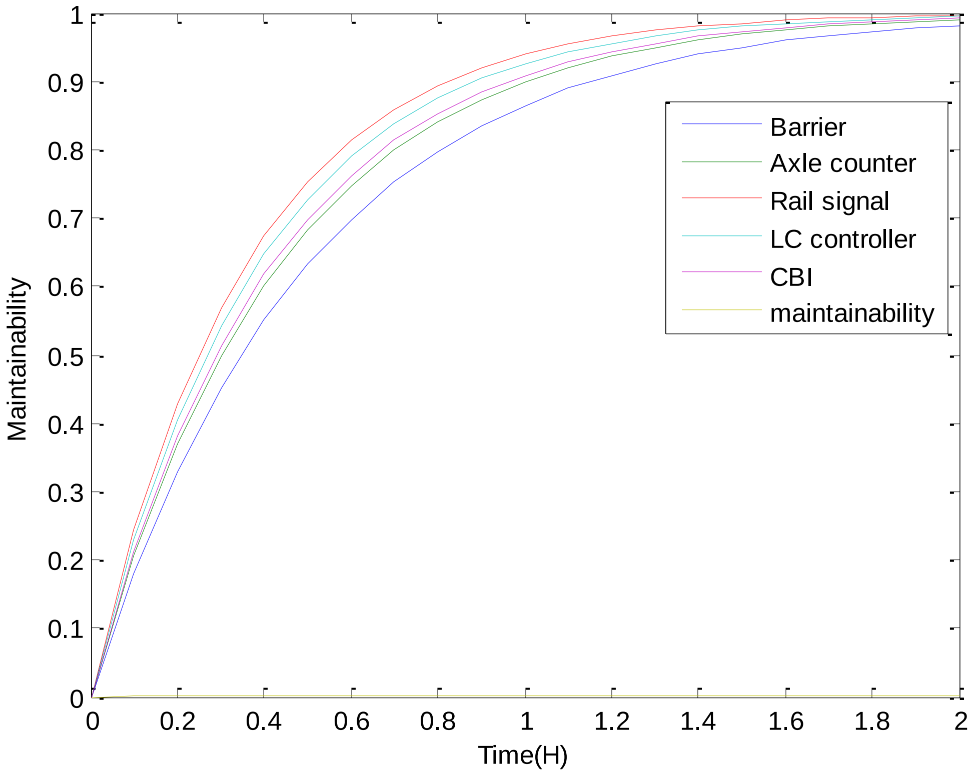

Figure 5. 2: Reliability of the level crossing signaling system.

The diagram of maintainability is the probability that the failure signaling system will be restored to an operational state within specified period of time. As shown in the figure5.2 maintainability of the Barrier, Axle counter, Rail signal, LC controller and CBI and maintainability of whole level crossing signaling system after one hour are 0.886, 0.899, 0.926 and 0.909 respectively. The maintainability of the axle counter, rail signal, LC controller and CBI are highest than the barrier. Thus, this design can improve the availability of the level crossing signaling system.

The trustworthiness and the confidence reliance as expected interval should be zero for any system. By correction planning and spare parts management for increased availability of the equipments might be reduced their maintenance time. The limit and caused for good trustworthiness and keeping on good condition considered and took in to account that the data was taken from the beginning design data, this will be reduce these are worthless. After these subsystems will start to perform and ready the work in the real environment. Once more, after these supplies completely start the operation exceptional action in connection to the maintenance and examine activities and logistics help is necessary to be done for making better the reliability and the maintainability condition of the level crossing signaling subsystem and system. For alternative percentage of considered in trusting and more reliability we had had different maintenance interval from the first design data AA-LRT. From Table 5.4 for expected reliability of 0.10, maintenance interval is 21380 hours, for expected reliability of 0.2, maintenance interval is 14944 hours, for expected reliability of 0.30, maintenance interval is 11176 hours, for expected reliability of 0.40, maintenance interval is 8506 hours, for expected reliability of 0.50, maintenance interval is 6435 hours, for expected reliability of 0.60 maintenance interval is 4742 hours, for expected reliability of 0.70 maintenance interval is 3311hours, for expected reliability of 0.80 maintenance interval is 2072 hours and for expected reliability of 0.90 maintenance interval is 978 hours. On this way we need a small maintenance interval for high reliability of level crossing signaling systems.

Expected Reliability(%)	10	20	30	40	50	60	70	80	90	100
Maintenance Interval(hour)	21380	14944	11176	8506	6535	4742	3311	2072	978	0

Table5. 4: Expected reliability for level crossing signaling system for different maintenance interval.

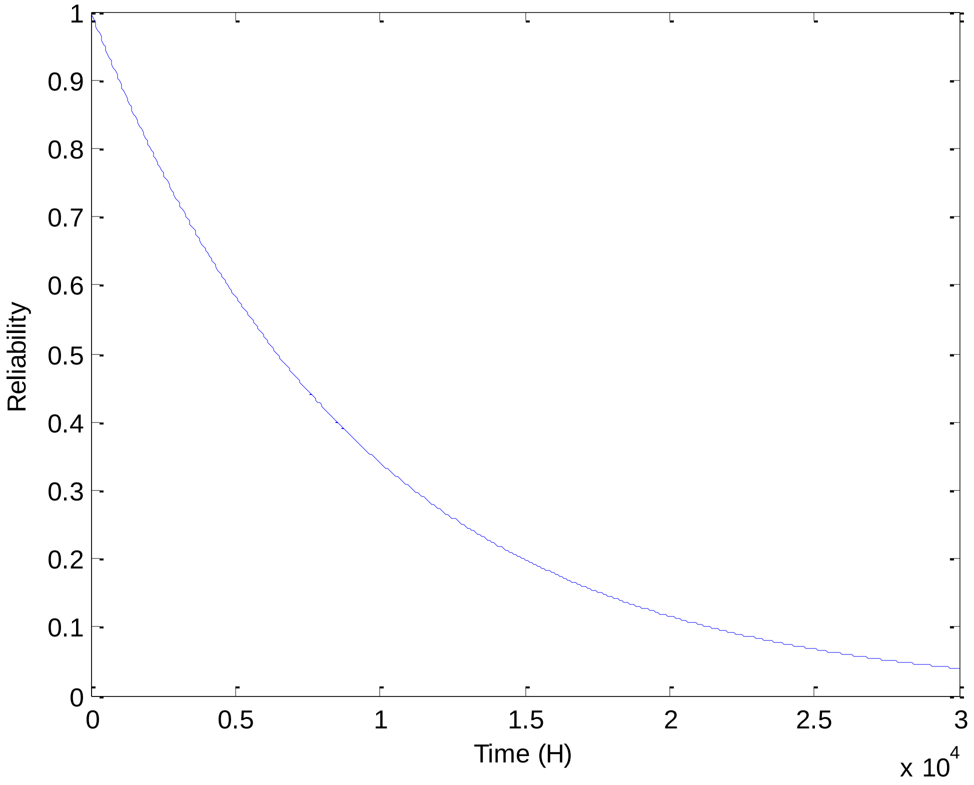

Figure5.3: Expected reliability for level crossing signaling system for different maintenance interval.

From the above it is found that the reliabilities of the subsystems and level crossing signaling system are in decreasing as time increase. It is also seen the failure and repair data taken is the initial design data the reliability of Barrier, Axle counter, LC controller, CBI and rail signal with time is satisfactory. The overall reliability of the level crossing signaling system drops slightly but in real environment drops significantly with time. For more improvement after these system start operation, the reliability of those subsystems requires strengthening the maintenance efforts, which can result in decreasing their failure rate or in increasing their time to failure (TTF). The reasons for good reliability and maintainability suggested that the data were not obtained from the operational data it was from initial design data. From the outcome of this analysis, it is clear that to maintain this good reliability and maintainability a better maintenance planning and for improving the RAM of the machine from this type of modeling and quantitative analysis by the Markov processes. This investigation provides data for predicting the control needs in maintenance or repair processes and potential design modification to ensure a desirable level of the level crossing signaling system‘s reliability, availability and maintainability. Again, special attention is required if decreased reliability and maintainability is observed to improve maintainability of the signaling system. So proper resource allocation, a maintenance strategy suitable for the environmental as well as technical problems, and design out maintenance can only reduce the frequency of machine failure or repair time and consequently improve the system availability (i.e. reliability and maintainability).

Chapter six

Conclusion and Recommendation

6.1 Conclusion

Analytical probability models for a level crossing system that consists of five main subsystems in series are developed. It is much easier to define every equipments, components and subsystems failure data and the probability model of failure for the individual subsystems and entire level crossing system presented. The models assume both failure and repair rates to be exponentially distributed. The reliability and maintainability of Barrier, Axle counter, rail signal and LC controller is evaluated at different time intervals. Reliability of barrier, rail Signal, LC controller, CBI and axle counter are 0.44, 0.94, 0.98, 0.90 and 0.90 consecutively after 10000 hours and maintainability of Barrier, Axle counter, LC controller, rail signal and CBI after one hour are 0.865, .899, 0.926, 0.939, and .909 respectively according to the design data. To generalize about the safety of the signaling system design, the overall level crossing signaling system design needs to be modeled perfectly with each equipments failure rate and repair rate.

In this thesis, a study is done to generate fault trees corresponding to five subsystems of level crossing signaling system of AA-LRT. But, the Combining maintenance improvements to reduce the failure rate and increase the repair rate is more efficient at increasing the probability of being in an operative state and reducing the probability of operating in a degraded state than simply reducing the failure rate or increasing the repair rate.

6.2 Recommendation

Based on the results of this thesis, the recommendation should consider the following areas:

- ✓ Improvement of the models proposed (e.g. considering all railway level crossing signaling systems for the safety and availability evaluation, considering the data distributions instead of the constant failure and repair rates, etc.).
- ✓ Further validation of the models and frameworks with the level crossing signaling systems of the components and architectures, comparing the results and identifying the reasons for the differences.

- ✓ Markov process may be used to the same level crossing signaling subsystems to the other section of AA-LRT.
- ✓ Improvement of the dependability of railway level crossing signaling systems by applying methodologies such as condition based maintenance (CBM), new preventive maintenance routines and reducing the time for failure identification.
- ✓ Development of availability importance measures based on failure rate and repair rate in order to simplify their application to other distribution.

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