Addis Ababa University
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Performance Investigation on AA-LRT Level cross Signaling System

By

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Advisor:
Mr. Abi Abate

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Approval by Board of Examiners

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Declaration

I certify that research work titled "***Performance Investigation on AA-LRT Level cross Signaling System***" 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.

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Abstract

Level crossings have been identified as a particular weak point in road and railway infrastructure. Installing efficient and reliable level crossing signaling system ensures the safe operation of the railway network. As most of its subsystem and components are working in open atmospheres, its operations are sometimes very difficult to monitor. Their reliability and maintainability directly affect the capacity and availability of the railway network in terms of both infrastructure and trains operation. Ensuring the safety of both those attempting to cross and the individuals on-board is a primary concern for all AA-LRT operators.

In this paper, 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 cross 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 process. Then reliability and maintainability of every sub systems are evaluated and graph is plotted for different time intervals to investigate their performance. Moreover, maintenance intervals at different reliability values and steady state reliability of different subsystems are estimated and modeled. Third, study methodologies selected which are quantitative and analytical data analysis methods are evaluated and graph is plotted for different time intervals.

The analysis from this thesis shows that reliability of barrier, rail Signal, LC controller, CBI and axle counter are 0.66, 0.98, 0.99, 0.96 and 0.96 respectively after 5000 hours, the reliability of the entire level crossing after 5000 hour of operation is 60.00 % 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, availability, reliability, maintainability, safety policy, Markov process, feared event, fault tree.*

Acknowledgement

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Abbreviations and Nomenclature

AA-LRT: -Addis Ababa Light Rail Transit

AFB: - Automatic Full Barrier

AHB: - Automatic Half Barrier

ATP: - Automatic Train Protection

ATS: - Automatic Train Supervision

ATS: - Automatic Train Supervision

CBI: - Computer Based Interlocking

CIP:- Control Indication Panel

DCS: - Data Communication System

DT: - Down time

EMU: - Electrical Multiple Unit

EN: - Europe Standard

ERC: - Ethiopian Railway Corporation

FHA: - Fault Hazard Analysis

FMEA: - Failure Mode Effect Analysis

FMECA: - Failure Mode Effect & Criticality Analysis

FTA: - Fault Tree Analysis

IEEE: - International Electrical and Electronics Engineers Association

LED: - Light Emitting Diode

LRT: - Light Tail Transit

MA: - Markov Analysis

MTBF: - Mean Time Between Failures

MTTF: - Mean Time To Failures

MTTR: - Mean Time To Repair

NGOs: - Non-Government Organizations

NRN: - National Railway Network

NRNE: - National Railway Network of Ethiopia

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

UP: - Up Time

WHO - World Health Organization

WO: - Work Order

Chapter One

1. Introduction

1.1 Background

The long and phenomenal story of development in science and technology manifests itself in railways in its present form, beginning from steam engines in early 19th century, through diesel engines, electrified railways and high speed trains, benefitting and significantly influencing the life of everyone. Since the world's first railway journey, the railway systems have evolved hugely. Speed, comfort, costs, quality of service led engineers to continuously invent new machines and devices to develop the rail transport. Going with this development, more and more requirements appeared. Nowadays, one wants the train to go faster, more frequently, more safely, while being cheaper and environmentally friendly.

The Ethiopian Railway Corporation (ERC) is working hard to have the safest and modern railway system. AA-LRT has a total length of 34.25 km (North-South) and East-West. The two line North-south and East-West line use common track of about 2.7 km.

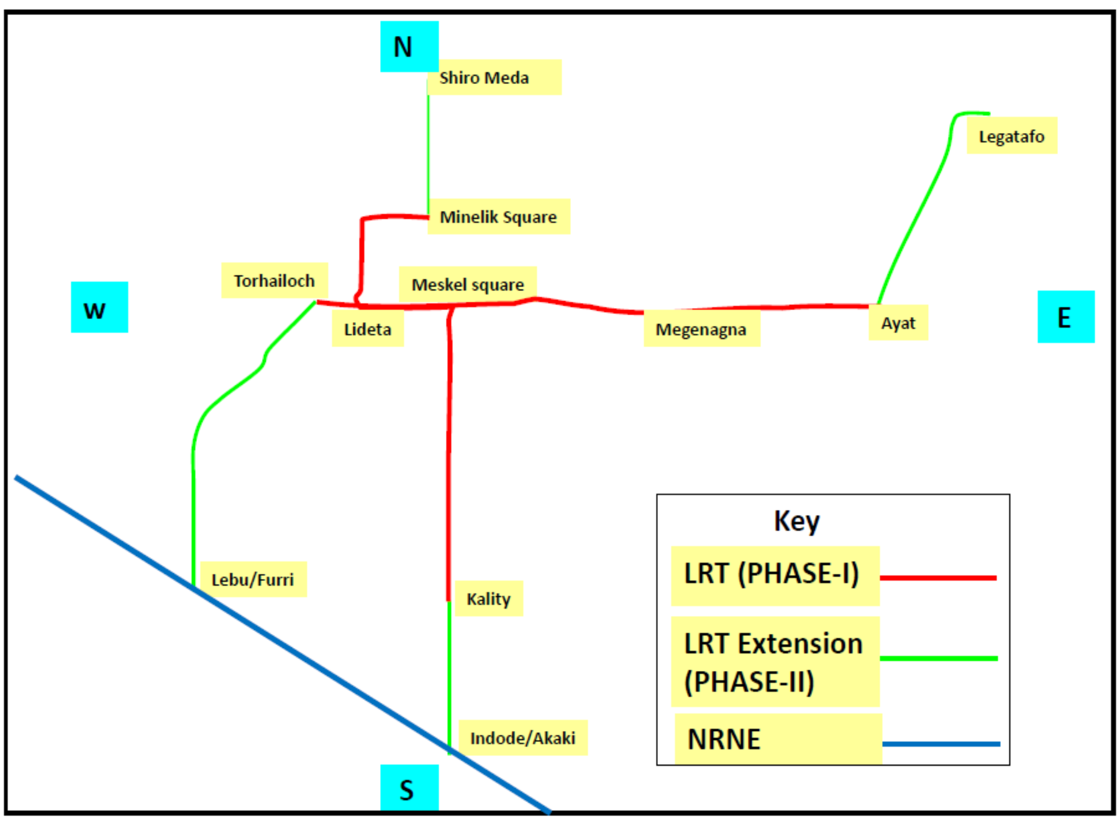


Figure 1-1AA-LRT South-North and East-West Corridors [28]

In road and railway infrastructure level crossing systems requires for high level of safety. Being safe and reliable is the most important issue in regulating and managing AA-LRT level crossings. It includes the safety of rail users, passengers and drivers of trains, and of non-rail users of level crossings, drivers of cars and other vehicles, cyclists, pedestrians, wheelchair users and horse riders. In deciding how best to reduce risk to those using level crossings, different interests need to be balanced, including the convenience of rail and non-rail users of level crossings. If the level crossing is protected (equipped with some kind of level crossing installation) then the road driver approaching the level crossing may be informed about approaching rail vehicle via:

- Audible warning (acoustic signal generated by mechanical or Electronic equipment (bells, horns)
- visual warning (two alternatively flashing red lights)
- protection in the form of barriers(full-or half-barriers)

Figure 1-2 AA-LRT level crossing signaling around CMC area

1.2 Statement of the Problem

Every year, more than 330 people are killed in more than 1200 accidents in rail-road level crossings in the European Union [1]. Together with tunnel and specific road black spots, level crossings have been identified as being a particular weak point in road infrastructure, serious affecting road safety. In the case of railway transport level crossing can represent as much as 50% of fatalities caused by railway operators [1].

According to the WHO data published in April 2011, deaths resulting from road traffic accidents in Ethiopia reached 22,786 or 2.77% of the total deaths in the nation [5] .There are various causes of road accidents in Ethiopia. But the two main contributors are the inexperience of many drivers, adding on the ineffective policies and generally awkward road and vehicle conditions. Several Ethiopians have called on the Ethiopian Road and Traffic Authority to prohibit road side parking on undesignated areas, increase the number of suitable traffic and pedestrian signs, firm traffic law enforcement and speed control, train pedestrians on proper use of road and control the use of narcotics among drivers, among other things [2].If railway transportation is added problem the problems will be out of control.

Therefore, this paper will motive to establish the safe, efficient and reliable train operation in AA-LRT by analyzing and estimating the availability reliability and maintenance of AA-LRT railway level cross signaling system and proposes various approaches to improve maintenance performance currently installed by Chinese Corporation in Addis Ababa and introduce different level crossing risk reduction mechanism.

1.3 Objective

1.3.1 General Objective

In general, the objective of this paper is to perform an in-depth analysis of safety, efficiency, availability, reliability, maintainability competitiveness and sustainability of AA-LRT Level cross signaling system and to help the railway administrations concerned to strengthen their safety culture, increasing the effectiveness of the level cross signaling systems, reducing maintenance and sparing cost and develop the monitoring tools required by modern safety management.

1.3.2 Specific Objective

Specifically the aim of this work is to:

- To estimate reliability and maintainability pattern of different level crossing signaling subsystems at different time intervals.
- Increasing the effectiveness of the AA-RLT level crossing signaling system.
- Analyses the availability reliability, dependability and maintenance of AA-LRT railway level cross signaling system and proposes various approaches to improve maintenance performance.
- Reducing maintenance and sparing costs while maintaining and/or increasing production levels.
- Adequately allocating the spare inventory;
- Identify and evaluate the principal technical challenges related to level crossings signaling system
- And make recommendations pertaining to the selection of effective protection systems.

1.4 Methodology

As it has been mentioned above the research is based on an in-depth analyses of reliability, availability, dependability, maintenance and risk evaluations of AA-LRT Level cross signaling system and a description of AA-LRT level cross signaling system is 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 methodology are considered:

1. Literature Reviewing: this includes reading books, articles, and simulation tools.
2. Model the current AA-LRT level crossing signal installation; how events or errors are propagated from the bottom to the top feared events uses fault tree analysis.
3. Reliability, availability and maintainability of level crossing signal quantitatively analysis using Markov process based on the design data.

4. 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
   - Inspection

Investigate the main factors contributing to accidents and reducing the performance of AA-LRT level crossing 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.

1.5 Literature Review

Rail is playing a very important role in the transportation hence work is being done in this field from many years. Many research works has been 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 be stopped by minimum effort. Some of the researches conducted on the area level cross signaling and related to this work are briefly reviewed below:

Reference [11] they 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 and data.

Reference [28] 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.

Reference [17] 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.

In reference [12] 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.

In reference [13] sets out the requirements for specifying of Reliability, Availability and Maintainability (RAM) as well as requirements for designing to achieve specified RAM targets.

In reference [14] the method suggest an approach for developing the technical safety report in accordance with EN 50129, with focus on the steps necessary to carry out a reliability assessment.

In reference [29] 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 we 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.

In reference [12] presented a brief retrospective of the development and application of reliability-based techniques for assessment of complex structures with emphasis on inspection optimization of offshore and bridge structures.

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.

1.6 Beneficiaries

The deliverables and out puts of this research directly or indirectly will benefit the following members of the society to have safest, efficient, reliable and sustainable of AA-LRT Level cross signaling system:

- The Researcher (student)
- Ethiopian Railway Corporation (ERC)
- The Government of Ethiopia
- People of Ethiopia, Inland and Foreign Tourists;
- Government Organizations and NGOs;
- Ethiopian Roads Authority, Producers and Distributers;

- ❖ Railway accident investigation Branch;
- ❖ Railway infrastructure managers;
- ❖ Highway authorities;
- ❖ Road authorities;
- ❖ Planning authorities;
- ❖ Train and station operators;

1.7 Scope of the Study

The scope of this research was to perform an exploratory analysis which will provide visibility to the best areas to consider improving the reliability, availability, dependability and maintainability of railway subsystems of level crossing signaling systems. The case study of the AA-LRT railway level cross signaling system single type II was chosen as a good representation of the railway level cross signaling systems.

Some limitations related to the research must be acknowledged:

- ➢ Lack of organized maintenance data of AA-LRT level crossing signaling system was one of big limitation of this thesis.
- ➢ The research focused on the AA-LRT railway level cross signaling systems and the data analysis is limited to level crossing signaling system between CMC and Meri station.
- ➢ The research focused on studying the reliability, availability and maintainability of axle, barrier, LC controller, rail signal and CBI (Computer Based Interlocking system) by calculating their failure rate and repair rate to estimate their reliability availability and maintainability.
- ➢ This research was based on design data, documents, interviews and surveys and human factors can affect the quality and reliability of the data.
- ➢ Failure that occurs in a system that is redundant and thereby continuous to fulfill its purpose was not considered.

1.8 Contribution

This research lays a baseline for system and subsystem based RAM analysis of AA-LRT level crossing signaling system. So this paper contribute to 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 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: 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 performance analysis methods to any signaling system (Electrical, Mechanical ...). Hence, the same analysis can be employed for other systems of railway which Ethiopia is implementing.

1.9 Organization of the Thesis

This paper is organized into five chapters:

Chapter1: In this chapter the overview of railway transportation and AA-LRT networks are introduced. After this general and specific Objectives of present work is discussed and on this basis organization of thesis is done. Many research works has been done to improve working of signaling systems to make it more reliable and efficient. Therefore, different literature survey is also done in this chapter.`

Chapter 2: In the chapter 2 AA-LRT railway, level crossing signaling system is overviewed. Here level crossing Signaling system is divided in five level crossing signaling subsystems namely barrier, axle counter, rail signal, LC controller and CBI. The functions and importance of every subsystem is discussed. Performance Reliability, maintainability, availability and other terms are defined which is used in this paper.

Chapter 3: Different qualitative and quantitative reliability analysis techniques and comparison of each technique are briefly discussed. Relationship between reliability and inspection and different railway operational state were explained.

Chapter 4: In this chapter the Fault Tree which is used to evaluate the occurrence probability of the feared event (collision between a train and a vehicle) over the time of the AA-LRT Level Crossings by integrating human factor and components failures data is introduced and also Reliability, Maintainability, Availability Modeling of Different level crossing signaling subsystems is done with the help of Markov process and also the advantage of Markov process over any other reliability modeling techniqcs are explained. In this section a reliability block diagram (RBD) of the Signaling system 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 level crossing signaling system has been discussed. Reliability block diagram (RBD) of the level crossing Signaling system for reliability modeling and performance analysis is constructed. It is a graphical representation of the components of the system from a reliability viewpoint. With the help of repair and failure rate data's, then graph of reliability, maintainability is plotted with respect to time interval and finally expected reliability for different maintenance interval is calculated and graph is plotted between expected reliability and different maintenance interval using mat lab.

Chapter 5: In this chapter quantities of reliability, availability and maintainability of the level crossing signals system were discussed. And also results and discussions based on the models described under the fourth chapter.

Chapter 6: Finally in this chapter conclusion of all the five chapters is summarized and future scope of work is discussed.

Chapter Two

2. AA-LRT and Level crossing signal system

In the previous chapter, the background of the railway system and objective of the thesis were briefly discussed. In this chapter, overviews of current N-S and E-W line of AA-LRT level crossing signaling system are presented.

The chapter is organized as follows. In Section 2.1 overview of AA-LRT project in section 2.2 AA-LRT level crossing signaling system and Composition of level crossing subsystem are explained. And finally, in Section 2.2.3 AA-LRT signaling system Reliability, Safety, Availability and Maintainability data are discussed briefly.

2.1 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 [29]. 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.

2.2 Overview of AA-LRT Level crossing system

2.2.1 Composition of Level crossing Subsystem

On both E-W and N-S line there are 12 level crossing areas, each of the 12 level crossing for LRT line and highway will be provided with one set of independent level crossing equipment [29]. AA-LRT Level crossing equipment control system is mainly composed of the following equipment indoor unit and outdoor unit equipments:

- Main level crossing control equipment;
- Control and Indication panel (in the control cabinet);

- Barrier and barrier control Box.
- Road signal (warning light and Audible alarm device) ;
- Rail signal
- Axle counter for train detection

2.2.1.1 Main Level crossing Control Equipment;

The level crossing main control cabinet (MCC) includes main control units lightening protection terminals and power module. The main control units adopt 2 times 2 out of 2 techniques. Except the interface with the interlocking, the level crossing signaling system's control over level crossings are fully electronic.

2.2.1.2 Control and Indication Panel

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

2.2.1.3 Barrier and Barrier Control Box

The Barrier Control Box is 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 is adopted, with pressing and times recorded by PLC;

Barrier lowering button –non-stick button is adopted;

Barrier bypass switch – two-position switch that can only be operated by inserting the dedicated key;

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

Figure 2-1 AA-LRT level cross signaling around CMC area [29]

Outdoor equipment consists of barrier machine and road signal. Number of the barrier machine will be determined in accordance with the crossing type and width.

2.2.1.4 Barrier

Manned mode is adopted for the crossing in this project and there are 3 operating modes of the barrier:

Automatic operating mode (automatic lifting and manual lowering)

All-manual operation mode

On-site manual mode.

The automatic operation mode or all-manual operation mode will be set after system initialization and may be modified as required. Under normal condition, after train clearing out of the crossing and relevant conditions are satisfied, the barrier will be controlled by the level crossing subsystem to be lifted automatically. When the barrier is lifted, it should be judged that the conditions for train approaching in up /down from the interlocking system are all high level; after train leaves the crossing, the route at the axle-counting section within the crossing area will be released.

The interlocking system sends the high-level of train approaching and notice level crossing LRT train leave the crossing and level crossing subsystem which will automatically stop the outdoor train approaching alarm and lift the barrier.

If the conditions for lifting are not satisfied, the barrier will remain in the status of lowering and the control circuit will cut off the operation of lifting. Both manual and automatic lifting of barrier is not allowed. Lowering of the barrier will be controlled manually by the Crossing operator. When the train approaches the crossing, the Crossing operator will, according to the information of train approaching alarm notice, press the lowering button for manual control of lowering of the barrier after confirming that pedestrians and vehicles within the area of crossing road surface are cleared.

If the barrier cannot be lowered for some reasons or the interlock system does not get the status information about lowering of the crossing barrier for some reasons, the Crossing operator may press the barrier by-pass switch on the control and indication panel, to send the lowering status of crossing barrier to the interlock system, so as to control and open the road signal to allow LRT train passing through the crossing. In case of power failure or malfunction, the barrier may be lifted or lowered manually by the hand crank at the site.

In case of power failure or malfunction during lifting or lowering, the barrier will stop and stay at the current position, under which condition it may be lifted or lowered by manual control at the site. In case of power failure or malfunction at the lifting or lowering position, it will stay at the current position. Under automatic mode, unless power failure or system malfunction, the system must ensure that the crossing barrier will lift automatically until reaching the full-lifting position. Type II crossing consists of 2 crossings which are under independent control. At the same level crossing, all the barriers on both sides of LRT line are controlled by the same barrier control box[29].

2.2.1.5 Road signal (warning light and audible alarm device)

The road signal will be controlled by the control cabinet. Its normal status will be displayed by green light, under which condition the municipal road vehicles and pedestrians are allowed to pass through the crossing. When the train approaches the crossing, the road signal system will, after receiving the train approaching information from the interlocking system, turn into red light after the green light flickers for 5 seconds, reminding vehicles and pedestrians no entry of the level crossing or speed-up to pass the level crossing which is within the crossing area.

When the crossing area is clear and the system controls the barrier to be lifted automatically, the road signal will be automatically recovered to be in green light. For the road signal with side indication, the lights at the front and at the side should be kept the same without occurrence of inconsistency of the light at the front with that at the side [29].

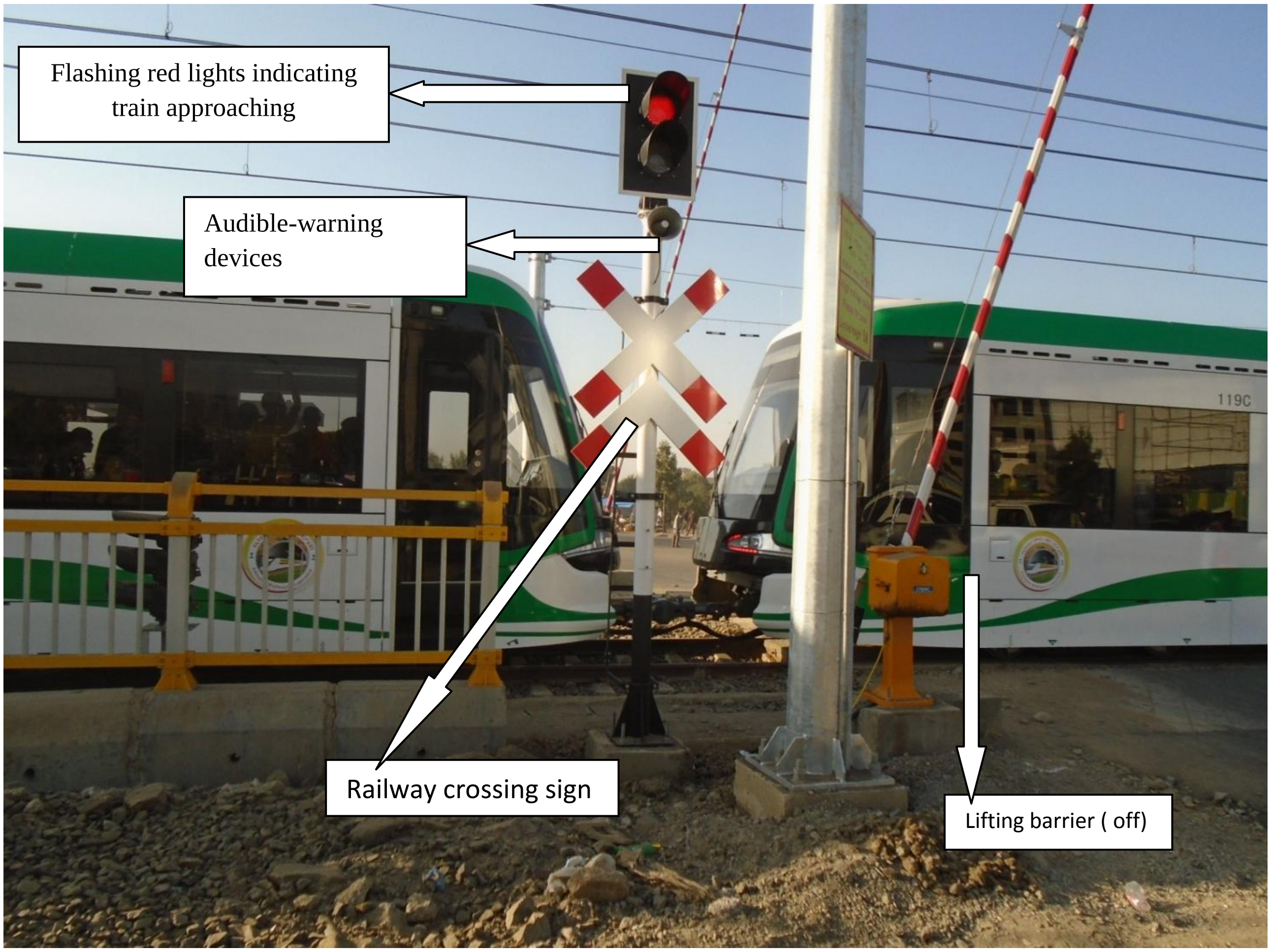


Figure 2-2 Level crossing signaling system proto type

If visibility at a crossing is a problem, then flashing lights may be increased in intensity and may be installed so as to suit the lay of the surrounding land and buildings. Similarly, audible-warning devices may be increased in frequency and amplitude, to compensate for the sound absorption qualities of the physical environments of level crossings.

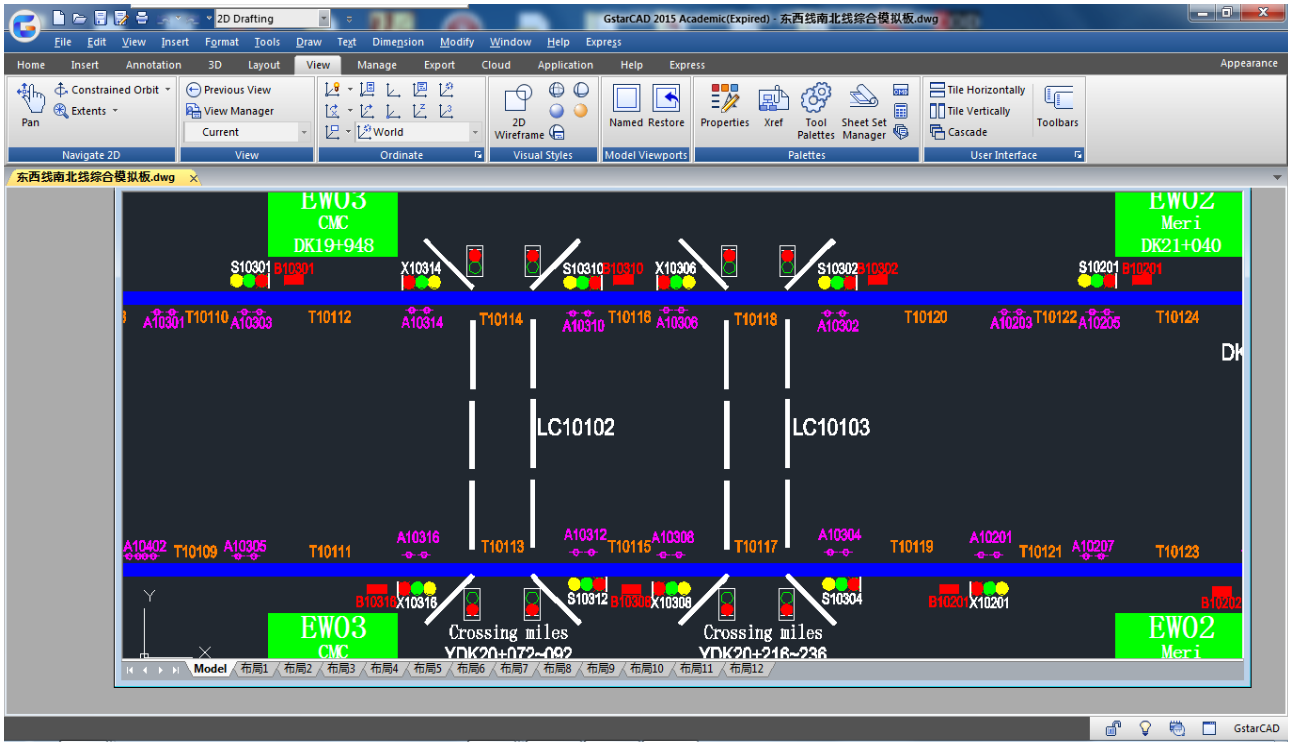


Figure 2-3 two AA-LRT level crossing design structure between CMC and Meri on E-W line [29]

2.2.1.6 Rail Signal

Rail signal is one of the track side signaling equipment used to allow the train to the level crossing area or not allow the train from passing through the level crossing. Diagram of the Crossings Signaling Control System below illustrate the general description of the control principle.

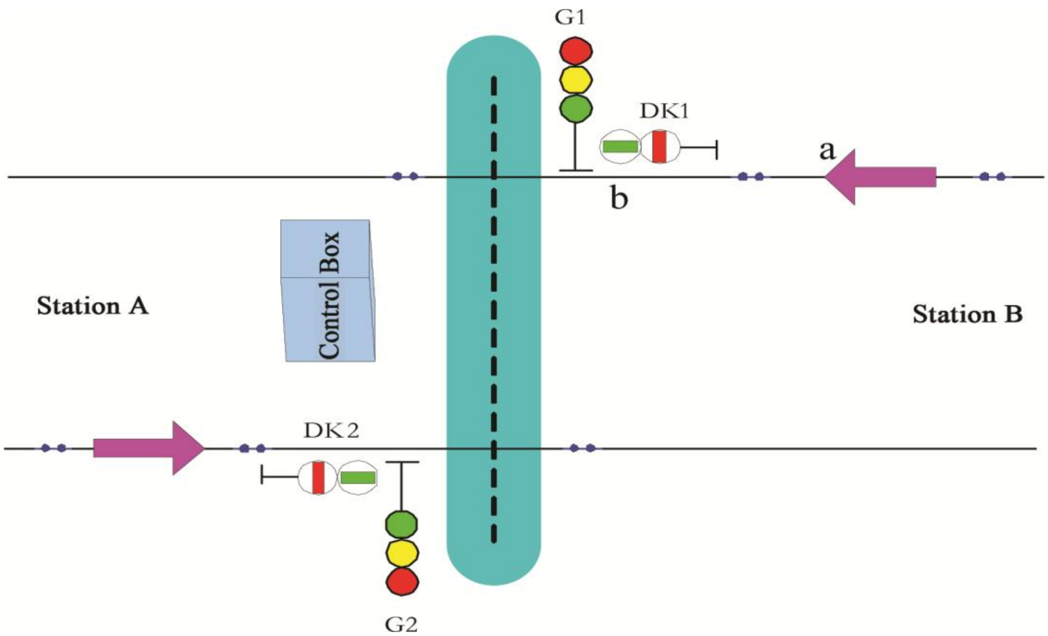


Figure 2-4 Equipment Diagram of the Crossings Signaling Control System [29]

For example take the train running from Station B to Station A. The control principle is generally described as follows: [29]

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.

2.2.1.7. Axle counter for Train Detection

Axle counting is used to detect the train approaching or releasing the level crossing area. In this variant, a wheel detection component is used as activation and an axle counting section located in the centre of the level crossing (train has completely passed the level crossing) is used as a releasing element.

In AA-LRT, the axle counter is arranged at the main track and depot for inspection of position of the train and it is also used detects a train at level crossing to activate or deactivate. It is divided into the indoor and outdoor equipment, a wheel sensor is arranged respectively at the starting point and ending point of the track section, and used together with the evaluation board for detecting of information of wheel set of the train. Each wheel sensor includes 2 groups of systems, which are used for distinguishing the driving direction of the train. Each wheel sensor is connected with the evaluation board by four-core signal cable, which supplies the power for the wheel sensor and transfers the data of axle to the evaluation board [29].

The axle counting board of the axle counting system processes the data of axle of all connected counting probes, and outputs the results of vacancy and occupation of the detected section into the relevant system interlocking system.

2.2.1.8. Computer Based Interlocking (CBI)

CBI is used to implement all the interlocking functions, which is located in the signaling equipment room of main station. CBI with the relay interface system, when LRT train approaches the crossing from any direction, the CBI will send the information of train approaching to the LX subsystem according to the occupation condition of the approach section to the crossing or the condition of route setting [29].

CBI subsystem is mainly composed of “2*2oo2” interlocking computer hot-redundant network. CBI shall ensure the safety train-running, and control the routes, signals and switches under the stipulated interlocking conditions and time sequences to make sure that the interlocking among the signal elements in the route such as track sections and level crossing signals is safe. Therefore, for safe and reliable operation of the train at level crossing area CBI is one of the main systems.

2.2.1.9. Configuration of Equipment at the Crossing

The typical layout of AA-LRT level crossing equipment at crossing is shown in the following:

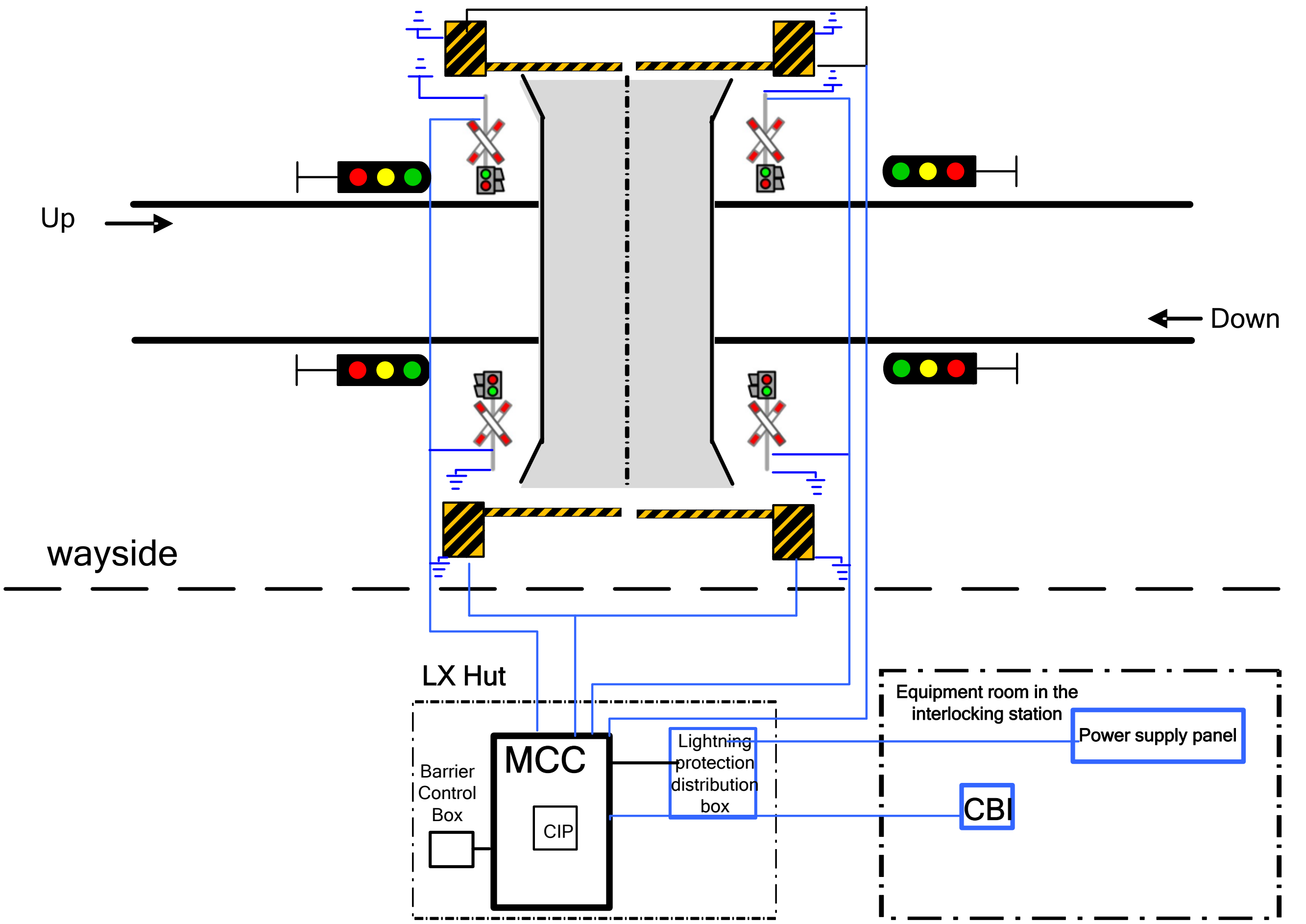


Figure.2.4: Layout and Arrangement of level crossing Equipment at crossing [29]

AA-LRT level crossing has the following two types of crossings:

1) Configuration of equipment for Type I crossing:

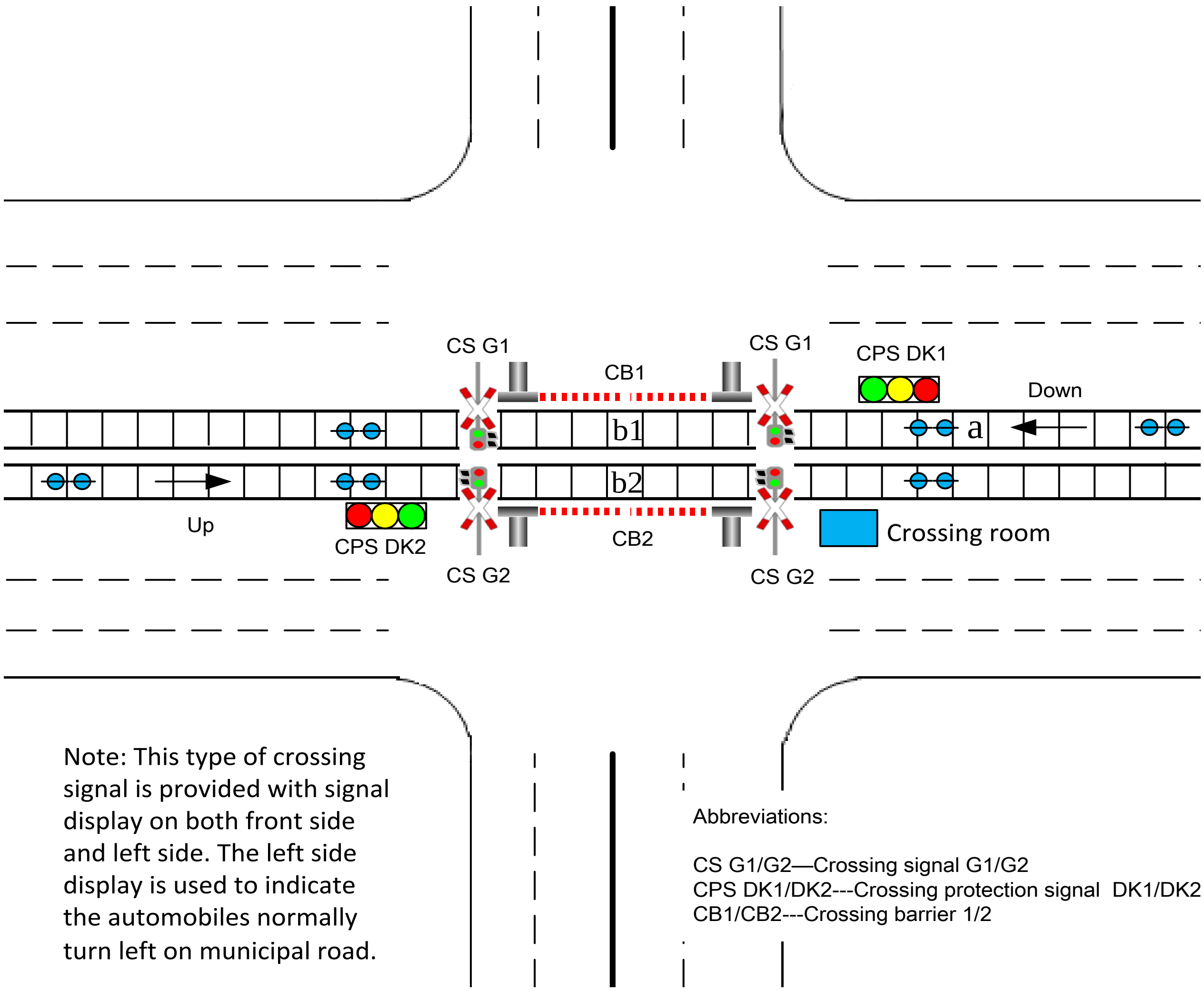


Figure. 2.5: Schematic Diagram of Composition of level crossing subsystem Equipment at Type Crossing [27]

For Type I crossing, all the barriers on both sides of LRT line are controlled by the same barrier control box, provided with 4 road signals, 4 barriers, 1 control cabinet, 1 control and indication panel, 1 barrier control box and 1 set of automatic audible and visual alarm device for indoor and outdoor.

2) Configuration of equipment for Type II crossing:

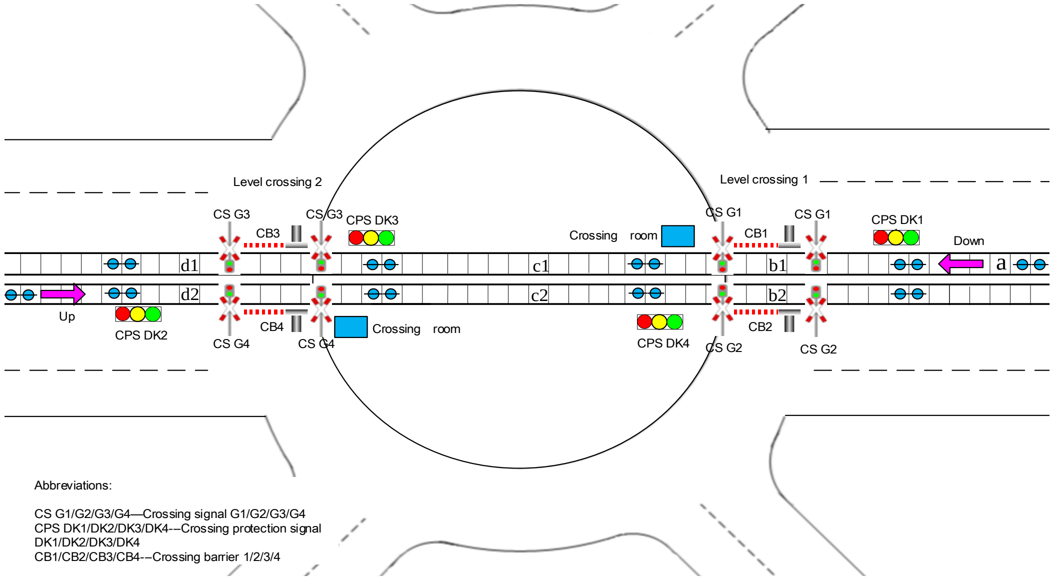


Figure 2-5 Schematic Diagram of Composition of level crossing subsystem Equipment at Type Crossing [29]

Type II crossing consists of 2 crossings which are under independent control. Each crossing is provided with 4 road signals, 2 barriers, 1 control cabinet, 1 control and indication panel, 1 barrier control box and 1 set of automatic audible and visual alarm device for indoor and outdoor.

2.2.2. Function of Level crossing Subsystem

AA-LRT level crossing control equipment system is with the functions of giving approaching alarm notice and controlling road signals and barriers.

2.2.2.1. Approaching Alarm Notice

Via the relay interface with interlocking system, when LRT train approaches the crossing from any direction, the interlocking system 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.

The level crossing subsystem will, according to the information of train approaching, automatically send the indoor and outdoor train approaching alarm notices.

Buzzer alarm will be adopted for indoor train approaching alarm notice;

Audible and visual alarm and indication of signal are adopted for informing the pedestrians and the vehicle on the road of train approaching and status of level crossing. The outdoor audible alarm device is installed at the top of the road signal post and horn loudspeaker is adopted, with the sound level of 50~80dB and volume adjustment device. Voice alarm is adopted for audio alarm of the approaching notice.

If there are trains approaching the crossing in both up and down direction, the level crossing subsystem is able to send the train approaching alarm notice continuously or send such alarm once again. The indoor train approaching alarm notice can be canceled by the guard by pressing the Acknowledge button on the control and indication panel.

2.2.2.2. Description of Control Process of Level crossing subsystem

When the train approaches in up or down direction[29]:

Train Position	Action of Barrier	Action of Outdoor Equipment	Indoor Equipment and Screen Display
No train approach (normal state)	In vertical position	The road signal lights in green	The repeater of road signal light on green.
Train approach in up or down direction			Train approach mark in up or down directionkeeps in red and indoor/outdoor audio alarm is activated.
		The road signal light on red after the green light flickers for 5s The outdoor audio alarm is activated.	The repeater of road signal will turn into red after the green light flickers for 5s. The blue down arrow is to indicate the barrier of horizontal position.
	The person on duty presses the acknoledge button		The indoor audio alarm stops.
	The barrier is lowered down to	The road signal lights in Red	The barrier repeater indicates the

Train Position	Action of Barrier	Action of Outdoor Equipment	Indoor Equipment and Screen Display
	the horizontal position		horizontal position; Repeater of road signal lights in red
Clearing of train	The barrier starts to be lifted automatically	The road signal remains in red light; The outdoor audio alarm is stopped.	Blue up arrow is indicated at the vertical position of the barrier (indicating that the barrier is being lifted) The repeater road signal lights in red light
	The barrier is lifted to the vertical position	The road signal lights in green.	Train approach mark in up or down direction is recovered; The barrier repeater is lifted to the vertical position; The repeater of road signal;lights in green.

The AA-LRT level crossing subsystem will provide a relative priority for LRT train's passing of level crossing. According to the busy extent of traffic flow and actual condition on site, a shortest opening time will be set for the control equipment at each crossing respectively.

If the shortest opening time is not met when a train approaches the crossing, the road signal system will not trigger the train approaching alarm. The interlocking system will, according to the lifting status of the barrier, maintain a close status of railway protective signal to allow no passing of LRT train through the level crossing and continuously send the level crossing subsystem the train approaching alarm. Until the shortest opening time is met, the railway protective signal will then be opened to allow passing of the LRT train through the crossing.

In the current AA-LRT, the level crossing is designed to be manned. The lowering of the crossing barrier will be 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:

Normally, when a train approaches the crossing, the operator should first make sure that the crossing area is cleared (without people and vehicle), and then press the lowering button of barrier for lowering control of the barrier;

The crossing barrier can be lowered by on-site manual control in case of power failure or malfunction.

The lifting of the crossing barrier can be achieved by three control modes: automatic control, indoor manual control and the on-site manual operation:

Normally, when a train is leave of a crossing and relevant requirements are met, the protection system will stop the train approaching alarm in up/down direction and the road signal system will make the barrier lifting automatically;

The crossing operator can adopt indoor manual control when the automatic-lifting function is invalid. After confirming that the light for indicating the lifting of the barrier is ON, he can then press the button on the crossing control panel to achieve manual-control lifting.The barrier can be made lifted by on-site manual control in case of power failure or malfunction.

2.2.2.3. Train Approaching Notice

When the LRT train approaches the crossing from any direction and the route for passing the crossing is processed (the railway protective signal remains closed due to the crossing barrier does not be lowered and locked), the interlocking system will send the level crossing subsystem train approaching notification in up/down direction, then the road signal system will automatically send out the indoor and outdoor train approaching alarm [29].

When there are trains approaching the crossing in both up and down direction, the level crossing subsystem can continuously or again send train approaching alarm notices. The train approaching alarm includes Audible indoor and outdoor alarms. The outdoor train approaching alarm notice should last until the train is cleared out of the leaving section. If the outdoor train approaching alarm cannot be normally cancelled due to malfunction, it can be removed by manual operation. The indoor train approaching alarm notice can be cancelled by the gateman by pressing acknowledge button on the control panel[29].

The time for train approaching notice can be calculated based on the time of vehicles, people and animals on the municipal road for passing the crossing with minimum speed, the normal response time of the Crossing operator, the lowering time of the barrier, the running time from the lowering of the crossing barrier to the train’s reaching of the level crossing, etc.

Normally, the time for train approaching notice T>= t1+ t2+ t3

Where: t1 refers to the time (unit: s) for vehicles on the road passing the crossing with specified minimum speed (before a train approaching notice, vehicles entering into the crossing should be ensured to be cleared out of the crossing), in AA-LRT,

The length of the crossing is about = 14m (subject to modification according to site condition).

Suppose the minimum speed of people and animals is =5km/h and

the specified minimum speed of vehicles is =10km/h and

take the vehicle length into consideration,

the t1 $= \frac{0.014km}{5km/h} = 10.08s$ is calculated as about 10s;

t2 refers to the time spent on the closing of the crossing barrier, taken as 10s;

t3 refers to the time from the closing action of the barrier to the time the train approaches the crossing.

The level crossing subsystem will provide a relative priority for LRT train's passing of level crossing. According to the traffic flow and actual condition on site, a shortest opening time will be set for the control equipment at each crossing respectively. If the shortest opening time is not met when a train approaches the crossing, the road signal system will not process the train approaching notice from the interlocking system. Meanwhile, the interlocking system will, according to the lifting status of the crossing barrier, maintain the close state of the crossing protective signal to allow passing of no LRT train through the crossing. Until the shortest opening time is met, the road signal system will then process the train approaching notice at the crossing. After the crossing barrier is lowered with the control of the Crossing operator, the crossing protective signal will then be opened to allow the LRT train's passing through the crossing[29].

2.2.3. AA-LRT signaling system: Reliability, Safety, Availability and Maintainability data

This thesis deals with reliability, availability, maintainability modeling and performance analysis of AA-LRT level crossing signaling system failure and repair data analysis using a Markov model.

Signal: A signal is a mechanical or electrical device erected beside a railway line to pass information relating to the state of the line ahead to train. The driver interprets the signal's indication and acts accordingly. Typically, a signal might inform the driver of the speed at which the train may safely proceed or it may instruct the driver to stop.

Reliability: The ability of a system or component to perform its required functions under stated conditions for a specified period of time. Reliability Engineering is a sub-discipline within Systems Engineering. Reliability is 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. Reliability engineering is closely related to safety engineering, in that they use common methods for their analysis and may require input from each other. Reliability engineering focuses on costs of failure caused by system downtime, cost of spares, repair equipment, personnel and cost of warranty claims. The focus of safety engineering is normally not on cost, but on preserving life and nature, and therefore deals only with particular dangerous system failure modes. Reliability engineering for complex systems requires a different, more elaborate systems approach, than reliability for non-complex systems. Reliability analysis has important links with function analysis, requirements specification, systems design, hardware design, software design, manufacturing, testing, maintenance, transport, storage, spare parts, operations research, human factors, technical documentation, training and more. Effective reliability engineering requires experience, broad engineering skills, and knowledge from many different fields of engineering.

Maintainability: It is the ease with which a product can be maintained in order to: isolate defects or their cause correct defects or their cause, meet new requirements make future maintenance easier, or cope with a changed environment. In some cases, maintainability involves a system of continuous improvement - learning from the past in order to improve the ability to maintain systems, or improve reliability of systems based on maintenance experience. In telecommunication and several other engineering fields, the term maintainability has the following meanings: A characteristic of design and installation, expressed as the probability that an item will be retained in or restored to a specified condition within a given period of time, when the maintenance is performed in accordance with prescribed procedures and resources. The ease with which maintenance of a functional unit can be performed in accordance with prescribed requirements.

Safety: is the freedom from an unacceptable risk of harm.

Availability: The degree to which a system, subsystem, or equipment is in a specified operable and committable state at the start of a mission, when the mission is called for at an unknown, *i.e.*, a random, time. Simply put, availability is the proportion of time a system is in a functioning condition. This is often described as a mission capable rate. Mathematically, this is expressed as 1 minus unavailability. The ratio of (a) the total time a functional unit is capable of being used during a given interval to (b) the length of the interval. The most simple representation for availability is as a ratio of the expected value of the uptime of a system to the aggregate of the expected values of up and down time, or [13]

$$A=\frac{E[uptime]}{E[uptime+E[downtime]}$$

If we define the status function X(t) as

$$X(t)=\begin{cases}1, system\ function\ at\ time\ t\\ 0, \qquad otherwise\end{cases}$$

Therefore, the availability A(t) at time t>0 is represented by

A(t)=Pr [X(t)=1] = E[X(t)].

Average availability must be defined on an interval of the real line. If we consider an arbitrary constant C>0 , then average availability is represented as

$$A_c=\frac{1}{c}\int_0^c A(t)dt$$

Limiting (or steady-state) availability is represented by

$$A=\lim_{t\to\infty} A(t)$$

Limiting average availability is also defined on an interval (0,C) as,

$$A\infty=\lim_{c\to\infty} Ac=\lim_{c\to\infty}\frac{1}{c}\int_0^c A(t)dt, \quad C>0.$$

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 whole 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:

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

3) Reliability

ATS system: MTBF$\geq 2.0\times 10^{5}$ h;

ATP system: MTBF$\geq 2.0\times 10^{5}$h;

CBI system: MTBF$\geq 2.0\times 10^{5}$h;

Single outdoor balise beacon: MTBF$\geq 10^{6}$h;

Onboard DMI: MTBF$\geq 2.0\times 10^{5}$h;

Mean correct counts of axle counter is $\geq 1\times 10^{9}$ axles;

Axle counter: MTBF$\geq 1.75\times 10^{5}$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

2.2.4. Conclusion

From above discussion outdoor and indoor units of AA-LRT level crossing equipments are main level crossing controller, barrier and barrier control box, road signal (warning light and audible alarm device), rail signal, axle counter and CBI. Axle counter is use to detect the train approaching to level crossing area and releasing level crossing area. These outdoor and indoor units of level crossing sub systems are highly affecting the overall performance of level crossing signaling system. And hence we considered these five subsystems of level crossing signaling system to analyze the overall performance AA-LRT level crossing system in our present thesis.

Chapter Three

3. Reliability Analysis Techniques and Inspection police

3.1. Introduction

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 critical systems, one goal has always been to make them safer and more reliable. But 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 more accurately represent these complex and safety critical systems. Both qualitative and quantitative methods have been developed to analyze complex and safety critical systems, and there are constantly more being 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. Therefore, some of reliability analysis techniques are summarized below [33].

3.1.1. Qualitative Techniques

Qualitative reliability analysis methods have always been 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 is generally done 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 be detected, and what provisions are provided to compensate for this failure in the design.

FMEA can be 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 be performed. No matter when it is performed, FMEA ultimately strives to list all potential failures and identify the magnitude of their effects [33].

3.1.2. Quantitative Techniques

3.1.2.1. Introduction

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 be 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 be applied 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 [33].

3.1.2.2. Fault Tree Analysis

The concept of FTA was developed in 1962 by Bell Telephone Laboratories for the U.S. Force for use with the Minuteman system [33]. 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. 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 be 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 events occur.

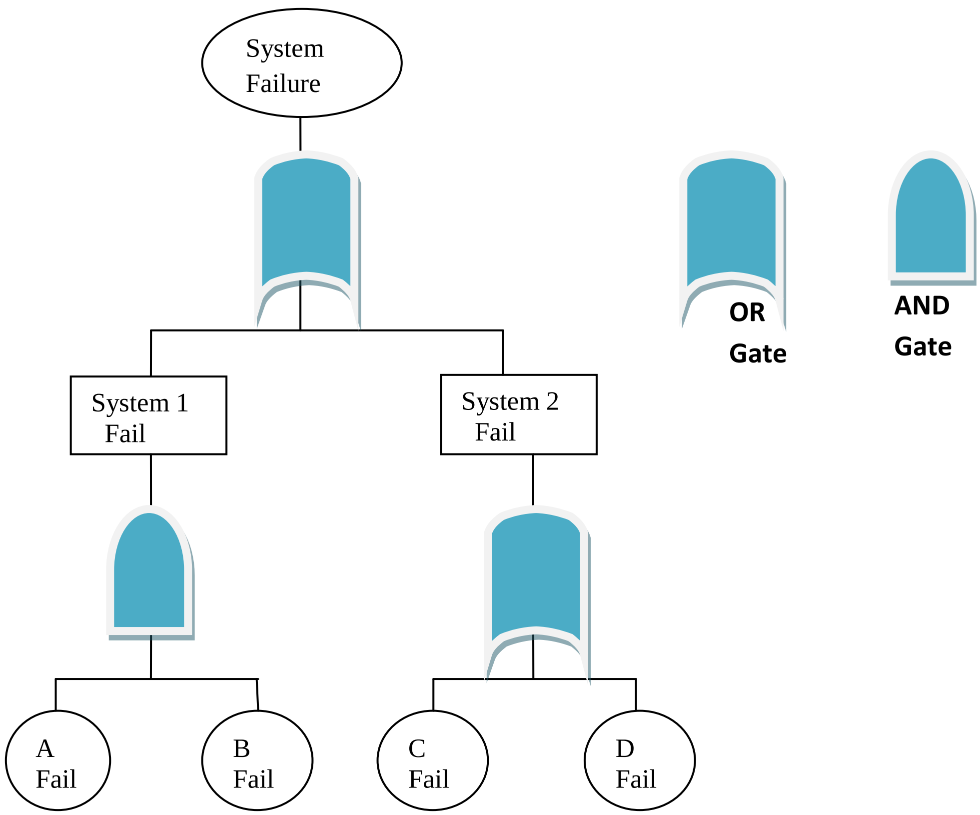


Figure 3-1 Sample FTA

These are the only two gates that were originally used when fault trees 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).

3.1.2.3. Reliability Block Diagram

System reliability can be 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 is 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 be seen 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 more complex systems [33].

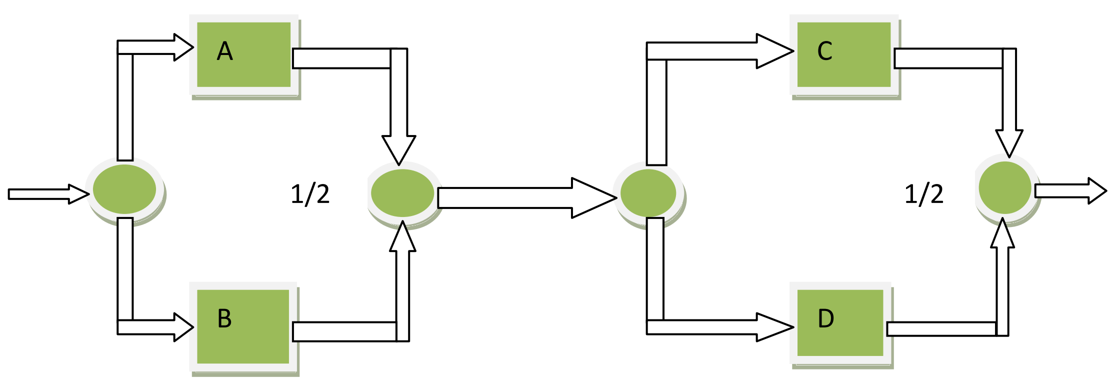


Figure3-2 Sample RBD of a series of two sets of two parallel gates

From the above RBD A and B are connected in parallel one out of two system and again C and D are connected in parallel one out of two systems. Again A,B and C,D are connected in series.

3.1.2.4. 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 modeled, 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 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. 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 is failed, B is working and A is failed, 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 be transitions from failed states back to working states with given constant rates as well. (There is no 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.)

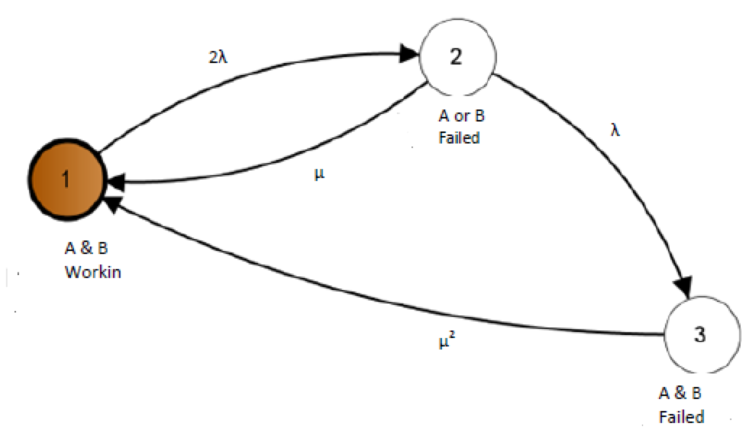


Figure3-3 Sample Markov Chain

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 considered, 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. The main disadvantage of Markov methods is as the size of the system increases the explosion of the number of state and limited to the use of constant failure rates for the transitions. The resulting diagram for large systems are generally extremely large and complicated, difficult to construct and computationally extensive [33].

3.1.2.5. Petri Nets

A Petri Net is another dynamic method of reliability analysis that is not used 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 [33]. In the case of reliability analysis, there are a number of places representing all of the possible states that whatever is being modeled could be in. A token, which could represent a number of things (including, but not limited to, a component, assembly, or subsystem) 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.

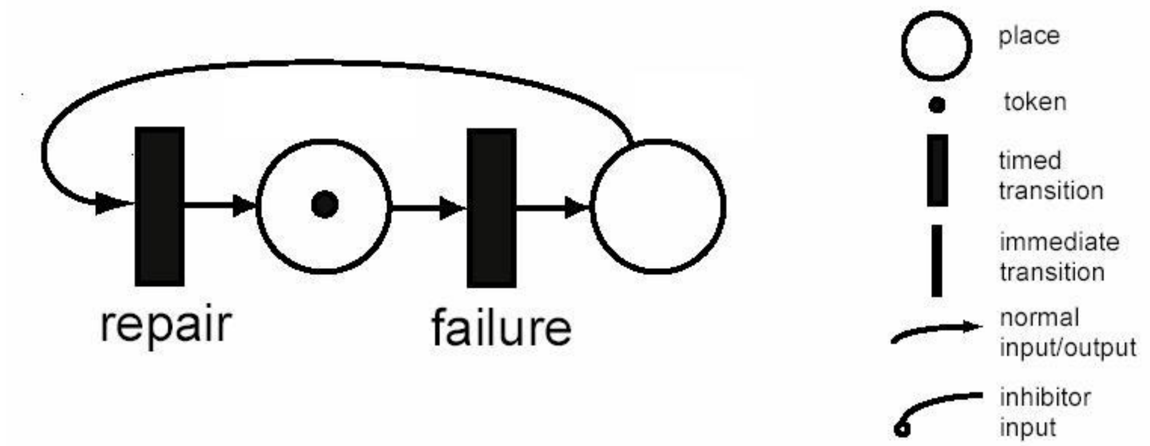


Figure3-4 Sample Petri Net [33]

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. Also, 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.

3.1.3. Comparison of Reliability Analysis Techniques

Table 3.1 shows a comparison of the different approaches to reliability analysis, and a summary of some of the important characteristics of the methods discussed

Characteristics	**FTA**	**RBD**	**MA**	**Petri Nets**
Static	X	X		
Dynamic			**X**	X
Logic-based	X	X		
State-space			X	X
Top-down	X	X	X	
Variable distributions	X	X		X
Can be used for dependant event			X	X
ICE standard	61025	61078	61165	

Table3-1 Comparison of Reliability Analysis Method Characteristics

3.2. Relation between Reliability and Inspection

Inspections form an important part of the integrity management process as a means of monitoring the performance of signaling system to ensure their safety and serviceability. However, inspections can represent a significant cost. Traditionally inspection planning was based on general guidelines and engineering judgments which is prescriptive and does not take into account the structure specific characteristics or make optimum use of the observed performance data. The end result is that a substantial amount of inspections may be ineffective by not focusing the most critical areas or by not using the most appropriate techniques therefore resulting in uneven safety levels and wastage of limited maintenance resources. Reliability techniques were developed to provide with a more rational tool for scheduling inspections in order to maximize their efficiency and control the safety levels maintained in these structures. The main characteristic of these techniques is that the uncertainties associated with the inspection planning and execution process are recognized. Furthermore, the use of Bayesian updating enables the inspection findings to be incorporated in the planning and decision model to optimize subsequent actions. In recent years, there have been significant developments in the area of reliability-based inspection planning for railway level crossing signaling system. Various tools and methodologies were developed for fatigue reliability analysis and inspection updating. The methods were used for developing optimum inspection plans for individual structures.

3.3. Railway Operational State

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:

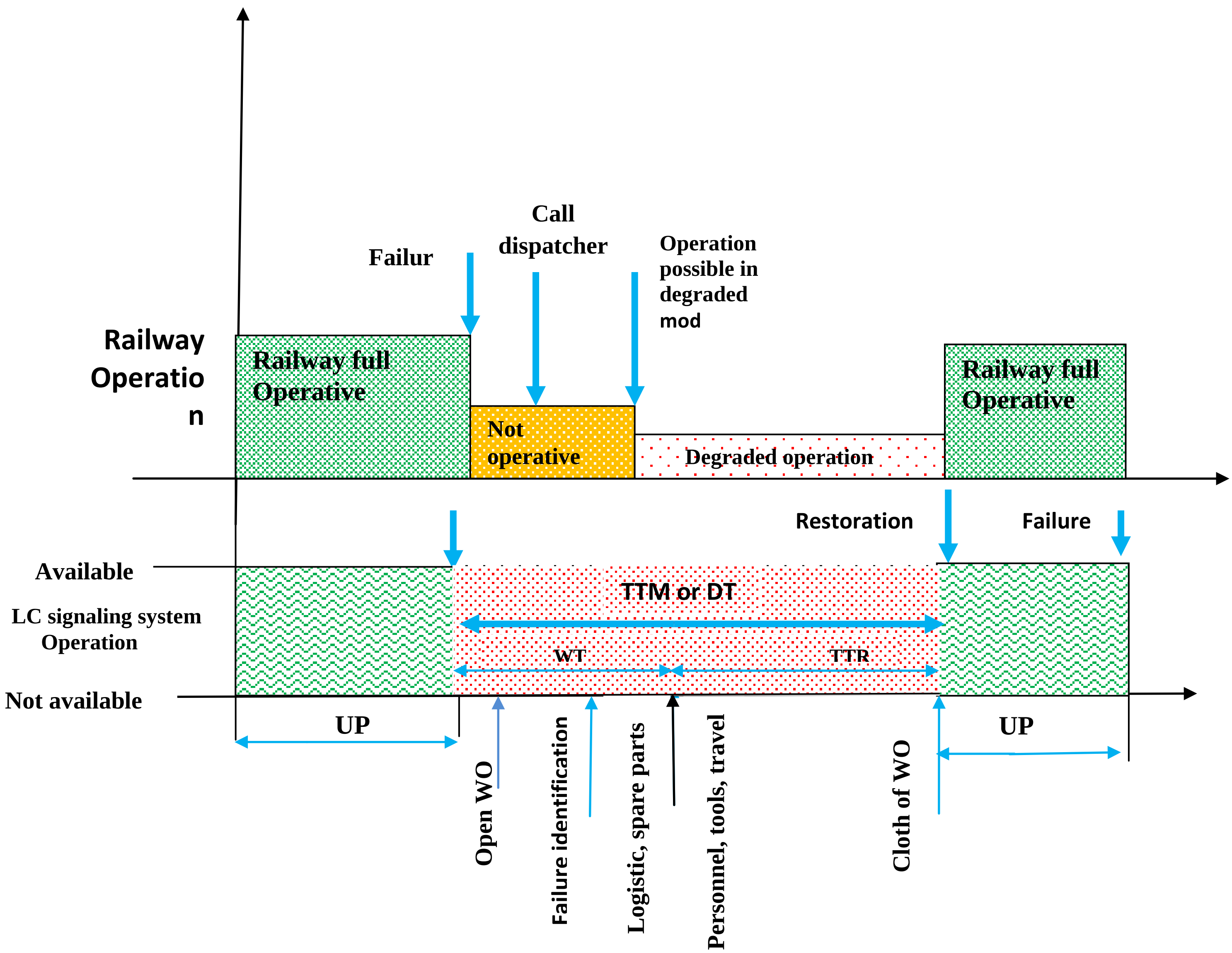


Figure 3-5 railway operations at different corresponding time

- **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 (20km/h, driver responsible for supervision and protection).
- **Degraded state:** In this state, railway operation is possible in a degraded mode (20 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[34].

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

- Available state or up time (UT): the system is fully operative:
- Not available or waiting time (WT): the time between when a failure occurs until the corrective action is started. During the waiting time, the WO (work order) is opened, the failure is identified, 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) are performed and the WO is closed.

To analyses the time data, calculate the total time spent on the corrective action (TTM) given by Equation (15), the time to restore (TTR) given by Equation (16), and the relative restoration time (RRT) against the total time to maintain for each WO given by Equation (17) 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) ---------------------------- (15)

TTR = t (finish o f corrective action) – t (start of corrective action) -------------------------- (16)

$$RRT\ (\%) = \frac{TTR\,(sec}{TTM\,(sec)} \text{---} (17)$$

Chapter Four

4. RAM Modeling of AA-LRT Level crossing system

4.1. Introduction

It is desirable to obtain a numeric indicator of how effective the level crossing signaling system is, taking into account other measures which are keys to its performance. When considering a level crossing, the important factors are reliability, availability, maintainability and safety (RAMS) and also inspection police to evaluate its performance.

RAM modeling can simulate the configuration, operation, failure, repair and maintenance of level crossing signal equipments. The inputs to RAM modeling will include the physical components and maintenance schedules in a system and the outputs can determine how effective the system can be over the plant life. RAM studies will generate sufficient data to base decisions for possible systems changes that may increase system efficiency and hence project profits. The application of relatively inexpensive but powerful RAM forecasting tools can provide a number of benefits to the level crossing 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 level crossing signaling system.

Those benefits can include [28]:

- ✓ 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 level crossing signaling system.

4.2. 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 rail-road) and of a human part (the operator of the train).
- ✓ **Road part:** it contains a material part (vehicle and road) and a human part (the driver of the vehicle).
- ✓ **Level crossing**: it consists of three main parts:
  - **Power network and communication** network between the components of the railway level crossing signaling system.
  - **Control part**: it consists of Programmable Logic Controller and its program.
  - **Operative part**: it consists of sensors (activation and deactivation of LC signal using axle counter) and actuators (the road lights, the alarms and the barriers).

4.3 AA-LRT Level crossing Fault Tree model

From the description of the AA-LRT railway level crossing signaling system in the previous section, we were able to model the Feared Event (Collision between train and vehicle) by a Fault Tree.

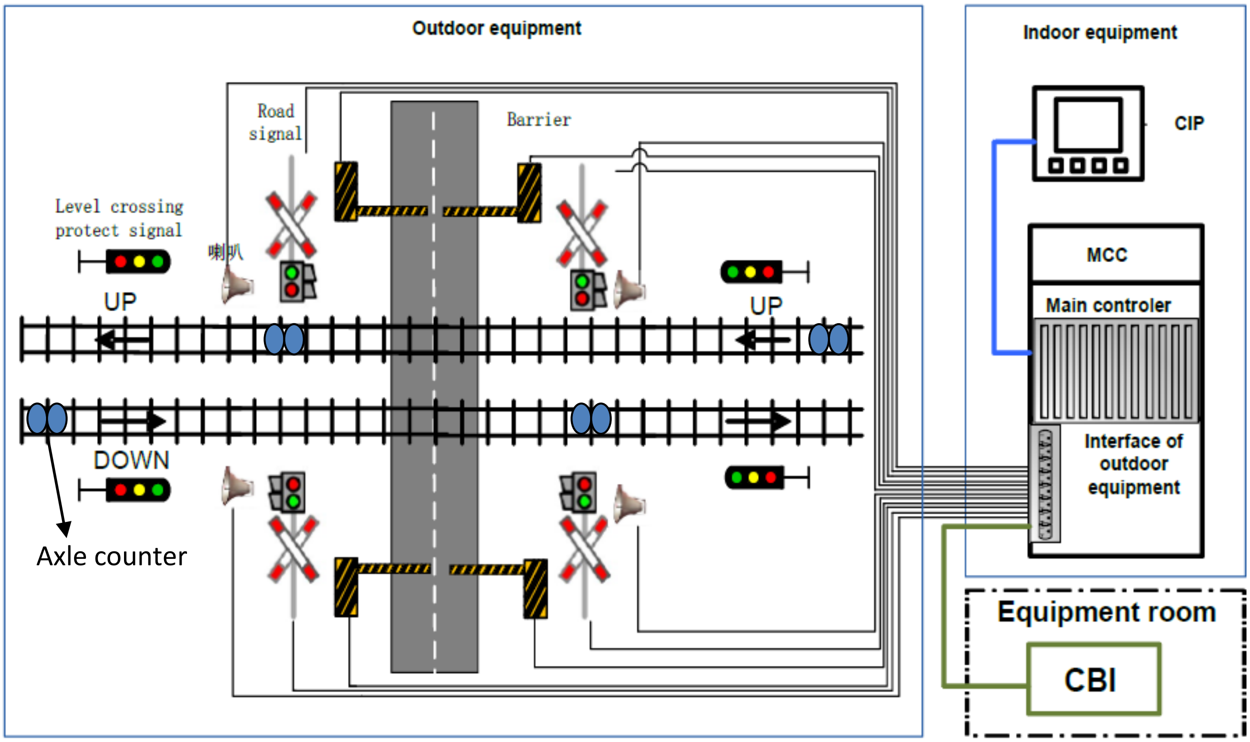
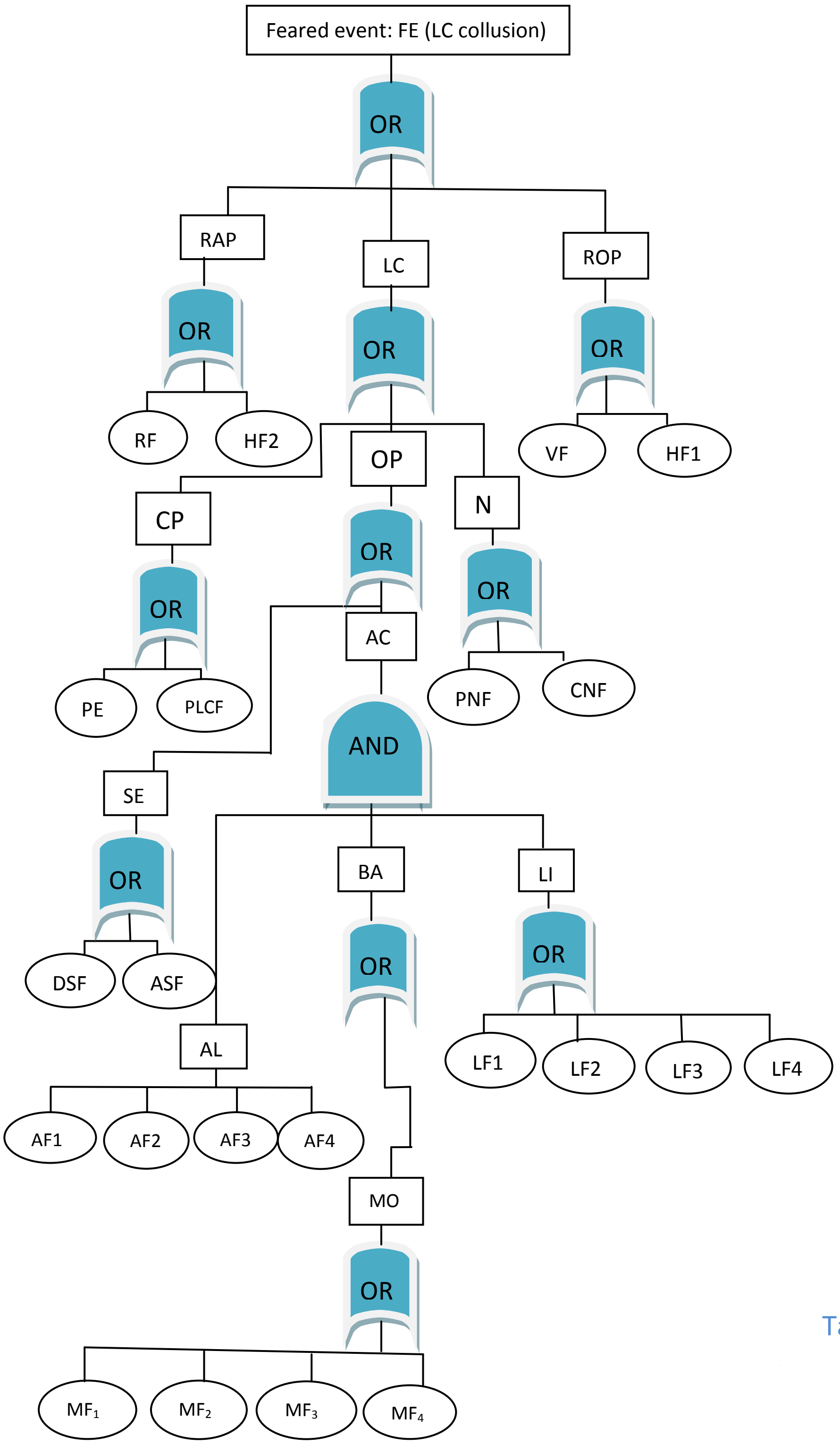


Figure 4-1 the structure of AA-LRT level crossing signaling system [29]

From above structure it is clear that Axle counter, Barrier, rail and LC controller are the measure part of AA-LRT level crossing signaling system and hence we considered these five subsystems of level crossing signaling system to analyze their performance in this thesis. From the structure above the following fault tree model in figure 4-2 was developed and analytically their performances were evaluated using Markov analysis. This would create a visual understanding of AA-LRT level crossing signaling system



Symbol	Intermediate Event
FE	Feared event
ROP	Road part
RAP	Rail part
LC	Level crossing
N	Network
CP	Control part
OP	Operative part
SE	Sensor
AC	Actuator
BA	Barrier
AL	Alarm (sound)
LI	Light
MO	Motor
TS	Transmission system

Table 4-1 Symbols of intermediate events

Figure 4-2 Fault tree of the AA-LRT Level Crossing

The basic events which produce the feared event are given in the table 4.2.

Symbol	Basic Event
HF	Human Failure
VF	Vehicle Failure
RF	Rail Failure
PLCF	Programmable logic Controller Failure
PE	Program Error
NCF	Network Communication Failure
PNF	Power Network Failure
ASF	Activation Sensor Failure(Axle Counter)
DSF	Deactivation Sensor Failure
AF	Alarm Surrender Failure
LF	Light Failure
MF	Motor Failure
TSE	Transmission System Failure

Table 4-2 Basic events

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 be easily solved. 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 system level reliability analysis. And also 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 performance AA-LRT level crossing signaling system.

4.4 Markov Analysis Model

4.4.1 Introduction

Modeling using Markov analysis is widely used in safety and reliability engineering**[25]** .the reliability behavior of a system is modeled by Markov chains as a state transition net of sequence which consists of a set of descript states that the system can be in, and defines the speed at which transitions between those states takes place[28] .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.

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 4.3), 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. Let P(t) be a vector that gives the probability of being in each state at time t. The system of differential equation that describes a Markov model is given by.

$$\frac{p(t)}{dt} = A.P(t)$$

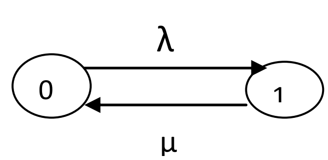


Figure 4-3 graphical elements of Markov modeling in a chain

The transition matrix A is easily constructed when Markov model is presented in terms of flow in and flow out. The element a_{ij} is equal to transition rate from i to j state, and its symmetric element a_{ji} is equal to transition rate from j to i stat. The diagonal entries are obtained by summing all transition rate from state i to another state and negating it. Hence the sum of all transition rate in the same rows are zero.

The solution of the deferential equation can be written as

$P(t)=P_0e^{At}$ …………………2.1

Where P_0= P(t=0) represents the initial state probabilities P(0). It can be used for system state probability evaluation at the time t (transient analysis) or in the steady state $t \to \infty$ (stationary analysis).

A Markov model divides the system configuration into a number of states. Each of these states is connected to all other states by transition rates. It then utilizes transition matrixes and state transition diagrams to represent the various system states and the possible transitions between these states. These state diagrams are more visual in nature than mathematical representations thus they are much easier to interpret. These advantages, however, must always be traded-off against the explosion in complexity and resulting increase in computation time as the number of states increase.

Therefore, Markov analysis can be a powerful RMS analysis tool. It allows the analyst to model complex, dynamic, highly distributed, fault tolerant systems that would otherwise be very difficult or impossible to model with classical techniques. Markov techniques decrease the analyst's task by reducing the problem from one of mathematical computation to that of state modeling. Model reduction techniques also exist which can yield relatively simple models with insignificant impact on model accuracy. In many situations it is also possible to use a combination of Markov analysis and more conventional approaches, e.g., reliability block diagrams, fault trees, etc. in such a way that the resulting individual dynamic portion are relatively small and easy to control.

4.4.2. Advantages of Markov Analysis Model

Markov methods offer significant advantages over other reliability modeling techniques discussed above in section 3.1, some of these advantages are:

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.

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.

4.4.3. 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. Various degradations on level crossing signaling system can be viewed as different Markov states and further degradation can be treated as the outcome of the present state. In this paper the level crossing signaling system 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 of the level crossing signaling system is complicated since the system has elements or subsystems exhibiting dependent failures and involving repair and standby operations. As discussed in chapter three Markov model is a better technique that has much appeal and works well when failure hazards and repair hazards are constant than other reliability analysis techniques . This paper is an insight into presenting a Markov model of the system by means of the different states and transitions between these states.

The assumptions are as follows:

- ✓ Time between failure (TBF) and time to repair (TTR) data are exponentially distributed. So there are no simultaneous failures of subsystems and the probability of more than one failure or repair in a time interval is zero.
- ✓ The repaired units are as good as new (AGAN) one repair or replacement is carried out only in case of failure.
- ✓ Failure rates and repair rates for all the subsystems of the system are constant over time and statistically independent.
- ✓ Standby system, partial degradation failures and partially working were not considered in this paper.

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

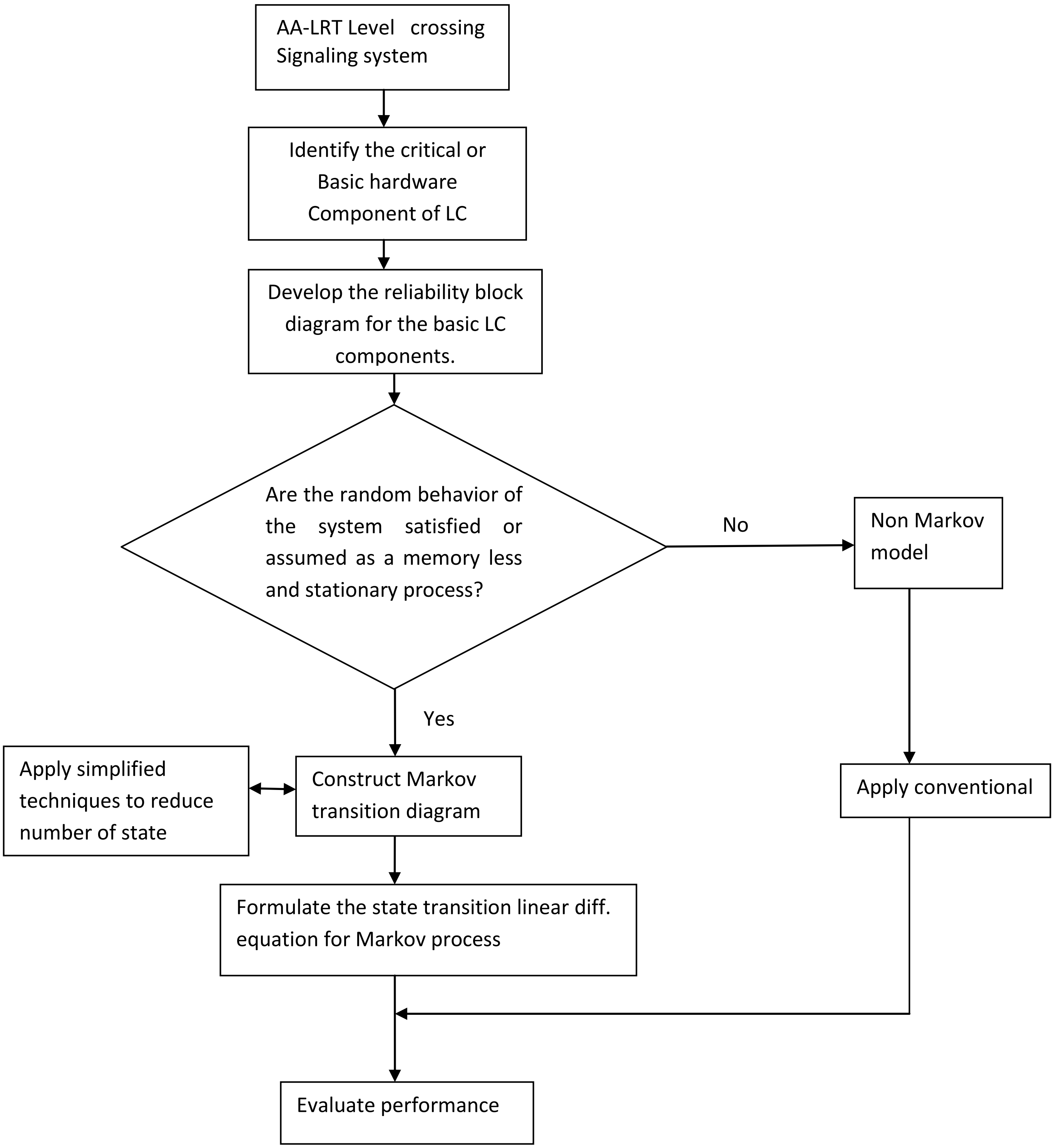


Figure 4-4 Framework for reliability modeling by Markov process

4.4.4. Description of the AA-LRT Level crossing signal Model

The Schematic description of AA-LRT single type II level crossing signal signaling system model is presented in figure 4-5 in this paper five main subsystems of type II level crossing signal were selected to estimate their reliability, availability and maintainability. These were used to analysis the overall performance and reliability of the level crossing signaling system. In the figure 4-5 the road signal or the traffic signals (the 4 barriers, 4 light signal and 4 audio alarm signal) which were connected in parallel in this model because all were used to inform the road user (vehicle and pedestrian) to cross the level crossing or not to cross the level crossing areas. From these parallel connected road signals we used the barrier for this model. And the second subsystem we used in this model was the axle counter which is used to activate and deactivate the level crossing signal.

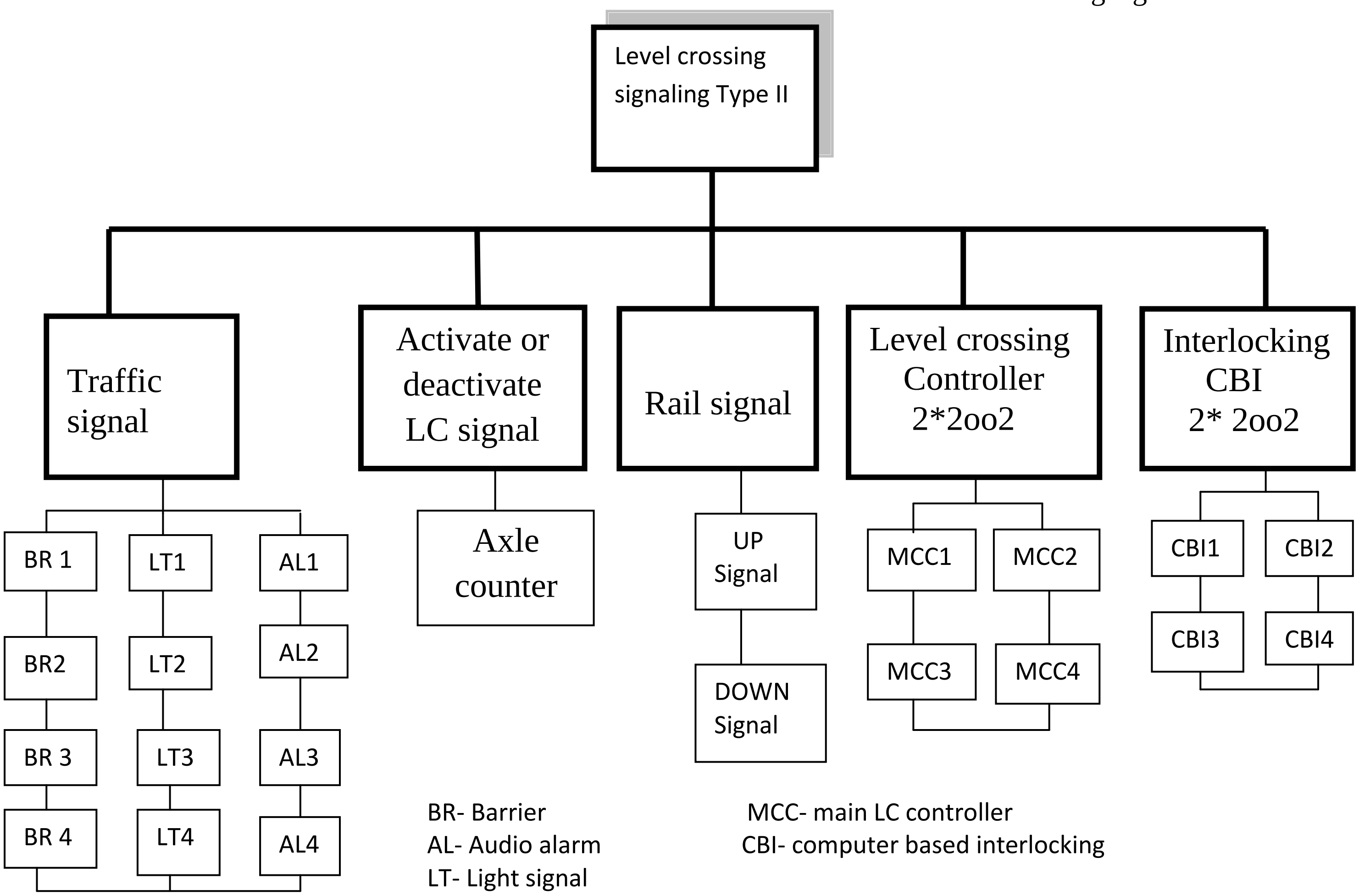


Figure 4-5 Figure schematic presentation of single type II AA-LRT level crossing signal subsystem

Activation and de activation sensors were connected in series to each other. the third signal is the rail signal which is used to allow the train in both up and down direction to cross the or not cross the level crossing. The forth one is the level crossing controller which is 2*2oo2 computer system used to control over all level crossing signals. The fifth subsystem used in this model was the computer based interlocking system (CBI) which used to implement all interlocking functions of the level crossing signals. It is also uses 2*2oo2 computer system.

Therefore, the simplified reliability block diagram of AA-LRT single type II level crossing was presented in figure 4-6 using only five main level crossing subsystems were selected for this paper. The network (the power network, and communication network) and human factors were not used in this paper.

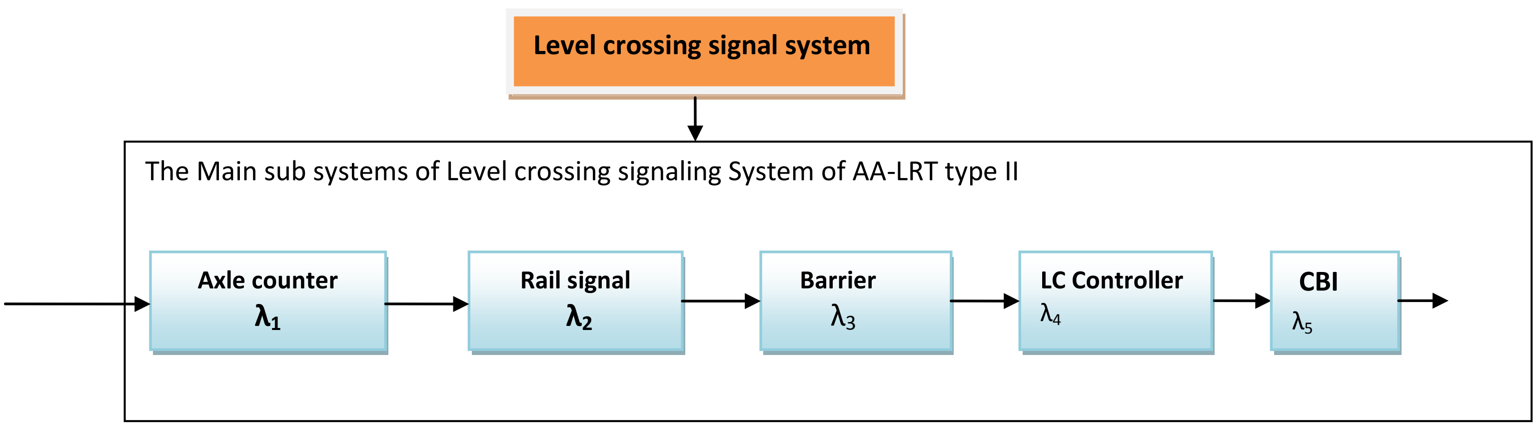


Figure 4-6 Simplified AA-LRT LC Reliability Block Diagram of type II

4.4.5. State Transition and Mathematical Analysis of Markov Model

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

$$[P_{ij}] = \begin{pmatrix} p_{11} & P_{12}\ldots\ldots\ldots & P_{1j}\ \ldots\ldots\ldots\ldots & P_{1n} \\ P_{11} & P_{12}\ldots\ldots\ldots & P_{2J}\ldots\ldots\ldots\ldots & P_{2n} \\ - & - & - & - \\ - & - & - & - \\ P_{i1} & P_{i2}\ldots\ldots\ldots & P_{ij}\ \ldots\ldots\ldots\ldots & P_{in} \\ P_{n1} & P_{n2}\ldots\ldots\ldots & p_{nj}\ldots\ldots\ldots\ldots & p_{nn} \end{pmatrix}$$

$R(t) = \Pi R_i = R_1.R_2.R_3.R_4.R_5$ (for five subsystems of level crossing signaling system.)

Where: R_1- (the reliability of the four barriers connected in series)

R_2- (Reliability of single axle counter)

R_3- (Reliability of 2oo2 (series connection) LC controller)

R_4- (Reliability of two series connection rail signal)

R_5- (Reliability of 2oo2 (series connection) CBI)

Therefore $R(t) = e^{-\lambda 1t}.e^{-\lambda 2t}.e^{-\lambda 3t}.e^{-\lambda 4t}.e^{-\lambda 5t}$

Where: λ_1 - the failure rate of the identical four barrier

λ_2– The failure rate of axle counter

λ_3 - the failure rate identical 2oo2 LC controller

λ_4= - the failure rate of the two identical series connection rail signal

λ_5=–the failure rate of identical 2oo2 CBI

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

$= e^{-Ft}$ (where $F = \Sigma \lambda_i$, $i = 1, 2, 3, 4, 5$)

From the transition diagram presented in Figure 4.7 there are two discrete state of the transition, state 0: all level crossing signaling subsystems working normally and state 1: only the barrier is down, whereas the rest of subsystem are up; state 2: only axle counter is down; state 3: only LC controller is down; state 4: only rail signal is down; state 5: only the CBI is down within a continues time interval. The Markov equations and the steady state availability of the level crossing signaling system is found as follows:

$$P0=\frac{1}{1+\sum\frac{\lambda i}{\mu i}} = \frac{1}{1+D} \text{where } D = \sum\frac{\lambda i}{\mu i}$$

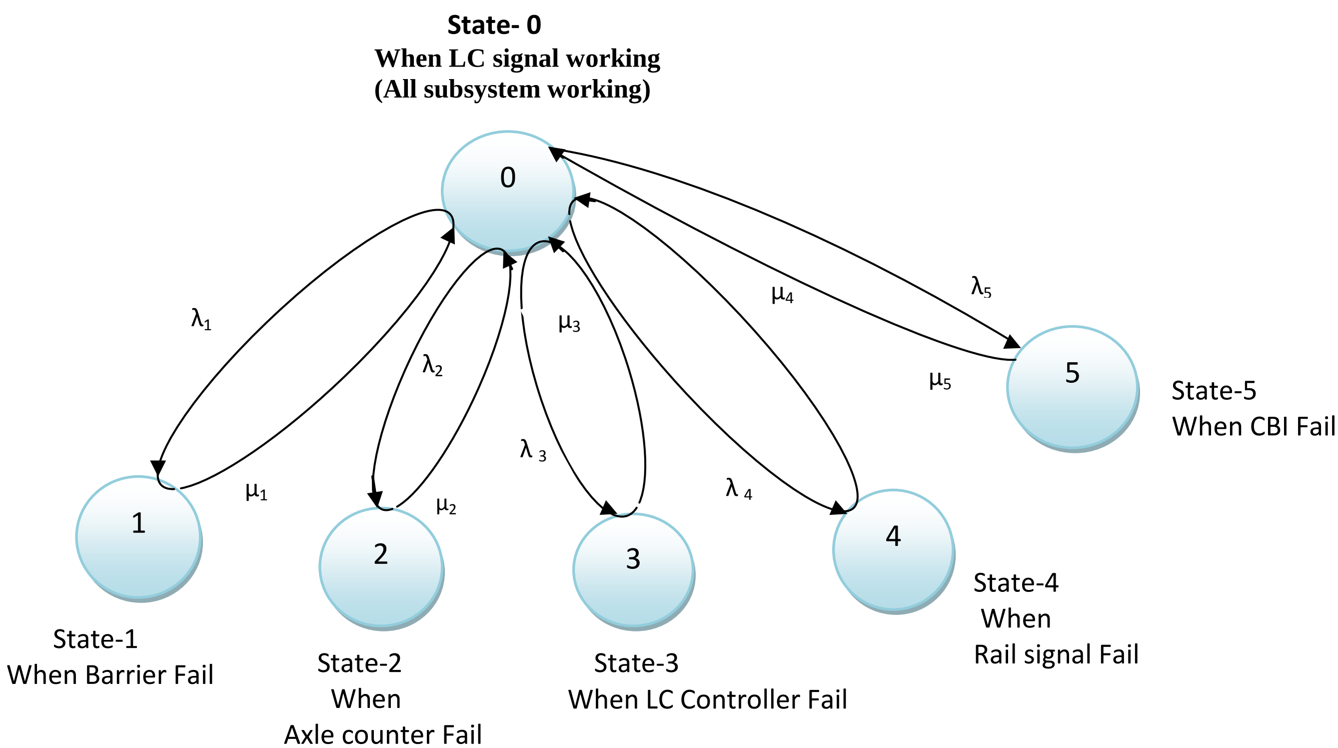


Figure 4-7 Transition diagram for level crossing signaling system and subsystems

The probability that the system is in the operating state after time interval dt i.e. at time (t+dt) is given by:-

PS0(t +dt) = [Probability of being in operating state at time t) and (Probability of not failing between t and t+dt] +[Probability of being failed states at time t) and (Probability of being repaired between t and t+dt).

Probabilities of failure between t and dt are $\lambda i dt$ and Probabilities of not failing between t and dt are ($1-\lambda i dt$).Similarly the probabilities of repair are μ idt. Using the addition and multiplication rule for probabilities gives;

$$PS0((t+dt) = PS0(t)(1-[\lambda 1dt + \lambda 2dt + \lambda 3dt + \lambda 4dt + \lambda 5dt]) + [\mu 1dt\ PS1(t) + \mu 2dt\ PS2(t) + \mu 3dt\ PS3(t) + \mu 4dt\ PS4(t) + \mu 5dt\ PS5(t)]]$$

and this is equal to;

Where: μ_1–Repair rate of the four barrier

μ_2– Repair rate of axle counter

μ_3– Repair rate of the 2oo2 LC controller

μ_4– Repair rate of rail the two rail signal

μ_5– Repair rate of the 2oo2 CBI

$$PS0((t+dt) = PS0(t) - [\lambda 1dt\ PS0(t) + \lambda 2dt\ PS0(t) + \lambda 3dt\ PS0(t) + \lambda 4dt\ PS0(t) + \lambda 5dt\ PS0(t)]] + [\mu 1dt\ PS1(t) + \mu 2dt\ PS2(t) + \mu 3dt\ PS3(t) + \mu 4dt\ PS4(t) + \mu 5dt\ PS5(t)]]$$

$$PS0((t+dt) - PS0(t) = (-\lambda 1dt - \lambda 2dt - \lambda 3dt - \lambda 4dt + \lambda 5dt)\ PS0(t) + \mu 1dt\ PS1(t) + \mu 2dt\ PS2(t) + \mu 3dt\ PS3(t) + \mu 4dt\ PS4(t) + \mu 5dt\ PS5(t)$$

(Rearranging)

$$\frac{PS0((t+dt) - PS0(t)}{dt} = (-\lambda 1 - \lambda 2 - \lambda 3 - \lambda 4 - \lambda 5)\ PS0(t) + \mu 1\ PS1(t) + \mu 2\ PS2(t) + \mu 3\ PS3(t) + \mu 4\ PS4(t) + \mu 5 PS5(t)$$

$dt \longrightarrow 0$

or $d\frac{PS0(t)}{dt}$ =- PS0(t)($\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5$) + μ_1 $PS_1(t)$ + μ_2 $PS_2(t)$ + μ_3 $PS_3(t)$+ μ_4 $PS_4(t)$ + $\mu 5 PS5(t)$

$= \sum \mu i PSi(t) - PS0(t) \sum \lambda i$ --- [1]

Similarly for other states will be

$$d\frac{PS1(t)}{dt} = \lambda 1PS0(t) - \mu 1PS1(t)$$

$$d\frac{PS2(t)}{dt} = \lambda 2PS0(t) - \mu 2PS2(t)$$

$$d\frac{PS3(t)}{dt} = \lambda 3PS0(t) - \mu 3PS3(t)$$

$$d\frac{PS4(t)}{dt} = \lambda 4PS0(t) - \mu 4PS4(t)$$

$$d\frac{PS5(t)}{dt} = \lambda 5PS0(t) - \mu 5PS5(t)$$ -- [2]

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

$$\begin{vmatrix} d\frac{PS0(t)}{dt} \\ d\frac{PS1(t)}{dt} \\ d\frac{PS2(t)}{dt} \\ d\frac{PS3(t)}{dt} \\ d\frac{PS4(t)}{dt} \\ d\frac{PS5(t)}{dt} \end{vmatrix} = \begin{pmatrix} -(\lambda 1+\lambda 2+\lambda 3+\lambda 4+\lambda 5) & \mu 1 & \mu 2 & \mu 3 & \mu 4 & \mu 5 \\ \lambda 1 & -\mu 1 & 0 & 0 & 0 & 0 \\ \lambda 2 & 0 & -\mu 2 & 0 & 0 & 0 \\ \lambda 3 & 0 & 0 & -\mu 3 & 0 & 0 \\ \lambda 4 & 0 & 0 & 0 & -\mu 4 & 0 \\ \lambda 5 & 0 & 0 & 0 & 0 & -\mu 5 \end{pmatrix} \begin{bmatrix} PS0(t) \\ PS1(t) \\ PS2(t) \\ PS3(t) \\ PS4(t) \\ PS5(t) \end{bmatrix}$$

Equating first order derivative to zero for a steady state these equations will take the following form for three level crossing signaling subsystems only,

$P_0(\lambda_1+\lambda_2+\lambda_3+\lambda_4)= \mu_1 P_1 + \mu_2 P_2 + \mu_3 P_3+ \mu_4 P_4 + \mu_5 P_5$

[(i.e. taking Psi(t)=Pi(i=0,1,2,3,4, 5)].

$P_1\mu_1 = P_0\,\lambda 1$ so $P_1=\frac{\lambda 1}{\mu 1}P_0$

$P_2\mu_2= P_0\,\lambda_2$

$P_3\mu_3 = P_0\,\lambda_3$

$P_4\mu_4 = P_0\,\lambda_4$

$P_5\mu_5 = P_0\,\lambda_5$ -- [3]

$P_0 + P_1 + P_2 + P_3 + P_4 + P_5 = 1$-- [4]

Substituting the value of P_1, P_2, P_3, P_4, P_5 in equation (4) the steady state at $t \to \infty$ availability of level crossing signaling system is found as :

$A_s = P_0 = \frac{1}{1+\sum\frac{\lambda i}{\mu i}} = \frac{1}{1+D}$ where $D = \sum\frac{\lambda i}{\mu i}$ ------------------------------------ [5]

Unavailability of the level crossing system is found as:

$UA_s = P_1 + P_2 + P_3 + P_4 + P_5$ --- [6]

Where:

$$\left.\begin{aligned} P_1 &= \frac{\lambda 1}{\mu 1}\left[\frac{1}{1+D}\right] \\ P_2 &= \frac{\lambda 2}{\mu 2}\left[\frac{1}{1+D}\right] \\ P_3 &= \frac{\lambda 3}{\mu 3}\left[\frac{1}{1+D}\right] \\ P_4 &= \frac{\lambda 4}{\mu 4}\left[\frac{1}{1+D}\right] \\ P_5 &= \frac{\lambda 5}{\mu 5}\left[\frac{1}{1+D}\right] \end{aligned}\right\} \qquad \text{-- [7]}$$

The reliability of different subsystems is :

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

Where R_1, R_2, R_3, R_4 and R_5 are reliability of Barrier, Axle counter, LC controller, rail signal and CBI.As these subsystems are connected in series, so the reliability of the level crossing signaling system will be the product of the individual subsystem reliabilities.

$$R(t)=\Pi R_i=R_1R_2R_3R_4R_5=e^{-\lambda 1t}.e^{-\lambda 2t}.e^{-\lambda 3t}.e^{-\lambda 4t}.e^{-\lambda 5t}=e^{-\sum\lambda it}$$

$=e^{-Ft}$ [where $F=\sum\lambda i$, ($i = 1,2,\ldots 5.$)]. The maintainability of different subsystems is as follows**:**

$M1(t) = 1 - e^{-\mu 1t}$ Where μ is the repair rate.

$M2(t) = 1 - e^{-\mu 2t}$

$M3(t) = 1 - e^{-\mu 3t}$

$M4(t) = 1 - e^{-\mu 4t}$

$M5(t) = 1 - e^{-\mu 5t}$-- [8]

Mean time to failure MTTF = $\frac{1}{\Sigma\lambda i} = \frac{1}{F}$

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

Now mean time to repair MTTR = MTTF x D , where D = $\Sigma \frac{\lambda i}{\mu i}$

System repair rate (μs) = $\frac{1}{MTTR} = \frac{1}{MTTF}$x D

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

$R(t)=e^{-Ft}$

Again,

$\therefore t =\frac{-\ln R\ (t)}{F}$

$$Ps0(t+dt) = Ps0t[(1-\lambda 1dt) + (1-\lambda 2dt) + (1-\lambda 3dt) + \mu 1dtPs1(t) + \mu 2dtPs2(t) + \mu 3dtPs3(t) + \mu 4dtPs4(t) + \mu 5dtPs5(t)$$

Steady state reliability

$P_1 = \frac{\lambda 1}{\mu 1}[\frac{1}{1+D}]$

$P_2 = \frac{\lambda 2}{\mu 2}[\frac{1}{1+D}]$

$P_3 = \frac{\lambda 3}{\mu 3}[\frac{1}{1+D}]$

$P_4 = \frac{\lambda 4}{\mu 4}[\frac{1}{1+D}]$

$P_5 = \frac{\lambda 5}{\mu 5}[\frac{1}{1+D}]$ -- [9]

Chapter Five

5. Results and Discussions

Failure and repair rate data of the subsystems of level crossing signaling systems for this study were obtained from Signaling System detailed design of AALRT Part I Technical Specification [29], interview and site assessment. With the help of these data reliability and maintainability of five main subsystems and the entire level crossing system versus time at different intervals were calculated and estimated using Markov process. The graphs for reliability and maintainability versus time at different intervals were also plotted to estimate reliability and maintainability of the five main subsystems and the entire level crossing system. The failure and repair rate is shown in figure 5-1.

COMPONENTS	FAILURE RATE/HOUR (λ)	REPARE RATE/HOUR (μ)
Barrier	0.00008	2
Axle counter	0.000005714	2.3
Rail signal	0.000002	2.8
LC controller	0.000010	2.6
CBI	0.000010	2.4

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

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 the table 5.2.

Time(hour)	Barrier	Axle counter	Rail signal	LC controller	CBI
0	1	1	1	1	1
100	.99800	.99942	.999900	.999500	.99989
200	.99600	.99886	.999800	.99900	.99979
300	.0.99400	.99829	.99970	.99850	.99969

Table 5-2 Reliability of different level crossing signaling components for different time interval

From Table 5.1 and 5.2 reliability of different level crossing signaling is calculated and reliability Versus Time (H) graph is plotted. This is shown in figure 5.1.

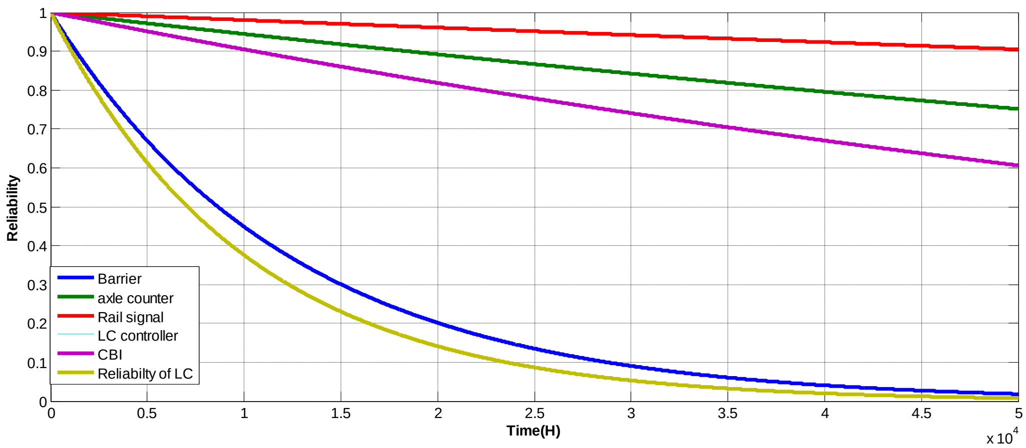


Figure 5-1 Reliability versus time pattern of axle counter rail signal and LC controller of AA-LRT LC using initial design data

In figure 5-1 the diagram of reliability of subsystems and the entire level crossing system were plotted and the following observations were made:

- ✓ The reliability of barrier, axle counter, rail signal, LC controller and CBI are 0.66, 0.98, 0.99, 0.96 and 0.96 respectively after 5000 hours of operation. So reliability of barrier is lowest out of the five subsystems level crossing system. Hence it is required more attention than Axle counter, rail signal, LC controller and CBI.
- ✓ the reliability of the entire level crossing after; 5000 hour of operation is 60.00 %; in $2x10^4$h of operation is 16.00 % and in $2.5x10^4$ of operation drops down to 8.0%. As we can observed from the graph the reliability of one single subsystem can affect the entire level crossing system. This means that the failure of single subsystem can stop the entire level crossing system.

Time(hour)	Barrier	Axle counter	Rail signal	LC controller	CBI
0	0	0	0	0	0
.5	0.69673	0.73629	0.87838	0.85145	0.81856
1	0.86466	0.89974	0.93919	0.92572	0.90928
1.5	0.88843	0.902987	0.92031	0.91418	0.90973

3	0.975106	.96658	0.98222	.98085	0.97926
6	0.97744	0.98329	0.99911	.98762	0.99897

Table 5-3 Maintainability pattern of different level crossing signaling components

With the help of the design data and by using mathematical expressions as shown in the Table 5.3 Maintainability pattern of five level crossing signaling components are calculated and graph is plotted as shown in figure 5.3.

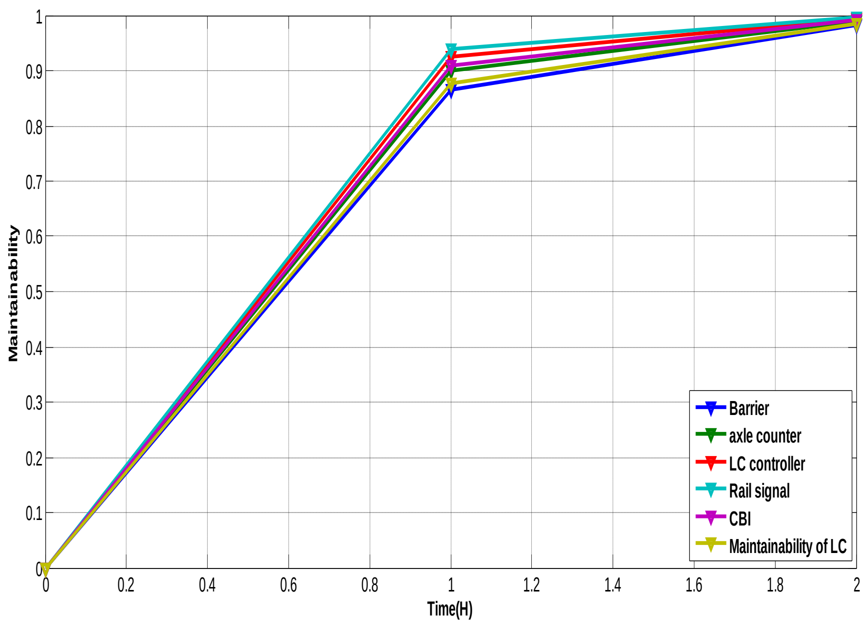


Figure 5-2 Maintainability pattern of level crossing signaling components

In figure 5-2 the diagram of maintainability pattern of subsystems and the entire level crossing system were plotted and the following observations were made:

- ✓ From figure 5.2 maintainability of Barrier, Axle counter, LC controller, rail signal, CBI and maintainability of the entire LC after one hour are 0.865, .899, 0.926, 0.939, and .909 respectively. Maintainability of Axle counter, LC controller, CBI and rail signal is almost good except barrier which is lowest.
- ✓ A failure at all subsystems and for the entire level crossing will be repaired within one hour except the Barrier.

For 100 percent of expected reliability maintenance interval should be zero for any system. Maintenance time may also be reduced by proper planning and spare parts management for increased availability of the equipments. The constraints and reasons for good reliability and maintainability suggested that the data was taken from the initial design data, this will be different or lower than these value after the these sub system will start operation in the real environment. Again, after these equipments fully start the operation special attention in relation to maintenance and inspection activities and logistics support is required to be taken in improve the reliability and maintainability of level crossing signaling subsystems and system. For different percentage of expected reliability we got different maintenance interval from the initial design data AA-LRT. From Table 5.4 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 (%),	50	60	70	80	90	100
Maintenance interval (Hour)	6435	4742	3311	2072	978	0

Table 5-4 Expected reliability of level crossing signal for different maintenance interval

From the figure 5.3 it is observed that due to significant, causes are for the barrier, rail signal, LC controller, CBI and axle counter level crossing subsystems the reliability and maintainability of the level crossing signaling system with different time intervals get effected which is shown by the graph below.

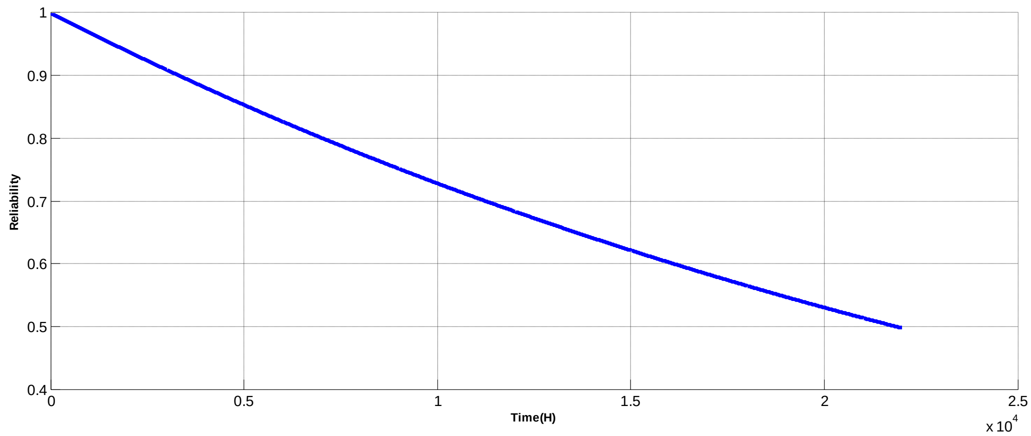


Figure 5-3 Expected reliability of level crossing for different time interval (h)

It is found that the reliabilities of the different subsystems are different as well as decreasing with time. It is also seen that system will almost not fail for 20 hours of operation. It is observed that the reliabilities of the subsystems are decreasing overtime and reliability of Axle counter, LC controller and rail signal will be about 97% after 2500 hours and similarly maintainability of Barrier, Axle counter, LC controller, CBI and rail signal will be 40% to 50% after half hours. Again, special attention in relation to maintenance and inspection activities and logistics support is required to be taken to improve the reliability and maintainability of signaling subsystems and system. With different expected reliabilities of the signaling system, the maintenance interval is given in Table 5.4.

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

6. Conclusion and Recommendation

6.1. Concluding Remarks

Analytical probability models for a level crossing system that consists of five main subsystems in series are developed. The models assume both failure and repair rates to be exponentially distributed. The mathematical model of operation and the probability model of failure for the individual subsystems and entire level crossing system are presented. These models were applied to investigate the effect of system parameters on system performance in the actual level crossing system. It was pointed out that:

1. 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 0.66, 0.98, 0.99, 0.96 and 0.96 respectively after 5000 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.

2. The maintenance department of AA-LRT may adopt the appropriate maintenance policy for the level crossing signaling system, focusing primarily on Barrier that displays the lowest reliability and maintainability.
3. Maintenance intervals for 90 % of expected reliability of level crossing signaling system is found to be 978 hours according to the design data.

Moreover, the steady state probability models described in equations (5), (6), and (7) can be applied in each subsystems consisting of individual components which fail more or less frequently, leading to failures in the equipment. Thus, it can estimate the demand for subsystems support/spare parts and determine the inventory management.

6.2. Recommendation of the Work:

Recommendation of this work is described as follows:

1. Markov process may also be applicable to other signaling subsystems (signal unit, switch machine track circuit..) of AA-LRT.
2. Due to lack of real repair and failure data of level crossing signal from ERC, the models developed in this thesis were using detail design signaling system data which result in good reliable and maintainable. Thus, by considering the actual repair rate and failure rate properly logged data we can analyze the performance of the system using Markov processes more accurately.
3. Markov process may be used to the same level crossing signaling subsystems to the other section of AA-LRT.
4. By considering the power and communication network, human factors and environmental condition we can get more accurate results in the analysis.

5. Modeling proper inspection policies can be further use for the cost optimization of railway level crossing signaling system.
6. By proper resource allocation, a maintenance strategy suitable for the environmental as well as technical problems, and proper design improvement can reduce the frequency of machine failure or repair time and consequently improve the system availability (i.e. reliability and maintainability).

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