# Assessment Framework and Processes for Asset Management of Passenger Terminals

Shanika Kanchani Manamperi

(218069T)

Research submitted in partial fulfilment of the requirements for the degree Master of Science in Transport and Logistics Management

Department of Transport and Logistics Management

University of Moratuwa
Sri Lanka

August 2022

## Declaration of the Candidate & Supervisor

I declare that this is my own work, and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature: S.K.Manamperi Date: 23.02.2023

The supervisor/s should certify the research report with the following declaration.

The above candidate has carried out research for the Masters thesis under my supervision.

Signature of the supervisor: Prof. Asoka Perera Date:23.02.2023

# Abstract

Asset management has become one of the significant areas demarcating its key concepts and has branches. There are records of good asset management practices worldwide, but local industry is yet to establish the asset management practice. Nevertheless, condition assessment is a major discipline of the asset management that is essential to develop effective and efficient maintenance strategies for any organization. On the other hand, condition assessment makes the foundation to develop systematic models that many of the organizations are experimented for, since managing of assets and the cost of repairing have made real-time challenges for them. Hence, the objective of this study is to develop a framework for predictive maintenance of assets considering the existing assessment frameworks of the early researchers. However, the significance of this research is that the framework is developed focusing the passenger terminals where this concept has been narrowly addressed. Kandy Multimodal Transit Terminal was selected for the case study. Generally, assets deteriorate with the time but the tendency of assets to get damaged by the external ways and means like disasters is more. Since this study further expected to in cooperate the asset management with the disaster management of the passenger terminals. Accordingly, Markov Chain was used for developing the framework for the predictive maintenance of assets and the cost projections whereas a conceptual framework was introduced for predicting the cost of maintenance considering the availability of data. Disaster assessment method was conceptually developed by introducing the disaster risk score of assets and simple approach of asset damage calculation for pre and post disaster assessments respectively. Hence, the outcome of this research facilitates to reduce the consequences in asset maintenance management and to manage the budget allocation for the maintenance in the passenger terminals.



*Keywords: Asset predictive maintenance management, Disaster management, Passenger terminals, Condition evaluation, Risk score value, Markov chain*

# Acknowledgements

It is always a pleasure to remember those nice individuals for their sincere counsel, which enabled me to uphold my experience, skills, and abilities in order to successfully accomplish this piece of work.

Bearing in mind, I am grateful to my parents for their unfailing support. First, I express my sincere gratitude to my supervisor, Prof. Asoka Perera, for being the critical reader of my thesis work and for being supportive and optimistic throughout the entire process, which had its ups and downs.

Secondly, I sincerely thank to Prof. Asoka Perera (Head of Department of Transport and Logistics Management), Prof. Amal S. Kumarage (Former Head of Transport and Logistics Management), Prof. R.U. Halwatura (Professor of Department of Civil Engineering) and Dr. T. Sivakumar (Research coordinator of Department of Transport and Logistics Management) for giving this valuable opportunity and paying attention through evaluations.

Also, Central Province Passenger Transport Authority and all the other staff members of the Department of Transport and Logistics Management deserve a heartfelt thank you for their assistance towards this research.

Finally, I hope this thesis will inspire the reader to use logic and reasoning to understand things, even if they encounter any shortcomings in this piece of work that needs to be improved.

# Table of Contents

# List of Tables

# List of Figures

# Abbreviations

| | |
|---|---|
| ADB | Asian Development Bank |
| AMS | Asset Management System |
| DMS | Disaster Management System |
| GIS | Geographic Information System |
| HVAC | Heating, Ventilation and Air Conditioning |
| IIMM | International Infrastructure Management Manual |
| KMTT | Kandy Multimodal Transit Terminal |
| MEP | Mechanical Electrical Plumbing |
| NAMS | National Asset Management Support |
| RM | Malaysian Ringgit |
| UNISDR | The United Nations (UN) International Strategy for Disaster Reduction |

# 1. INTRODUCTION

## 1.1. Introduction

Asset management is one of the emerging disciplines in worldwide which provides a systematic approach to asset maintenance management. It concerns on the key aspects like customer satisfaction, financial efficiency, risk management and sustainability such that it is defined as the organizational strategic plan, an organization manages its assets and asset systems optimally and sustainably, considering their performance, risks, and costs that go along with them over their lifetime.((IAM), 2008). In the sense, asset management does not emphasis merely on itself rather it focuses on the value it can provide to the organization. Generally, assets deteriorate with time. On the other hand, improper operation and maintenance and improper risk management (both natural and man-made disasters) also contribute for the failures in optimized asset management. However, asset management encounter challenges when it gets incorporated with the disaster management since disasters might trigger hostile consequences on assets in many factors perhaps depending on the nature of them. Hence, the deficiencies in the sound disaster management practices result in the deterioration of the asset management within an organization, project or an infrastructure development making the sense that it touches the passenger terminals which are abundant of assets. Therefore, this study focuses on the establishment of a framework for asset management of passenger terminals in local context examining the current maintenance practices and optimizing them accordingly.

## 1.2. Background

Even though both the asset management and disaster management take a prominent place in most of the countries, asset management is a new knowledge area, yet the disaster management is relatively far ahead of it in Sri Lankan context. It is evident that most of the efforts had been taken related to mega infrastructure projects as well as to the donor funded projects in local context. But not any considerable research work had been carried out related to the application of disaster management practices on assets in passenger terminals although it is a very significant area to be addressed.

Practice of these aspects in Sri Lankan passenger terminals is at a very low level narrowing towards the facilitation of basic facilities yet at minimum conditions with less security arrangements. Bus terminals like these and other bus terminals around the country currently have issues with overcrowding, ticket issuing, over loading, safety issues, passenger dissatisfaction due to the lack of dynamic timetable information, limited seating arrangements for waiting passenger and lack of sanitary and restroom facilities (Liyanage, Jayaratne, & Kumarage, 2008). Further the poor arrangement of these terminals as well as the unseparated circulation of vehicles and passengers add no value to the user convenience. This all add up to the ad hoc nature of the asset management in Sri Lankan passenger terminals.

It is evident that these are rehabilitated in the forms of minor repairing time to time, but the ad hoc nature has resulted with the non-evaluation of their functionality, safety which includes the absence of maintenance records etc. On the other hand, there is not any tangible document including the disaster contingency plans related to the public transport terminals that can be executed. But it is necessary to identify the risks associated with the disasters vulnerable to terminals to convert them in to actionable steps to reduce likelihood of possible occurrences on assets. Therefore, a better functionality needs to be maintained in meeting the passenger requirements to satisfy them with reliable facility usage.

### 1.3. Problem Statement

According to the historical records of the local passenger terminals, it can be pinpointed that the asset management had been practiced mostly based on the socio-economic requirements raised then and there whereas the maintenance decisions had been made considering the tradition, personal experience and resource availability. Hence, no systematic analytical background can be noticed in those approaches rather they have been lasted without any future overview. Nevertheless, these have not focused on the long-term management of assets which creates an incompatibility with compared to the contemporary conditions of the terminals. Additionally, many of these asset management strategies disregard a systematic broad emphasis that entails grouping many assets under a single entity (Stapelberg & Frederick, 2006). Moreover, it is questionable whether these decisions had been in cooperated with the consequences of disasters on assets. In other words, asset-management frameworks do not include criteria for concern related to natural or man-made disaster (Abuzayana, Whytea, & Bella, 2014). Thus, the necessity is raised to develop assessment criteria based on the techniques  of asset reliability management. Hence, in addressing this deficiency, study intends to review and identify an optimizing system performance that ensure the current needs and meet the future needs of the assets in the local passenger terminals.

### 1.4. Significance of the Research

Currently, several asset-management frameworks exist, but there are no reference models exist that detail all fundamental processes and change management approaches for asset management deployment (Abuzayana, Whyte, & Bell, 2014). Establishment of a framework by developing an assessment criteria for assets related to their predictive maintenance through an analytical approach emphasis the significance of this study whereas it involves the variables related to physical condition and performance condition of the assets. As previously stated, a study dealing with adverse conditions (post-conflict; disaster-zone; and high-alert locations) is noticeably lacking in current academic review (Abuzayana, Whyte, & Bell, 2014). Thus, this approach is further developed through the integration of disasters and their consequences on the assets in which the outcomes work strives to fill the current gap in local context.

### 1.5. Scope of the Study

The scope of this study is to identify the variables to measure the physical and performance condition of the assets and the variables to assess the preventive and predictive maintenance of assets in the passenger terminals. Also, it is necessary to recognize the disasters that are vulnerable to the terminals, their likelihood of occurrence and the effects of them on the life of the assets. There onwards a model can be developed integrating both the assets and the disasters for the establishment of an optimized system. However, considering the time constraints and other circumstances, the research would use both raw data and published data in the sense reliability and accuracy of data will moderately be contingent. Although the framework is developed with the intention to accommodate all the passenger terminals, this piece of work is solely focused on the non-current assets of the Kandy Multimodal Transit Terminal (KMTT).

## 1.6. Objectives of the Research

Accordingly, research objectives can be stated as,

1. To establish assessment methods related predictive maintenance of assets in passenger terminals
2. To establish assessment methods related to disaster management for asset management
3. To optimize management processes for asset management

## 1.7. Organization of the Report

The report comprises of seven chapters as follows,

**Chapter one**: outlines the background and the objectives of the research.

**Chapter two**: includes the literature review on the asset maintenance and disaster management.

**Chapter three**: outlines the research methodology

**Chapter four**: introduces the proposed predictive assessment framework including data analysis and optimization of the processes.

**Chapter five**: concludes the research work with recommendations for the future work.

# 2. LITERATURE REVIEW

This section outlines an overview to the research area elaborating the key aspects, concerned processes associated with the asset management and disaster management related to passenger terminals in Sri Lanka.

## 2.1. Introduction

Asset management, as defined by ISO 55000, is the coordinated activity made by an organization to derive value from its assets. Although it was first practiced in oil and gas industry, currently it has been able to become one of the most trending aspects in worldwide which plays a significant role in optimizing the performance of both public and private sectors. On the other hand, many sectors have encountered challenges in the maintenance management of non-current assets. However, similar to other sectors asset management holds a prominent place in transportation sector too as passenger terminals are with a wide variety of assets including architectural, structural, mechanical, electrical and outdoor elements. Thus, maintenance management of assets is an essential requirement in passenger terminals since the terminal environment quality is directly linked with the passenger satisfaction. Also, disasters affect the passenger terminals whereas the poor disaster management have triggered the alterations in existing asset management practices. Hence, it is essential to link the asset management with the disaster management as well. Accordingly, it is vital to develop a framework based on a specific assessment criteria addressing the maintenance management of assets in passenger terminals both qualitatively and quantitatively in order to benefit future process optimization.

## 2.2. Asset Management

### 2.2.1. Asset Maintenance

Implementing and sustaining the provision of facilities are two different issues but both will create barriers for them when nothing is being done (Awang, Chua, & Ali, 2017). Sustaining is effectively managed through the maintenance. Maintenance the effort in combination with various technical and administrative processes to maintain or reinstate a physical asset to a state where it can perform a required purpose (British

Standard Institution, 1993) as mentioned in Awang, Chua & Ali (2017). Nevertheless, at early stages maintenance of course made a simple impact on the functionality but at present with the technological development its significance has been considerably increased merely as it creates a dilemma to measure the results of investments in maintenance in total economic terms. At the same time, the equipment that is not well maintained and fails periodically tends to produce defects whereas the poorly maintained equipment may lead to more frequent failures, scrap or questionable quality (Awang, Chua, & Ali, 2017) .

Literature suggests that the asset maintenance management consists of three key processes as corrective maintenance, preventive maintenance and predictive maintenance whereas the first covers the maintenance in correcting faults in assets, second covers the programmed maintenance to avert the occurrences of failures and the last covers the improvement of conditions of the assets. Nevertheless, maintenance can be planned (possible to control) or unplanned (breakdowns, emergency repairs etc.) and indirect (condition-based maintenance) or direct (fixed time maintenance). However, out of these key processes, first process is widely addressed in many of the early research works as well as in the existing maintenance practices whereas the latter are poorly addressed although the latter are cost effective, efficient and safe. But that does not define that the preventive/predictive maintenance is the best approach in every time rather it suggests that finding the appropriate strategy that fits each of the assets depends on the understanding of the way of strategy works on the asset management. Literature elaborates that there are a lot of factors (criticality, cost to maintain, cost of downtime, data required, safety risk & required compliance) to consider when deciding and implementing the best plan for an asset while no two assets or operations are the same (Fiix, 2022). Thus, it creates the foundation for a balanced maintenance framework giving performance baselines and benchmarks (Fiix, 2022).

### 2.2.2. Condition Assessment

Modern maintenance management is not merely to repair the assets rather to keep the assets operating at optimum conditions. Yet this real maintenance is impossible without condition assessments. Similar to the stability of a building can be examined through its physical condition as well as the condition of it can determine the performance of the building, assessing the condition of assets is the most efficient technique to identify the performance of the assets. Hence, defining the condition and performance requirements of assets are two main parameters for predictive maintenance of assets. NAMS (2009) defines condition monitoring as a process of assessing an asset's physical status, whereas performance is defined as the capacity to provide the required level of service and can be measured in terms of consistency, accessibility, ability, and meeting customers' demands (Keshavarzrad, 2015).

On the other hand, according to IIMM (2011), condition rating's two key outputs are the determination of an asset's residual life, and consequently its effective life, as well as the review, if necessary, of its maintenance management program in order to optimize the asset's life or accept greater risk (Keshavarzrad, 2015). Hence, condition assessments play a key role in asset maintenance management although there are different types of condition assessment methods depending on the organization policy in terms of their scope and objectives and their defined factors like age, serviceability and maintenance cost etc. However, in most of the cases, assessments are carried out via visual inspections and five-point condition rating system where condition 1 is "very good" and condition 5 is "very poor" and vice versa has been adopted appropriately to the organization. As such, condition assessment criteria identified in literature can be cited as in Table 2.1.

**Table 2.1:** Condition Grading System for Building Assets

| **Element** | **Condition Grade** | | | | |
|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** |
| | **Very good** | **Good** | **Moderate** | **Poor** | **Very poor** |
| Structure | Good structural integrity | Structure with good functionality | Structure is adequate, but there are some signs of foundation movement | The structure is operational, but there are issues due to foundation movement. | The structure has significant issues, and there is concern for the |

| | | | | | |
|---|---|---|---|---|---|
| | | | and minor cracking. | Some noticeable cracking. | structure's integrity. |
| Services | All components are functional and in good condition. | Every component is functional. | Breakdowns or blockages occasionally. Improved maintenance is necessary. | Plumbing, electrical, and mechanical component failures. | MEP components are defective or unsafe. |
| Fittings | Operative, secure, sound in terms of appearance and operation. | Minor wear and tear, operational and functional. | Generally functioning. Minor breakage. | Poor quality and appearance fittings, which are frequently inoperable and damaged. | The majority are damaged or non-operational. |

Source: (International Infrastructure Management Manual – Version 3.0, 2006)

Accordingly, condition evaluation can be related to the deterioration monitoring of assets and can also result in the development of prediction methods by examining deterioration trends and forecasting the future state of assets.

### 2.3. Asset Maintenance Frameworks (Different Models for Predicting Deterioration)

Predictive maintenance aims to foresee equipment failures to schedule corrective maintenance in advance and avoid unexpected equipment downtime thereby improving service quality for the customers (Ruben, Dmitriy, Fabian, & Zhuang, 2014). On the other hand, asset deterioration is a continuous process in which the performance and value of the assets decline over time; however, predicting the precise moment when a quality level drops and, consequently, the time by which a maintenance activity should be carried out has always been difficult due to uncertainties in the parameters of the deterioration process and a lack of reliable information (Berga, Leontaris, Boomen, Spaan, & Wolfert, 2019). However, literature introduced existing methods and techniques that had been developed for predicting the deterioration of assets as summarized in Table 2.2.

**Table 2.2:** Classification of Deterioration Models

| Predictive Model | Deterministic | Statistical | Artificial Intelligence |
|---|---|---|---|
| **Techniques** | ▪ Straight-line extrapolation<br>▪ Regression<br>▪ Curve fitting | ▪ Markov chain<br>▪ Ordinal regression<br>▪ Linear discriminant<br>▪ Gamma process<br>▪ Time-dependent reliability | ▪ Artificial neutral networks<br>▪ Fuzzy set theory<br>▪ Case-based reasoning |

Source: (Mohseni, Setunge, Zhang, & Wakefield, 2017)

According to Dasu and Johnson (2003) deterministic models and statistical models, whose structures are established by experts, are regarded as model-driven approaches, whereas artificial intelligence-based models, whose structures are determined by sample data, are considered as data-driven approaches (Mohseni, Setunge, Zhang, & Wakefield, 2017). However, out of the above models, deterministic model based on condition data and fixed deterioration curves is still frequently used in the industry without considering the uncertainties of the deterioration process such that the budget allocations represent deviations in the maintenance costs of the assets. On the other hand, stochastic modelling uses random variables to represent the asset degradation over time although a small change in the input variables results in a significant difference in the output whereas artificial intelligence models use long-term historical condition data to identify relationships between input and output based on data input (Berga, Leontaris, Boomen, Spaan, & Wolfert, 2019).

Considering the techniques, most research have used the multiple regression analysis which gives the relationship between the variables with the assumption that the relationship remains unchanged. However, the assumption may not always hold correct and might lead to erroneous results. Further, in developing predicting model on the basis of regression analysis, it is required to gather limited predictor variables and the relevant data for validation purposes. Conversely, literature also elaborates that the regression models forecast better than moving averages, exponential smoothing, or auto-regressive models for medium to long-term forecasting (Lee, Chung, & Oh, 2004). Similarly, studies have used some other techniques like Bayesian analysis, extrapolation, trend forecasting and curve fitting in developing the deterioration models although each of them have both pros and cons depending on the data availability. Accordingly, Bayesian analysis models' inference process can take certain time and it is not worthwhile if there are more data accessible for the dataset, and the regular probability approach does the task more effectively whereas extrapolation does not account for qualitative values in the sense values can be unreliable and can be affected by significant fluctuations when there are disparities in the data sets such that it can trigger changes in future values.

However considering the limitations and the accuracy level of different models, Tran (2007) asserts that a Markov model calibrated using various advanced techniques such as genetic algorithms (GAs) and Bayesian Markov chain Monte Carlo (MCMC) can be applied to infrastructure assets to improve the accuracy of deterioration models' predictions while considering the subjectivity and lack of sample data as well as the probabilistic nature of the deterioration process and it is a more comprehensive and accurate method for forecasting future conditions of the infrastructure assets (Mohseni, Setunge, Zhang, & Wakefield, 2017). Literature elaborated the advantages of using Markov Chain for prediction in terms of its ability to overcome uncertainties, ease of calibration using discrete condition data, comparatively accurate results depending on the present condition and ease of use for the maintenance budget plans. Further, Markov Chain has been mostly used to predict the condition of bridges, pavements, storm water piping components, hydraulic structures and fault occurrences of transformers (Yahaya, et al., 2018).

### 2.3.1. Markov Chain Modeling

A Markov Chain is a probabilistic model which determines the future condition depending only on the present condition data whereas in a discrete time Markov Chain is one which the random variables are observed at discrete points in time causing the Markov Chain to be subjected to a finite-state stochastic process that passes through a series of phases at those discrete points in time with fixed probabilities (Mohseni, Setunge, Zhang, & Wakefield, 2017).

However, main assumptions of the Markov Chain can be listed as follows. (Solanki, 2022)

1. All possible states of a stochastic system is finite
2. The variables change from one state to another, and the probability of transitioning from a given state is determined solely by the system's current state, not the state reached
3. States are mutually exclusive as well as collectively exhaustive
4. The probabilities of reaching different states from any given state are measurable and stable over time (i.e., throughout the operation of the system) The transition probabilities to alternative states in the next period, given a state in the current time period must sum to 1.0. Even the transition matrix remains stationery with time

Accordingly, initial step of Markov Chain modelling is the condition evaluation whereas a typical condition rating scale can be presented as in below Table 2.3.

**Table 2.3:** Typical Condition Rating Scale

| **Rating** | **Component Condition** | **Condition Description** |
|---|---|---|
| 1 | Very Good | The component is brand-new |
| 2 | Good | The component is sound; only minor deterioration, only minor maintenance is necessary |
| 3 | Moderate | Moderate damage necessitates moderate maintenance |
| 4 | Poor | Significant damage necessitates extensive repair |
| 5 | Very Poor | Significant damage; element needs to be replaced |

Source: (Mohseni, Setunge, Zhang, & Wakefield, 2017)

Based on this condition evaluation of states, initial distribution matrix and transient probabilities are determined, and the discrete Markov Chain principle is applied as elaborated below (Mohseni, Setunge, Zhang, & Wakefield, 2017).

If an element is in state i, there is a fixed probability of $P_{ij}$ of transferring to state j after the next time step, $P_{ij}$ which is called the transition probability. The matrix P whose ij th entry is called the transition matrix, In a Markov Chain, $P_{ij}$ should satisfy the following two conditions:

$P_{ij} \geq 0,$ where i = present state at time t; $X_t = 1$; and

$\sum P_{ij} \leq 1$ j = next state at time t + 1; $X_{t+1} = j$

This means that if an element is in state i, there is a $P_{ii}$ probability that this element will stay in state i, and $(1 - P_{ii})$ that it will move to the next state j.

The conditional probability statement of Markovian Property:

$Pr\{X_{t+1} = j \mid X_0 = k_0, X_1 = k_1, \ldots, X_t = i\} = Pr\{X_{t+1} = j \mid X_t = i\}$

Discrete time means $t \varepsilon T = \{0, 1, 2, \ldots\}$.

A typical transition matrix developed for five-point condition rating scale (presented in Table 2.3) with the associated transient probability curves and the expected deterioration curve are illustrated in Figure 2.1.

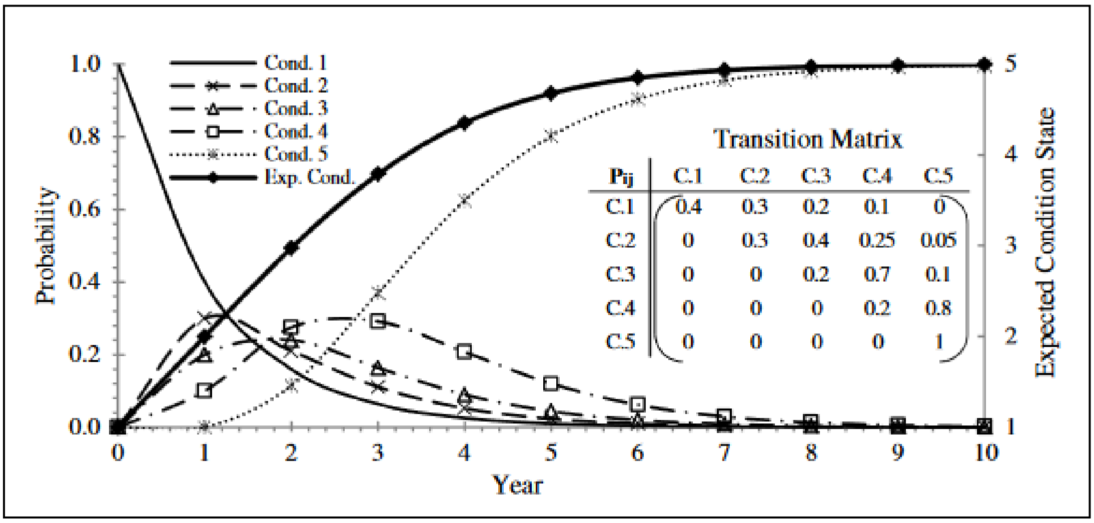



**Figure 2.1:** Transition Matrix and Transient Probabilities

Source: (Mohseni, Setunge, Zhang, & Wakefield, 2017)

An initial distribution matrix ‘v’ is a single row matrix representing the number of elements in each state. In a Markov Chain after one time step, the new distribution will be the product of the initial distribution ‘v’ and the transition matrix ‘P’.

Distribution after step 1 : vP

The distribution one step later, obtained by again multiplying by P, is given by,

$$(vP)P = vP^2$$

Similarly, the distribution after n steps will be $vP^n$ , where $P^n$ is the n-step transition matrix. This means that the ij th entry in $P^n$ is the probability that the system will pass from state i to state j in n steps.

Also, the expected condition of assets ($y' = \alpha_t \times C$) at discrete time intervals can be derived by the multiplication of condition at that time ($\alpha_t$) by the condition matrix (C = [ 1 2 3 4 5 ]) (Keshavarzrad, 2015).

In addition, asset overall performance (S) or the transient probabilities of a building component after being subjected to maintenance can be computed by Equation (1) given below (Keshavarzrad, 2015).

$$S = r * (M*P)^n \tag{1}$$

Where, r = Initial condition state vector

n = Time step (1,2,3,…,n)

M = Maintenance policy matrix (Denotes the transition probabilities that move to a better condition)

P = Transition matrix of normal deterioration (Denotes the transition probabilities that move to a worse condition)

### 2.4. Cost Prediction Methods

Prediction of maintenance cost is a demanding necessity of many of the organizations since it manages the budget allocations. Since a holistic approach needs to be applied for the prediction of maintenance costs since this cannot determine the exact future costs such that the estimated/projected cost may have variations to a certain degree. Hence, it is necessary to incorporate the lifecycle cost data (combination of capital investments, operations and maintenance costs, renewals and upgrading and demolition cost), useful life of assets and their maintenance records to improve the accuracy of the predictions whereas this can decide in when it is most cost-effective to take on the capital costs necessary for the asset’s repair or replacement (GE Digital, 2022). Performance comparison analysis whether it is better to replace an asset within a 15-year lifespan proactively at 5-year intervals, once at 10-years or to operate the asset until it reaches the end of its lifespan can be cited as an example (GE Digital, 2022).

However, literature introduced that the Markov Chain can be adopted for the cost projection of assets by developing a new transition matrix (M*P) to represent the effect of maintenance actions (i.e., routine monitoring, minor repair, major repair or a replacement) since it was challenging to find detailed information into the general maintenance policy (Yahaya, et al., 2018). The maintenance cost (repair/replacement) depends on different factors such as level of service, intervention criteria and discounted cashflow of costs etc. Accordingly, the estimated cost/ cost breakdown ($C_n$) illustrated in Table 2.4 had been sourced from the historical records of the organization.

**Table 2.4:** Transformers: Maintenance Procedures, Intervention Condition, and Cost Estimation Breakdown

| Maintenance Action | Intervention State | Activity | Estimated Cost (RM) |
|---|---|---|---|
| Condition assessment | 5,4,3,2,1 | Annual routine monitoring | 49,500.00 |
| Minor work | 2 | Oil regeneration + major parts restoration | 30% from new unit |
| Major work | 1 | Replacement | 1,700,000.00 |

Source: (Yahaya, et al., 2018)

Accordingly, expected maintenance cost can be calculated using the Equation (2) (Yahaya, et al., 2018).

$$\text{Expected Cost} = r * (M*P)^n * C_n \qquad (2)$$

Where, $C_n$ = Pre-defined maintenance cost associated with the asset condition

Note:

- For the total expected cost, the value obtained through the above equation had been multiplied by the number of assets at the particular condition (elaborated in Chapter 3)
- Combined effect of normal deterioration matrix and maintenance matrix had been considered for the determination of cost predictions since it reflects the overall performance of the asset

## 2.5. Disaster Assessment Methods

According to UNISDR (2017), disaster as a serious interruption of the community or the society's ability to function at any scale as a result of hazardous events interacting with exposure, vulnerability, and capacity conditions, leading to one or more of the following impacts and losses: human, material, economic, and environmental. On the other hand, disasters can be natural or man-made whereas passenger terminals are subjected to both categories of disasters.

Similarly, literature suggests the disaster risk as a function of the likelihood of a natural hazard of varying intensity occurring in a specific location, the number of people and physical assets located there and thus exposed to the natural hazard, and the degree of vulnerability of those exposed people and physical assets to the natural hazard (ADB, 2017). Out of these aspects, vulnerability and exposure held a significant place with adhered to the asset management since the vulnerability can raise risk even from even from very minor natural catastrophes (ADB, 2017). In the sense, if exposure and vulnerability are high, low levels of hazard intensity do not always imply low levels of risk (ADB, 2017). A severe earthquake that occurs in an area that is not populated is not disastrous, but a weak earthquake that occurs in a region with structures that are not earthquake-resistant causing great misery can be cited as an example (Kohler, Jülich, & Bloemertz, 2004).

However, typical risk assessment includes following key steps (Simmons, 2017).

1. Identify the hazards affecting the system or environment. It is important to consider the cascading events of hazards that might happen.
2. Assess the likelihood or probability of occurrence of hazards. For instance, return periods can be defined for variety of hazards but they cannot be calculated for events with a higher degree of randomness such as terrorist attacks, since information such as intent and opportunity, economic and social trends and threat analysis can be used to assess their plausibility (G20/OECD, 2012). Additionally, in reality, events with very low probabilities are disregarded in favor of those that are more likely to take place and may be managed, averted, or reduced (Simmons, 2017).
3. Determination of exposure to the hazard.
4. Assess the vulnerability of the hazard to the entity exposed.

5. Estimate the potential economic/social consequences of events of different magnitudes.

According to the early findings, disaster assessments can be carried out as pre-event risk assessments and post-event damage estimation and damage can be expressed as physical damage and/or monetary costs of repair/rehabilitation in terms of asset maintenance management. Hazard, exposure, and vulnerability are the elements that must be assessed and merged in the pre-event assessment case in order to provide a risk assessment. The estimated damage must be detailed in the post-event study based on the observed hazard characteristics, the configuration of exposed systems, and their susceptibility at the time of the occurrence, as outlined in Figure 2.2. Considering the integration of asset management with the disaster management, assets and disasters get connected with the preparedness of risks on assets and the repair/rehabilitation damage of assets due to disasters. Hence, as in Figure 2.2 assessment method can be developed under two aspects as quantifying the risk before disasters and quantifying the damage after disasters.

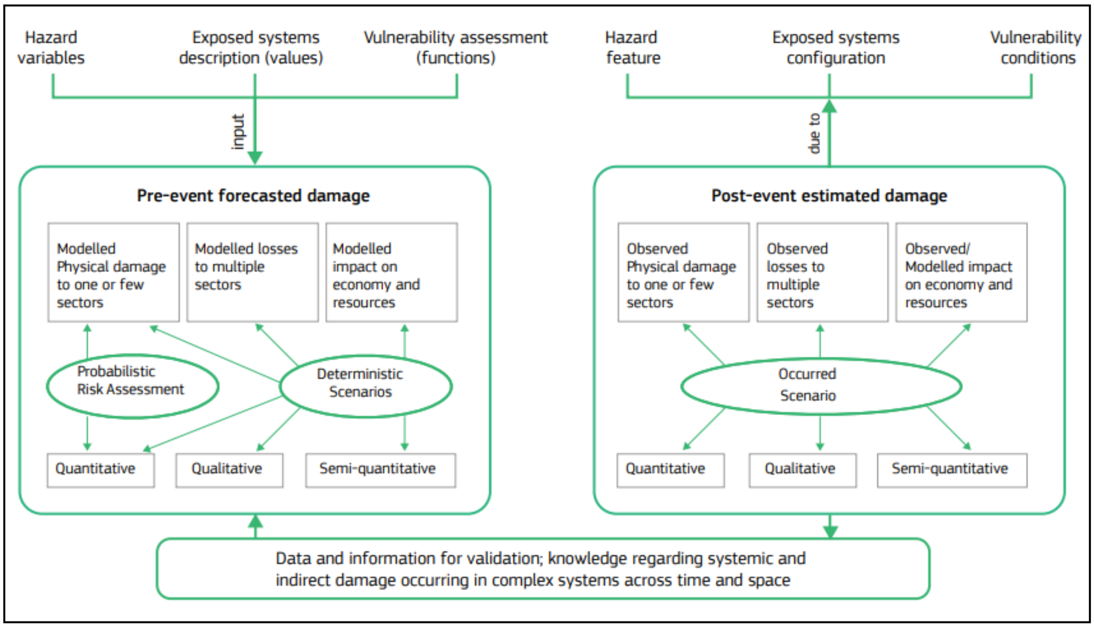



**Figure 2.2:** Pre - and Post - Disaster Damage Assessments

Source: (Simmons, 2017)

### 2.5.1. Pre-Disaster Assessment Methods

Pre-assessments allow to determine the which hazards will occur, their vulnerability, what assets will get affected and to what extent the assets will get affected thereby to adopt measures to control, reduce or eliminate the risks. Literature defined a quantitative risk rating (an empirical method) which simply determined whether the risk is minor, moderate, or severe (The Health and Safety Consultancy, 2022). Here, a 4-rating scale had been used and the multiplication of likelihood, severity of injury and the frequency of exposure resulted the risk rating value on which the control measures had been interpreted as in Table 2.5.

According to the defined scale,

A Most Unlikely Event [1] x Minor Injuries if event occurs [1] x Irregular [1] =

Risk Rating of [1] Minimal Risk (1x1x1=1)

An Inevitable Event [4] x Major Injuries if event occurs [4] x Irregular [4] =

Risk Rating of [64] High Risk (4x4x4=64)

**Table 2.5:** Empirical Risk Rating with Control Measures

| Rating Scale | Risk Rating | | | Control Measures |
|---|---|---|---|---|
| | **Likelihood** | **Severity of Injury** | **Frequency** | |
| 1 | Unlikely | Minor Injuries | Irregular | (1-3) Minimal Risk – Maintain Existing Measures |
| 2 | Feasible | Serious Injuries | Occasional | (4-12) Low Risk – Review Measures |
| 3 | Probable | Major Injuries | Frequent | (13-27) Medium Risk – Improve Measures |
| 4 | Inevitable | Death | Continuous | (28+) High Risk – Improve Measures Consider Stopping Work |

Source: (The Health and Safety Consultancy, 2022)

Further, early findings introduced a pre-disaster assessment carried out to identify the potential hazards that a university encounter and to assess the level of vulnerability to those potential hazards (Washington, 2022). Accordingly, pre-assessment had been carried out through the calculation of the relative risk score for each hazard in cooperating the likelihood of occurrence and the severity of the impact as summarized in Figure 2.3 (Washington, 2022). However, this method had in cooperated the response of the students (through questionnaire) in quantifying the probabilities.

| | | SEVERITY = MAGNITUDE OF IMPACTS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| THREAT EVENT/ HAZARD | PROBABILITY | HUMAN IMPACT | | FACILITIES IMPACT | | INSTITUTIONAL IMPACT | | SEVERITY IMPACTS | UNMITIGATED RISK | PREPAREDNESS | RELATIVE RISK |
| | Relative likelihood this will occur | Potential deaths or injuries | | Physical damage and costs | | Interruption research & teaching Impact reputation/image | | Overall Impact (Average) | Probability x Severity Impacts | Level of Preparedness | Unmitigated Risk/Preparedness |
| Natural Hazards Technological Human Terrorism | 1 = Not occur<br>2 = Doubtful<br>3 = Possible<br>4 = Probable<br>5 = Inevitable | Question 1 | Question 2 | Question 1 | Question 2 | Question 1 | Question 2 | 1 = Lowest<br>5 = Highest | 1 = Lowest<br>25 = Highest | 1 = None<br>2 = Poor<br>3 = Fair<br>4 = Good<br>5 = Prepared | |
| **Animal/Crop Eco-terrorism** | 3.2 | 1.4 | 2.5 | 3 | 2.3 | 2.9 | 1.4 | **2.25** | **7.2** | 2 | 3.6 |
| **Workplace Violence** | 4.4 | 3.4 | 4.3 | 1.4 | 1.1 | 1.4 | 3.7 | **2.55** | **11.22** | 3 | 3.74 |

**Figure 2.3:** Hazard Evaluation Example

Example explanation (Washington, 2022):

**Threat:** Animal/Crop Eco-terrorism **Probability** – 3.2

1. To calculate the possibility, you will need to tally all of the responses in the following way:

   10 participants rate it as 3 —30 points

   2 participants rate it as 4 —8 points

   Total score is 38 of 12 participants, 38/12 = 3.17 ~ 3.2

2. To calculate the **Severity,** take the average of the Severity impact scores.

$$(1.4+2.5+3.0+2.3+2.9+1.4)/6=2.25$$

3. To calculate the **Unmitigated Risk,** take the probability and multiply it by the Severity.

$$3.2*2.25=7.2$$

4. To calculate **Relative Risk**, take the unmitigated risk and divide it by the level of preparedness.

$$7.2/2= 3.6$$

Accordingly, it summarized that the workplace violence is a greater relative risk to the university.

It is evident that the pre-disaster assessments are mostly based on the past records of the hazards, but it is important to account for the hazards that may occur in the future except to the past records since past records do not usually provide complete temporal and spatial information about the hazards and the detailed records of the consequences (Mauro, 2014).

### 2.5.2. Post-Disaster Assessment Methods

Post-disaster assessments deals with the degree of damage of elements at risk. According to literature, asset damage can be determined by multiplying the asset value by the fraction of assets with hazard-related damage (Taguchi, Tanoue, Yamazaki, & Hirabayashi, 2022) whereas the fraction of damaged asset varies with different number of factors of both the asset and the hazard. Damage to the assets from flooding varies with flood type (i.e., riverine flooding, flashflood), velocity, flood height and duration of the flood as well as with the characteristics of the asset age, maintenance, height, floor space, volume, proximity to other assets and proximity to hazard source etc. Poor maintenance weakens the asset condition increasing its vulnerability to disasters and at the same time fast flowing floods increase the impact on the asset can be cited as an example. On the other hand, asset damage estimation can be a repair/replacement cost due to disasters or a rehabilitation cost due to tremors or cascading events of the disasters which needs to be considered accordingly.

Nevertheless in overall, literature introduces asset tracking software for disaster management, an automated solution that helps emergency bodies minimize damage through streamlined tracking of mission critical assets whereas EZOfficeInventory is the most effective asset tracking software used by many international emergency and relief services (ezofficeinventory, 2022). Accordingly, this software helps in all the phases of disaster management especially reducing the response time. Also, by tracking available inventory through the software, admins can easily update records and place purchase requests for replacements within time whereas considering the fund accountability to ensure transparency of grants, emergency management facilities can run custom reports to track information like grant dates and corresponding asset acquisition details and manage the reporting as well (ezofficeinventory, 2022).

### 2.6. Optimizations of the Processes

Whatever the predicting methodology/technique used for developing the models, optimization of it matters the most since it explores the maximum potential of the assets throughout the lifecycle. Accordingly, specific degradation curves can be developed with the historical asset records and the present performance conditions of the assets that can be used to predict asset renewals. Additionally, the model's outputs can be interactively investigated by the company's asset managers, planners, managers, and executives through user-friendly dashboards, while the capabilities of hypothetical scenario modeling allow users to test tactics and see the impact in real time before arresting (deloitte, 2022). Further optimization is significant in risk-based decision making of the asset maintenance whether it is the negotiation between asset maintenance and use, capital investment and operational costs, or short-term gains and sustainability (SEM, 2014). Consequently, analysis of these will demonstrate the impact of various strategies, such as carrying out the minimum amount of works necessary to ensure the asset reaches its intended target life and delaying unnecessary work on both the expenditure in any given year and the costed impacts of different strategies (Robery, 2014).

On the other hand, transition matrix is the decisive factor which determines the accuracy of the predictions in developing the Markov Chain. Hence, literature introduces several techniques that could be used to calibrate a transition matrix, including the direct absolute value difference method (ABS method), percentage prediction method, Poisson distribution, negative binomial distribution and combination of incremental model and ordered probity model (Keshavarzrad, 2015). Out of these techniques, direct absolute value difference method had been used in many of the early findings as the optimization technique for transition matrix which had offered better accurate prediction results with the use of genetic algorithm convergence method (GA method). Optimization done using ABS method can be illustrated in Figure 2.4 with compared to the use of GA method as illustrated in Figure 2.5 which further depicts a significant deviation of expected condition state (Mohseni, Setunge, Zhang, & Wakefield, 2017).

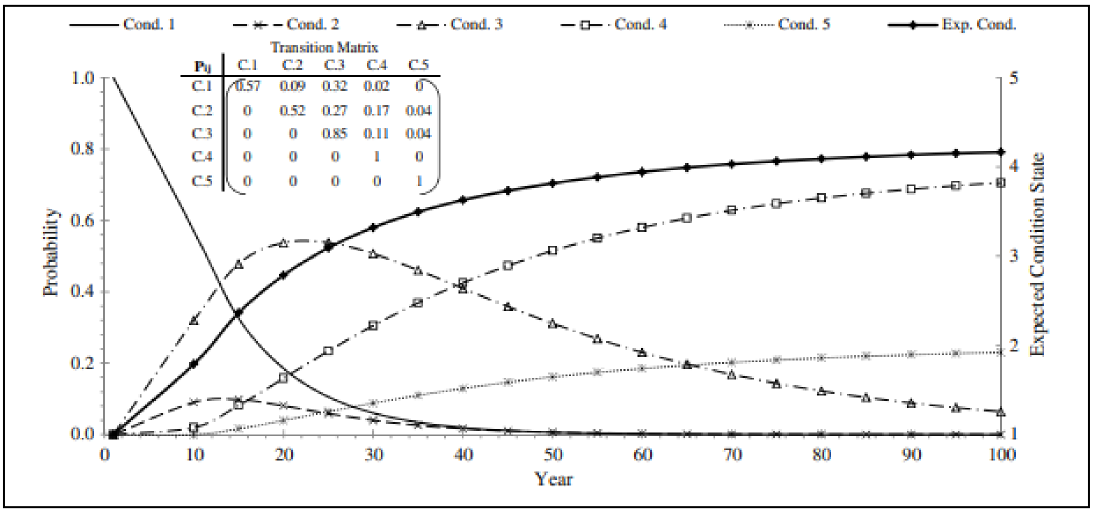



**Figure 2.4:** Markovian Properties: Superstructure (GA Method)

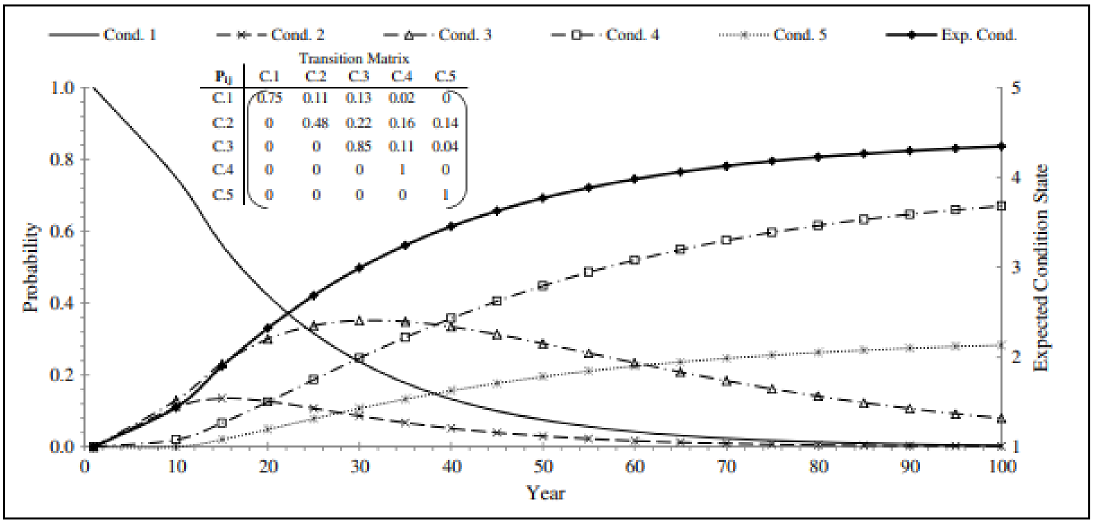



**Figure 2.5:** Markovian Properties: Superstructure (ABS Method)

## 2.7. Summary

Predictive maintenance is the compliment of preventive maintenance whereas the condition assessments makes the foundation for the maintenance management of assets. Nevertheless, effective maintenance programme depends on the asset history, reliability engineering with predictive/preventive maintenance and quality assurance. On the other hand, disasters too affect the assets whether it is natural or man-made such that the risk assessment is required to in cooperate with asset maintenance. At the same time balance between the asset maintenance and disaster management have a significant impact on the lifecycle costing of assets whether it is a repairing cost or replacement cost or any consequence cost resulting from failures due to disasters. However, according to the above-mentioned early research works in worldwide it is evident that there are different methodologies and techniques as well as monitoring techniques that have adopted in developing maintenance frameworks, cost modelling and managing risk assessments. But not any of the considerable research work has been carried out focusing the passenger terminals especially integrating the asset maintenance with disaster management in local context. Yet these approaches have certain limitations considering the availability of data. Therefore, the methodology and techniques for this study was chosen with respect to those constraints as elaborated in the subsequent chapters.

# 3. RESEARCH METHODOLOGY

## 3.1. Introduction

This chapter outlines the methodological framework used to proceed this study. The methodology including the literature review, data collection and assessment method are elaborated in this chapter.

The methodology for achieving research objectives includes following steps.

1. **Literature review:** A comprehensive evaluation of the literature was carried out by referring to database-accessible journal articles, books, conference papers, web publications, and the thesis. The review identified existing frameworks and database systems developed in several disciplines.
2. **Selecting a case study:** KMTT was selected as the case study for this research.
3. **Data collection:** Since KMTT was selected as the case study for this research, inventory records of this terminal were collected, and the condition assessments were carried out accordingly during the field surveys. **AMS** available in the department was used as the tool for data collecting and recording.
4. **Development of assessment framework:** Assessment framework for predictive maintenance in cooperating the lifecycle costing of assets integrated with disaster management was developed based on the condition evaluation results.
5. **Optimization of the processes:** Maximum potential of the assets throughout the lifecycle will be identified for further optimizations of the framework.

## 3.2. Field Survey: Data Collection

### 3.2.1. Preliminary Field Work

During the preliminary visit of the KMTT, asset inventory records and other relevant details such as ownership and operations, existing maintenance practices/records, and passenger satisfactions with respect to the available services and also, the potential disasters affected to the terminal and any records of them were collected.

These records covers the assets (from building structure up to the building services) of the Bogambara terminal (Main bus area, Kandy office) and Kandy roadside terminals (Bandaranayake Mawatha, Clock tower terminal, Kachcheriya Front, Central Market, Udunuwara Mawatha, Dhammananda Mawatha and Torrington terminal). Since AMS was used as the tool for data collecting and recording, asset data and location data gathered through the inventory records of the Bogambara terminal and Kandy office were entered via excel sheets (.csv format) into the database altogether at once as in Figure 3.1. However, if any of the asset records were noticed either as an additional or not entered, those were edited during secondary site visits.

| AssetID | SubCatID | AssetModID | AssetCode | odeof | alNum | DescriptionShort | DescriptionLong | ssetphot | ataloc | UserID | aEntryTime | LocationID | Location | Category | Subcategory |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 977 | 313 | 219 | PR-WT01 | | 1 | Water Tank 01 - Pump Room | Water Tank 01 - Pump Room | | 0 | 16 | 0000-00-00 00:00 | 70 | Bogambara Terminal Pump Room | | Water Tanks |
| 978 | 314 | 263 | GSH-DB01 | | 1 | Distribution Board 01 - Grocery Shop | Distribution Board 01 - Grocery Shop | | 0 | 16 | 0000-00-00 00:00 | 61 | Bogambara Terminal Shop | | Distribution Board |
| 979 | 316 | 262 | BT-SLSB01 | | 1 | Street Lamp Switch Breaker 01 - Bus Terminal | Street Lamp Switch Breaker 01 - Bus Terminal | | 0 | 16 | 0000-00-00 00:00 | 52 | Bogambara Terminal Bus Bays | | Street Lamp Switch Breakers |
| 980 | 316 | 262 | BT-SLSB02 | | 2 | Street Lamp Switch Breaker 02 - Bus Terminal | Street Lamp Switch Breaker 02 - Bus Terminal | | 0 | 16 | 0000-00-00 00:00 | 52 | Bogambara Terminal Bus Bays | | Street Lamp Switch Breakers |
| 981 | 316 | 262 | BT-SLSB03 | | 3 | Street Lamp Switch Breaker 03 - Bus Terminal | Street Lamp Switch Breaker 03 - Bus Terminal | | 0 | 16 | 0000-00-00 00:00 | 52 | Bogambara Terminal Bus Bays | | Street Lamp Switch Breakers |
| 982 | 316 | 262 | BT-SLSB04 | | 4 | Street Lamp Switch Breaker 04 - Bus Terminal | Street Lamp Switch Breaker 04 - Bus Terminal | | 0 | 16 | 0000-00-00 00:00 | 52 | Bogambara Terminal Bus Bays | | Street Lamp Switch Breakers |
| 983 | 282 | 252 | OFF-CEFA01 | | 1 | Ceiling Fan 01 -PTSA Office Building | Ceiling Fan 01 -PTSA Office Building | | 0 | 16 | 0000-00-00 00:00 | 46 | Kandy office | | Ceiling Fans |
| 984 | 282 | 252 | OFF-CEFA02 | | 2 | Ceiling Fan 02 -PTSA Office Building | Ceiling Fan 02 -PTSA Office Building | | 0 | 16 | 0000-00-00 00:00 | 46 | Kandy office | | Ceiling Fans |
| 985 | 282 | 252 | OFF-CEFA03 | | 3 | Ceiling Fan 03 -PTSA Office Building | Ceiling Fan 03 -PTSA Office Building | | 0 | 16 | 0000-00-00 00:00 | 46 | Kandy office | | Ceiling Fans |
| 986 | 282 | 252 | OFF-CEFA04 | | 4 | Ceiling Fan 04 -PTSA Office Building | Ceiling Fan 04 -PTSA Office Building | | 0 | 16 | 0000-00-00 00:00 | 46 | Kandy office | | Ceiling Fans |
| 987 | 282 | 252 | OFF-CEFA05 | | 5 | Ceiling Fan 05 -PTSA Office Building | Ceiling Fan 05 -PTSA Office Building | | 0 | 16 | 0000-00-00 00:00 | 46 | Kandy office | | Ceiling Fans |
| 988 | 282 | 252 | OFF-CEFA06 | | 6 | Ceiling Fan 06 -PTSA Office Building | Ceiling Fan 06 -PTSA Office Building | | 0 | 16 | 0000-00-00 00:00 | 46 | Kandy office | | Ceiling Fans |
| 989 | 323 | 268 | OFF-WALA01 | | 1 | Wall Lamp 01 -PTSA Office Building | Wall Lamp 01 -PTSA Office Building | | 0 | 16 | 0000-00-00 00:00 | 46 | Kandy office | | Wall Lamps |
| 990 | 323 | 268 | OFF-WALA02 | | 2 | Wall Lamp 02 -PTSA Office Building | Wall Lamp 02 -PTSA Office Building | | 0 | 16 | 0000-00-00 00:00 | 46 | Kandy office | | Wall Lamps |
| 991 | 323 | 268 | OFF-WALA03 | | 3 | Wall Lamp 03 -PTSA Office Building | Wall Lamp 03 -PTSA Office Building | | 0 | 16 | 0000-00-00 00:00 | 46 | Kandy office | | Wall Lamps |

**Figure 3.1:** Sample Excel Data Sheet

Also, physical and performance conditions of the assets were predefined prior to assess the existing conditions of the assets during secondary visits as in Table 3.1 and Table 3.2 respectively. Since some assets may have more than one condition variables weightages were defined to each condition variable based on the frequency of the issues related to assets addressed in the literature (Ahluwalia, A framework for efficient condition assessment of the building infrastructure, 2008) as in Table 3.3.

**Table 3.1:** Asset Physical Condition Ranking – Sanitary Fittings

| Condition Variable | Rating | Condition Description |
|---|---|---|
| Physical condition | 1 | As new |
| | 2 | Few scratches and discoloration |
| | 3 | Moderate damages |
| | 4 | Lot of physical conditions |
| | 5 | Cannot use |

**Table 3.2:** Asset Performance Condition Ranking – Sanitary Fittings

| Condition Variable | Rating | Condition Description |
|---|---|---|
| User acceptability | 1 | Very good |
| | 2 | Good |
| | 3 | Acceptable |
| | 4 | Not acceptable |
| | 5 | Unable to use |

**Table 3.3:** Assigned Weightages of Performance Condition Variables – Sanitary Fittings

| Performance Condition Variable | Assigned Weightages |
|---|---|
| User acceptability | 0.4 |
| Item smell performance | 0.3 |
| Water service performance | 0.3 |

Similar to the entering of asset data, physical conditions and performance conditions (with the condition rankings) of the asset categories were defined and were assigned to asset subcategories as in Figure 3.2 and Figure 3.3 and similar procedure was carried out in assigning the physical conditions of the assets.

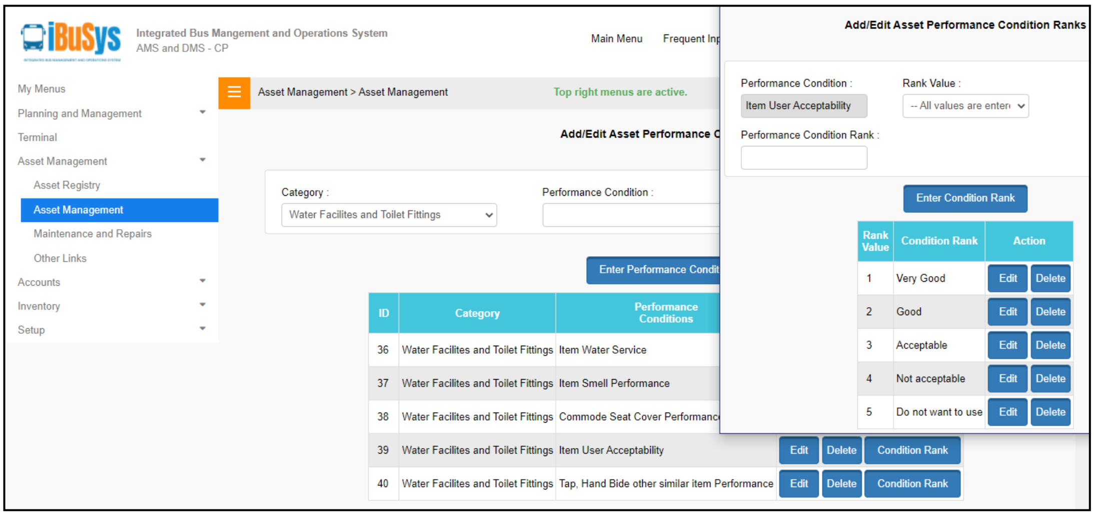



**Figure 3.2:** Condition Ranking of the Asset Subcategories

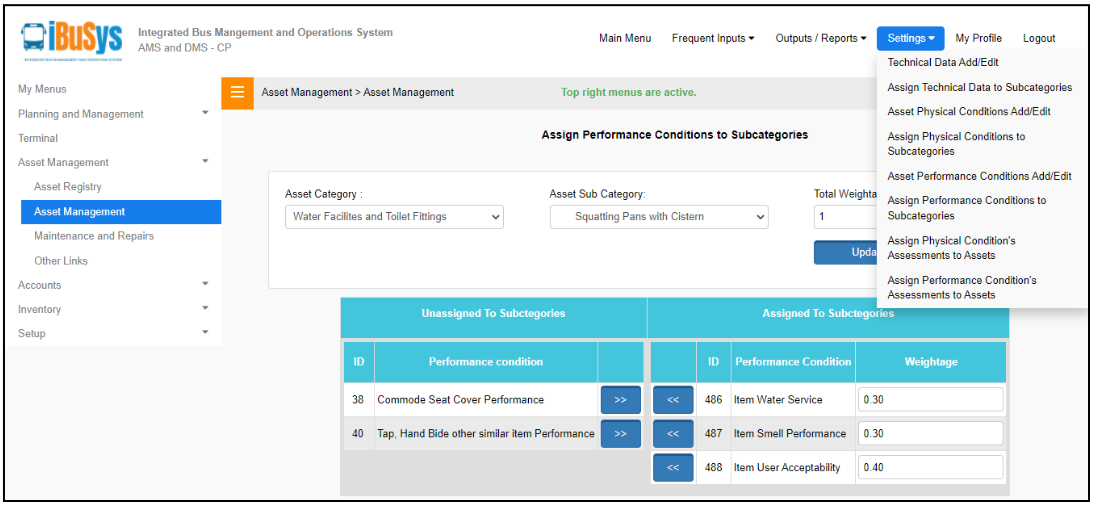



**Figure 3.3:** Assigned Performance Conditions to Asset Subcategories

### 3.2.2. Secondary Field Works

During the secondary site visits, almost all the asset data were collected, and the condition evaluations were completed by assessing their physical and performance conditions. Considering the literature findings, **visual inspection** was the suitable monitoring technique to perform condition assessments of building assets considering the components associated with them. Accordingly, visual examinations were carried out using tablets (7” & 10”) in which the photographs of each asset as well as the photographs depicting their existing conditions so as to apt with predefined conditions were taken and uploaded to the database at the same time. In parallel, both physical and performance conditions were ranked respectively. Photographs were uploaded through ‘frequent inputs’ under asset registry as in Figure 3.4.

Condition ranking was done through ‘frequent inputs’ under asset management as in Figure 3.5 and Figure 3.6. If the asset ranking is greater than one, repair needed was ticked and noteworthy defects/damages were noted down for further clarifications of the asset maintenance. Criticality which gives the priority rating of the assets need to be repaired, was also evaluated at this step as in Figure 3.7.

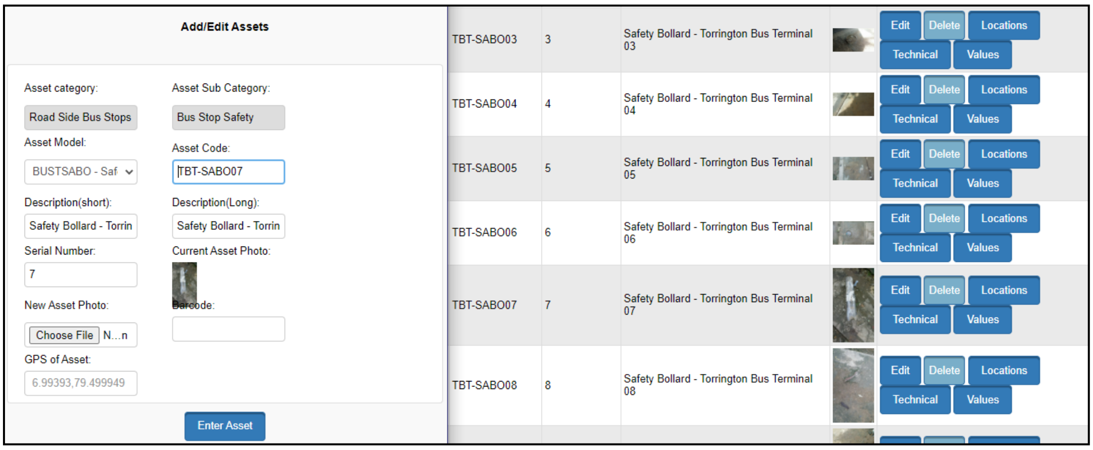



**Figure 3.4:** Add/Edit Asset through "frequent option" of Asset Registry

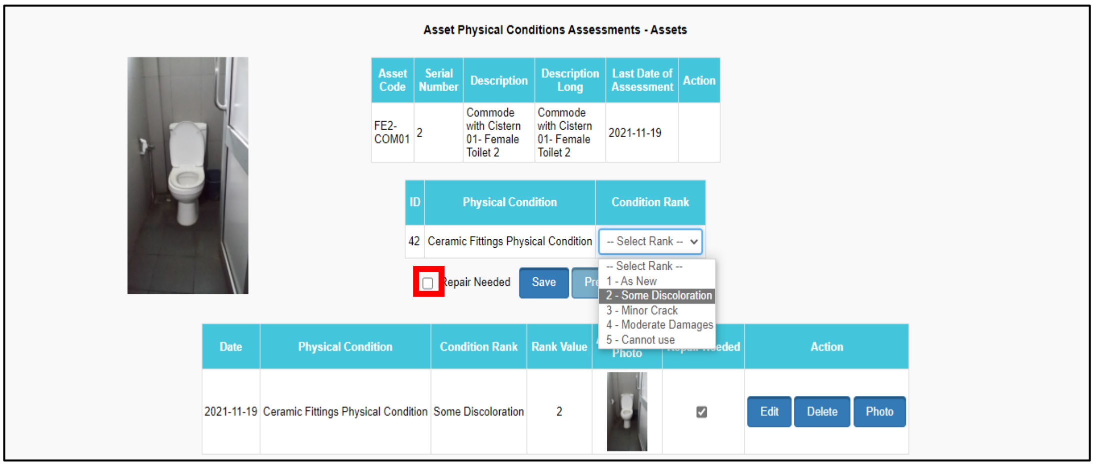



**Figure 3.5:** Physical Condition Assessment of the Sanitary Fitting

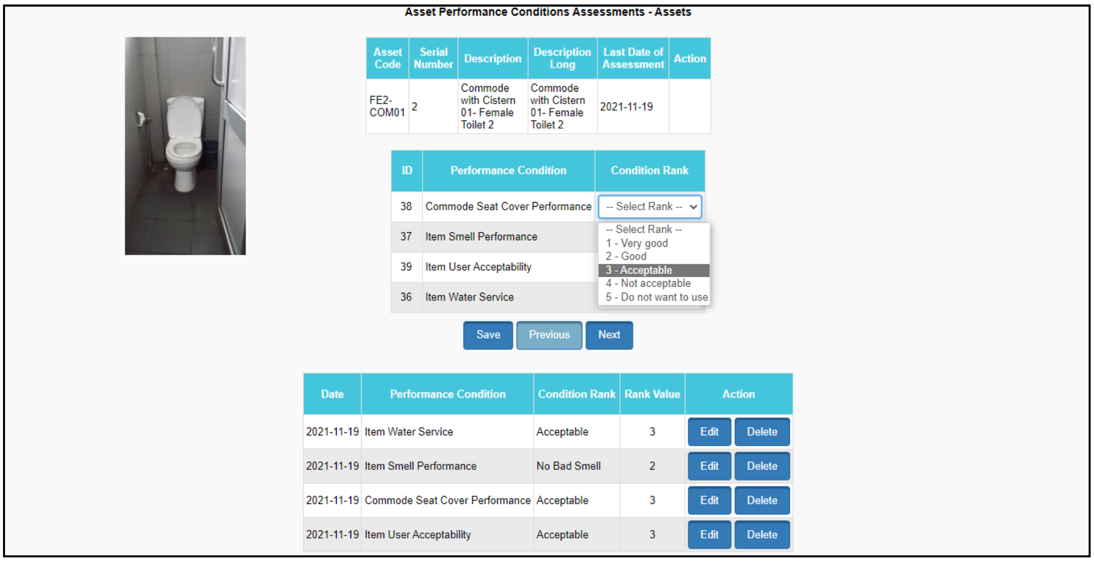



**Figure 3.6:** Performance Condition Assessment of the Sanitary Fitting

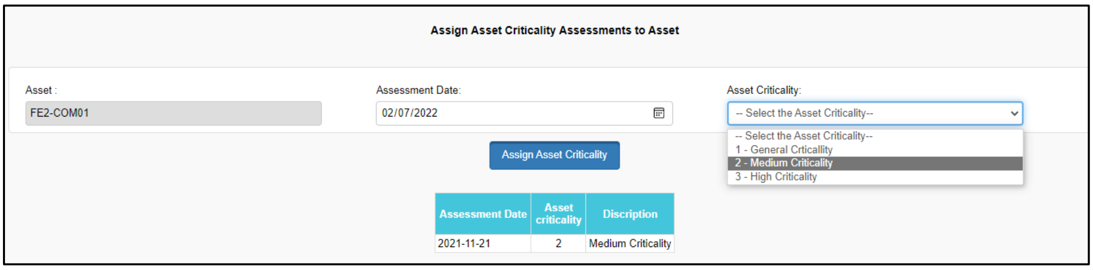



**Figure 3.7:** Criticality Assessment of Sanitary Fitting

This whole procedure was continued for all the assets in all the selected locations mentioned earlier. Correspondingly, feedback of the timekeepers and the passengers were involved for the asset condition evaluation mechanisms. Further asset maintenance data included in the maintenance contracts were collected yet a very few such contracts were available there.

In addition, according to the details gathered and observations made, terminals have not been subjected to any potential disasters except the thunder showers and storms. Also, no vandalism due to protest or explosions has been recorded and no such mechanism has been adapted for such circumstances that may occur in the future.

### 3.3. Assessment Method

Although literature introduced different methodologies and techniques for the development of predictive maintenance frameworks, this framework was developed by means of the **hybrid of both knowledge-based approach and model-driven approach** which used the experience and the judgments of the experts and probability theories to develop deterioration curves respectively. This approach was selected based on the data collection since most of other approaches demand more historical data for the simulations. Under such conditions, it will be necessary to utilize the judgement of the experienced engineers or use standard curves to make a first cut estimate of the deterioration curve such that these first cuts then provide a framework for collecting future data upon which to improve the reliability of the models (International Infrastructure Management Manual, 2006). Accordingly, the **Markov chain** (reviewed in chapter 2) with a stochastic approach was used incorporating the condition data and expert judgements to develop more convincing deterioration curves for realistic predictions. In this chain, future conditions depend only on the present condition and are independent of the previous conditions data. On the other hand, although deterioration is a continuous process, a **discrete time Markov chain** was used for this framework considering the discrete time intervals of inspections (i.e., discrete input data of asset conditions).

On the other hand, ultimate output of the predictive asset maintenance is the cost reduction eliminating the unnecessary costing whereas the cost prediction plays a key role in this regard. But the cost prediction can be a repair/replacement cost and whereas the repair/replacement cost is based on the maintenance cost. However, assessor/expert needs to determine whether it is a repair or a replacement whereas the maintenance policies are varied with the organizational policy of which the organization has made agreements for outsourcing or insourcing such that the maintenance cost is varying with the maintenance agency. Accordingly, the knowledge-based approach was applied for decision making process and Markov chain concept was used for the cost predictions for the maintenance of assets.

In addition to the deterioration of the asset condition with time, assets might get affected with the disasters whether they are natural or man-made. In the sense, developing as assessment method for disaster management and integration it with the asset management is essential. However, asset repair damage and the preparedness risk are the aspects that connect the assets with the disasters. Accordingly, pre-disaster forecasted damage and post-disaster estimated damage were calculated incorporating the aspects of vulnerability and asset values.

### 3.4. Demonstration of the Assessment Method

<u>Assessment method used for asset predictive maintenance; Markovian process includes the following steps.</u>

**<u>Step 01: Condition evaluation of assets</u>** (Carried out as mentioned in section 3.2)

Initial distribution matrix was developed by using the condition data which represents the present state of the asset as illustrated below.

| Condition | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Asset condition** | 1 | 0 | 0 | 0 | 0 |

∴ Initial distribution matrix, v = [ 1 0 0 0 0]

For this study, risk score calculated through the following equation was taken as the current overall condition of assets which had been elaborated in the next chapter.

Risk Score = Criticality x (Physical Condition + Performance Condition)

**Step 02: Derivation of transition matrices**

Generally, a transition matrix is developed by deriving a typical deterioration trend curve-based condition and the remaining life of the assets. The curve then is broken into the stages representing the condition transition whereas the gradient of the line represents the likelihood of a transition from one state to another, and these coefficients form the transition matrix for that specific asset. Table 3.4, Figure 3.8 and Table 3.5 illustrate the calibration of a transition matrix for fire services (Keshavarzrad, 2015).

**Table 3.4:** Remaining Life-Condition

| Condition | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|
| **Life (years)** | 38.27 | 32.25 | 27.09 | 19.35 | 0 |
| **Remaining Life (years)** | 4.73 | 10.75 | 15.91 | 23.65 | 43 |

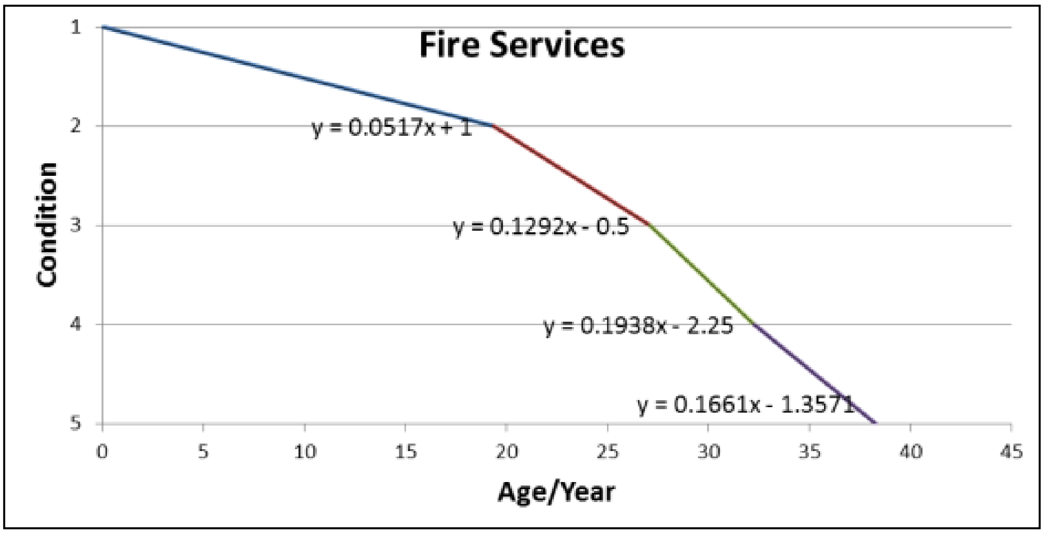



**Figure 3.8**: Deterioration Curve for Fire Services

**Table 3.5:** Transition Matrix of Fire Services

| Condition | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **1** | 0.9483 | 0.0517 | 0 | 0 | 0 |
| **2** | 0 | 0.871 | 0.129 | 0 | 0 |
| **3** | 0 | 0 | 0.806 | 0.194 | 0 |
| **4** | 0 | 0 | 0 | 0.834 | 0.166 |
| **5** | 0 | 0 | 0 | 0 | 1 |

**<u>Step 03: Derivation of expected deterioration curve</u>**

Deterioration table was produced by the multiplication of initial distribution matrix by the transition matrix that reflects the transition probabilities of conditions at discrete time intervals and expected deterioration curve was developed as in Table 3.6. and Figure 3.9 respectively (Keshavarzrad, 2015).

i.e., At time step 1,      Transition probabilities calculation,

$$[1 \quad 0 \quad 0 \quad 0 \quad 0]*\begin{bmatrix} 0.9483 & 0.0517 & 0 & 0 & 0 \\ 0 & 0.871 & 0.129 & 0 & 0 \\ 0 & 0 & 0.806 & 0.194 & 0 \\ 0 & 0 & 0 & 0.834 & 0.8346 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= [0.9483 \quad 0.0517 \quad 0 \quad 0 \quad 0]$$

$$\text{Expected condition} = [0.9483 \quad 0.0517 \quad 0 \quad 0 \quad 0] * \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{bmatrix} = 1.0517$$

**Table 3.6:** Deterioration Table of Transition Probabilities of Conditions

| Time | 1 | 2 | 3 | 4 | 5 | Expected Condition |
|---|---|---|---|---|---|---|
| **0** | 1 | 0 | 0 | 0 | 0 | 1 |
| **1** | 0.9483 | 0.0517 | 0 | 0 | 0 | 1.0517 |
| **2** | 0.8999273 | 0.0944058 | 0.006669 | 0 | 0 | 1.107396 |
| **3** | 0.85278 | 0.128417 | 0.017509 | 0.001294 | 0 | 1.167316 |
| **4** | 0.808692 | 0.15594 | 0.030678 | 0.004476 | 0.000215 | 1.231582 |
| **5** | 0.766882 | 0.177633 | 0.044843 | 0.009684 | 0.000958 | 1.300202 |
| **47** | 0.082499 | 0.054163 | 0.048036 | 0.076301 | 0.739001 | 4.335141 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **48** | 0.078234 | 0.051441 | 0.045704 | 0.072954 | 0.751667 | 4.368378 |
| **49** | 0.074189 | 0.04885 | 0.043473 | 0.06971 | 0.763777 | 4.400036 |
| **50** | 0.070354 | 0.046384 | 0.041341 | 0.066572 | 0.775349 | 4.430179 |
| **51** | 0.066717 | 0.0044038 | 0.039304 | 0.063541 | 0.7864 | **4.458871** |

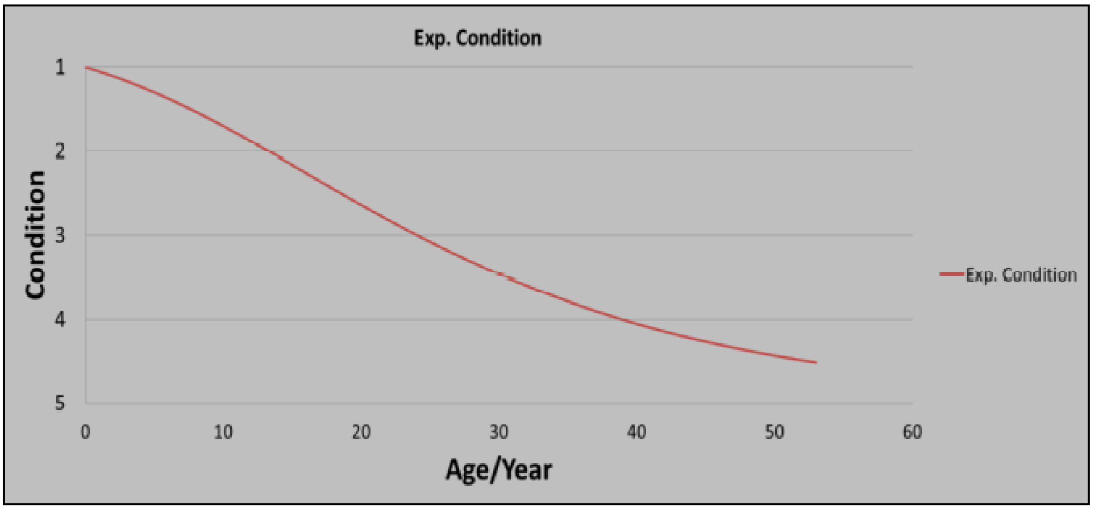



**Figure 3.9:** Expected Deterioration Curve

However, the major challenge is encountered in calibrating the transition matrix since it can amplify/simplify the condition transitions as well as it is required to have at least three consecutive condition data sets to derive a realistic transition matrix (Keshavarzrad, 2015). Considering this study, since no such sample data were available to calibrate the matrices, transition matrices calibrated and validated in a contemporary study for community buildings were used for developing the framework of this study with reasonable assumptions that were elaborated in the next chapter. Accordingly, the calibration methodology for that study was the direct absolute value difference method, which combines a generic algorithm with Monte Carlo sampling. Further, those matrices were then evaluated and confirmed using Pearson's chi-squared test (Mohseni, Setunge, Zhang, & Wakefield, 2017).

<u>Markov chain for the cost of maintenance could be applied according to following steps.</u>

**Step 01: Derivation of Maintenance Matrices**

As mentioned earlier, maintenance matrices depend on the organizational policy and vary with respect to each asset but such a developed maintenance matrix for the transformers can be given as below (Yahaya, et al., 2018).

$$M = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0.1 & 0 & 0 & 0.9 & 0 \\ 0.1 & 0 & 0 & 0 & 0.9 \end{bmatrix}$$

However, above matrix had been developed based on several assumptions since the matrix needs to be updated yearly depending on the external factors (Yahaya, et al., 2018).

**Step 02: Calculation of Expected Maintenance Cost**

Expected maintenance cost can be calculated using the Equation (2) and estimated cost defined for the asset (as in Table 2.4) mentioned in the Chapter 2 (Yahaya, et al., 2018).

Let, $r = [1 \quad 0 \quad 0 \quad 0 \quad 0]$

$$P = \begin{bmatrix} 0.8947 & 0.1053 & 0 & 0 & 0 \\ 0 & 0.5652 & 0.4348 & 0 & 0 \\ 0 & 0 & 0.7391 & 00.2609 & 0 \\ 0 & 0 & 0 & 0.9615 & 0.0385 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$$M = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0.1 & 0 & 0 & 0.9 & 0 \\ 0.1 & 0 & 0 & 0 & 0.9 \end{bmatrix}$$

At time step = 0, let number of transformers at state 5 = 120, then

Expected cost = 5.94Mn (according to Equation (2))

Accordingly, maintenance cost distribution for transformers in each state can be illustrated as in Figure 3.10 (Yahaya, et al., 2018).

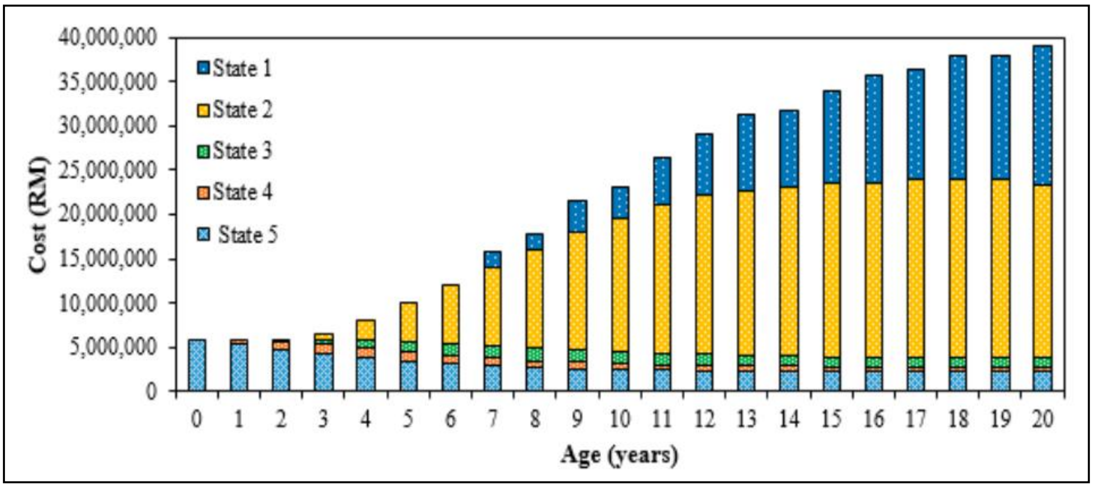



**Figure 3.10:** Maintenance cost for transformers in each state for transition states for the year 2013/2014

This can be carried out for all the asset components of the terminals with respect to the availability of maintenance details. Accordingly, for this study, considering the limited availability of data, maintenance matrix could not be derived since the cost prediction of assets maintenance was introduced as a theoretical model.

<u>Disaster Assessment Method was developed as follows.</u>

**<u>Pre-Disaster Assessment and Post-Disaster Assessment</u>**

During pre-disaster assessments, disaster risk score of asset could be calculated through the Equation (3).

$$\text{Disaster Risk} = (\text{Risk of Hazard})*(\text{Risk of Exposure})*(\text{Risk of Vulnerability}) \qquad (3)$$

Where; Risk score is a scale of 0-5 defined based on the vulnerability of the disasters, likelihood of occurrence and on the percentage of the individual asset damage (scale with descriptions are elaborated in Chapter 4).

Based on the disaster risk score of the asset, vulnerability of the assets to particular disasters can be accounted and this reflects the disaster preparedness risk on the assets to outline the mitigatory measures.

Asset damage during post-disaster assessments could be estimated as the product of asset value and the number of assets needs to be replaced (Estimate for the asset repairing by the experts) whereas the disaster measuring parameters (i.e., Inundation depth for floods) were in cooperated to determine the fraction of asset damage.

### 3.5. Optimization of the Processes

Considering the optimizations of the processes, reviews of the expertise were consulted through the workshops (verbally) conducted via online platform. Two such workshops were held with the expertise of the field in worldwide (12 expertise) and with the stakeholders of the KMTT project. Feedback received for further amendments that needs to in cooperate can be pinpointed as follows.

- Procedure for major repairs
- Depreciation of asset values
- Maintenance back logs, if repairing not occur on time
- Weightages assigned for the assets need to be reviewed further

Accordingly, concerns received through the expertise were facilitated for the future proceedings in developing the framework.

In addition, review of the discussions with Mrs. Anoja Seneviratne (Director, Mitigation Research and Development, Disaster Management Centre, Sri Lanka) was in cooperated in restructuring the risk scale rating for disasters.

On the other hand, transition matrices for this study were sourced from the study that had optimized the matrices using the combined method of the generic algorithm with Monte Carlo sampling called direct absolute value difference method. Since the optimization of the transition matrices for this study had been already in cooperated. However, future researchers are suggested to use the Generic Algorithm with the Monte Carlo Sampling technique as the data optimization technique as well as for calibrating the models.

### 3.7. Summary

In overall, it can be notified that the evaluations were completed capturing over 1000 asset records of all asset categories despite of some minor drawbacks as mentioned below.

- Add/edit assets during the visual inspections (when the assets are not complemented with the inventory records) is quite cumbersome at the same time it is time-consuming in this regard.
- Absence of inventory records in particular places affects to the reliability of the data collection since the asset records cannot be rechecked during the visual inspections.
- Since the database is modifying right throughout, some program disruptions and overruns were encountered during the evaluations.

Nevertheless, use of tablets made the work more convenient as well as the feedback received by the occupants is worth to be noted. Accordingly, during field study, it could be noted that the maintenance in the Bogambara terminal (Kandy office, Washroom complex 1) was in a satisfactory level whereas the maintenance of the assets (Bus shelters, Display Boards, Safety bollards etc.) in the Kandy roadside terminals was not acceptable. Since it was evident that there was no proper mechanism/guidance exists for ranking inspection tasks and defining the critical assets that need immediate maintenance such that uniform assessments can be performed. Therefore, field study facilitated to identify existing conditions and the necessity to implement a proper maintenance assessment method for KMTT.

On the other hand, Markov chain was adopted as the assessment method for asset predictions whereas a model was introduced for the cost prediction and the disaster assessment method too was developed as a theoretical model considering the limited availability of data.

# 4. ASSESSMENT FRAMEWORK DEVELOPMENT

## 4.1. Introduction

This chapter outlines the data analysis, proposed assessment method and the optimizations for the proposed assessment framework.

## 4.2. Data Analysis

Initially risk score was calculated with respect to the physical and performance assessments. Considering the five-point rating scale, both physical and performance conditions have a rating up to five and both add up to a score of 10 whereas each condition score was multiplied by the weightage if more than one condition variable was defined as in Equation (4). As such risk score value was auto calculated in the AMS as illustrated in Figure 4.1and Figure 4.2.

| Category | Location | Asset Code | Asset Description | Assessments Date Range | | Risk Score |
|---|---|---|---|---|---|---|
| | | | | Physical | Performance | |
| Water Facilites and Toilet Fittings | Bogambara Terminal Toilet Female 1 | FE1-BS01 | Bidet Spray 01-Female Toilet 1 | 2021-11-18 - 2021-11-18 | 2021-11-18 - 2021-11-18 | 16.00 |
| | | FE1-COM01 | Commode with Cistern 01- Female Toilet 1 | 2021-11-18 - 2021-11-18 | 2021-11-18 - 2021-11-18 | 13.20 |
| | | FE1-FLGU01 | Floor Gully 01 - Female Toilet 1 | 2021-11-18 - 2021-11-18 | 2021-11-18 - 2021-11-18 | 6.00 |
| | | FE1-MIR01 | Mirror 01- Female Toilet 1 | 2021-11-18 - 2021-11-18 | 2021-11-18 - 2021-11-18 | 4.00 |
| | | FE1-MIR02 | Mirror 02- Female Toilet 1 | 2021-11-18 - 2021-11-18 | 2021-11-18 - 2021-11-18 | 8.00 |
| | | FE1-MIR03 | Mirror 03- Female Toilet 1 | 2021-11-18 - 2021-11-18 | 2021-11-18 - 2021-11-18 | 10.00 |
| | | FE1-PAHO01 | Toliet Paper Holder 01- Female Toilet 1 | 2021-11-18 - 2021-11-18 | 2021-11-18 - 2021-11-18 | 16.00 |
| | | FE1-SQP01 | Squatting Pan with Cistern 01- Female Toilet 1 | 2021-11-18 - 2021-11-18 | 2021-11-18 - 2021-11-18 | 6.60 |
| | | FE1-SQP02 | Squatting Pans with Cistern 02- Female Toilet 1 | 2021-11-18 - 2021-11-18 | 2021-11-18 - 2021-11-18 | 4.60 |
| | | FE1-SQP03 | Squatting Pans with Cistern 03- Female Toilet 1 | 2021-11-18 - 2021-11-18 | 2021-11-18 - 2021-11-18 | 4.60 |

**Figure 4.1:** Risk Score Values of Sanitary Fittings in the Bogambara Terminal

| | | | | | | |
|---|---|---|---|---|---|---|
| Road Side Bus Stops | Kandy Torrington Bus Terminal | TBT-BUSH01 | Bus Shelter - Torrington Bus Terminal 01 | 2021-11-17 - 2021-11-17 | 2021-11-17 - 2021-11-17 | 16.07 |
| | | TBT-BUSH02 | Bus Shelter - Torrington Bus Terminal 02 | 2021-11-18 - 2021-11-18 | 2021-11-17 - 2021-11-17 | 16.07 |
| | | TBT-BUSH03 | Bus Shelter - Torrington Bus Terminal 03 | 2021-11-17 - 2021-11-17 | 2021-11-17 - 2021-11-17 | 16.07 |
| | | TBT-BUSH04 | Bus Shelter - Torrington Bus Terminal 04 | 2021-11-17 - 2021-11-17 | 2021-11-17 - 2021-11-17 | 16.73 |
| | | TBT-RSB01 | Route Sign Board - Torrington Bus Terminal 01 | 2021-11-17 - 2021-11-17 | 2021-11-17 - 2021-11-17 | 8.00 |
| | | TBT-RSB02 | Route Sign Board - Torrington Bus Terminal 02 | 2021-11-17 - 2021-11-17 | 2021-11-17 - 2021-11-17 | 20.00 |
| | | TBT-RSB03 | Route Sign Board - Torrington Bus Terminal 03 | 2021-11-17 - 2021-11-17 | 2021-11-17 - 2021-11-17 | 30.00 |

**Figure 4.2:** Risk Score Values of Kandy Roadside Terminal's Assets

Risk Score = Criticality x (Physical Condition + Performance Condition) (4)

(Haster, Freese, & Nichols, 2016)

Accordingly,

Maximum Risk Score = 3 x (5 + 5) = 30

Minimum Risk Score = 1 x (1 + 1) = 2

Based on the risk score analysis and the review of the findings of Mohseni, Setunge, Zhang & Wakefield (2017), a typical condition ratimg scale was developed for this study as illustrated in Table 4.1 and Table 4.2. Here 1-30 risk score values were consolidated into a 1-5 asset conditions.

**Table 4.1:** Matrix Analysis of Risk Score Values

| Scale | | Level of Criticality | | |
|---|---|---|---|---|
| | | **3** | **2** | **1** |
| **Level of Condition Summation of Assets** | **10** | 30 | 20 | 10 |
| | **9** | 27 | 18 | 9 |
| | **8** | 24 | 16 | 8 |
| | **7** | 21 | 14 | 7 |
| | **6** | 18 | 12 | 6 |
| | **5** | 15 | 10 | 5 |
| | **4** | 12 | 8 | 4 |
| | **3** | 9 | 6 | 3 |
| | **2** | 6 | 4 | 2 |

**Table 4.2:** Developed Condition Rating Scale

| AMS Rating | | Developed Condition Rating (Risk Rating) | |
|---|---|---|---|
| **Scale** | **Condition** | **Scale** | **Condition Description** |
| **1** | Very Good | **1-6** | Asset is as new |
| **2** | Good | **7-12** | Minor damage, monitoring is required |
| **3** | Average | **13-18** | Moderate damage; require minor repairing and continuous monitoring |
| **4** | Poor | **19-24** | Major damage; major repairing/replacement is required |
| **5** | Very Poor | **25-30** | Serious damage; asset should be replaced |

Source: (Mohseni, Setunge, Zhang, & Wakefield, 2017)

### 4.3. Assessment Method for Predictive Maintenance of Assets

Risk rating is the base of this assessment method.

As the initial step of Markov Chain, initial distribution matrices were formed by using the condition evaluation data in cooperating the developed condition rating in Table 4.2. Accordingly, '1' was allocated to the condition state corresponding to the risk score value and '0' for the other states as presented in Table 4.3.

**Table 4.3:** Initial Distribution Matrices of Assets

| Asset | Risk Score | Asset Present Condition | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| Commode with Cistern 01- Female Toilet 2 | 9.6 | 0 | 1 | 0 | 0 | 0 |
| Squatting Pan with Cistern 01- Female Toilet 1 | 4.6 | 1 | 0 | 0 | 0 | 0 |
| Urinal 01- Male Toilet 2 | 8.0 | 0 | 1 | 0 | 0 | 0 |
| Washbasin 01- Female Toilet 1 | 10.2 | 0 | 1 | 0 | 0 | 0 |
| Bidet Spray 01-Female Toilet 1 | 16.0 | 0 | 0 | 1 | 0 | 0 |
| Tap 01 - Female Toilet 1 | 4.0 | 1 | 0 | 0 | 0 | 0 |
| Floor Gully 01 - Female Toilet 1 | 6.0 | 1 | 0 | 0 | 0 | 0 |
| Mirror 01- Female Toilet 1 | 4.0 | 1 | 0 | 0 | 0 | 0 |
| Soap Tray 01-Female Toilet 1 | 12.0 | 0 | 1 | 0 | 0 | 0 |
| Toilet Paper Holder 01- Female Toilet 1 | 16.0 | 0 | 0 | 1 | 0 | 0 |
| High Back Chair - OCC 01 | 4.0 | 1 | 0 | 0 | 0 | 0 |
| Lobby Seating - OCC 01 | 6.0 | 1 | 0 | 0 | 0 | 0 |
| Work station Table - OCC 01 | 4.0 | 1 | 0 | 0 | 0 | 0 |
| Door 01- Female Toilet 1 | 4.4 | 1 | 0 | 0 | 0 | 0 |
| Fanlight 01- Female Toilet 1 | 6.4 | 0 | 1 | 0 | 0 | 0 |
| Bogambara Terminal Bus Bay 01 | 7.0 | 0 | 1 | 0 | 0 | 0 |
| Display TV 01 - OCC | 4.0 | 1 | 0 | 0 | 0 | 0 |
| Photocopy/ Printer/ Scanner/ Fax all in one Machine 01 - OCC | 6.0 | 1 | 0 | 0 | 0 | 0 |
| Air Conditioner Complete Set 01 - PTSA Office Building | 8.0 | 0 | 1 | 0 | 0 | 0 |
| Ceiling Fan 01- PTSA Office Building | 8.0 | 0 | 1 | 0 | 0 | 0 |
| LED Downlight 01 - PTSA Office Building | 7.0 | 0 | 1 | 0 | 0 | 0 |
| Generator (30KV) 01 - Generator Room | 9.0 | 0 | 1 | 0 | 0 | 0 |
| 5A Socket Outlet 01 - Female Toilet 1 | 8.0 | 0 | 1 | 0 | 0 | 0 |
| Two Gang Switch 01 - Female Toilet 1 | 6.0 | 1 | 0 | 0 | 0 | 0 |
| CO2 Extinguisher 01 - Fire System | 8.0 | 0 | 1 | 0 | 0 | 0 |
| Dry Powder Extinguisher 01 - Fire System | 4.0 | 1 | 0 | 0 | 0 | 0 |
| Water Extinguisher 01 - Fire System | 6.0 | 1 | 0 | 0 | 0 | 0 |
| Hose Reel 01 - Fire System | 12.0 | 0 | 1 | 0 | 0 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Route Sign Board 01 - Clock Tower Terminal | 20.0 | 0 | 0 | 0 | 1 | 0 |
| Time Table Display Board 01 - Torrington Bus Terminal | 20.0 | 0 | 0 | 0 | 1 | 0 |
| Time Keeper Shed 01 - Dhammananda Mawatha Terminal | 8.93 | 0 | 1 | 0 | 0 | 0 |
| Bus Shelter 08 - Bandaranayake Mawatha | 25.4 | 0 | 0 | 0 | 0 | 1 |
| Safety Railing 01 - Central Market Terminal | 10.0 | 0 | 1 | 0 | 0 | 0 |
| Safety Bollard 01 - Kachcheriya Front Terminal | 12.0 | 0 | 1 | 0 | 0 | 0 |

Note: Table 4.3 covers the single asset evaluation data from each asset category in AMS.

Considering the derivation of transition matrices, since no consecutive condition data sets were available for this study, matrices that were calibrated and validated as mentioned in the section 3.4 were applied for this study. However, following assumptions (except to the provisions need to be considered for Markov Chain as mentioned in section 2.3.1) were made when in cooperating those calibrated matrices for this study although both the studies used the five-point rating scale for assessments.

- Reference study had used an upper triangular stochastic matrix that represents the probability of conditions moving to worst condition
- Transition matrices for assets in the roadside terminals (Route sign boards, Time table display boards, Safety bollards, Safety railings, Bus shelters and Time keeper shed) and building assets like chairs, tables and display TVs could not be derived for this study since the reference study had not carried out the analysis for those assets
- A common transition matrix was used for the services which includes electrical, fire, mechanical and plumbing services since the contemporary study had developed it in a similar manner
- Considering the doors and windows, transition matrices for external doors and windows were adopted for the doors and windows of washrooms in this study respectively

Accordingly, following transition matrices (Mohseni, Setunge, Zhang, & Wakefield, 2017) were used for the respective assets in this study.

**Table 4.4:** Transition Matrix of Services

| Condition | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **1** | 0.64 | 0.08 | 0.28 | 0 | 0 |
| **2** | 0 | 0.24 | 0.31 | 0.46 | 0 |
| **3** | 0 | 0 | 0.63 | 0.16 | 0.2 |
| **4** | 0 | 0 | 0 | 0.39 | 0.61 |
| **5** | 0 | 0 | 0 | 0 | 1 |

**Table 4.5:** Transition Matrix of External Doors

| Condition | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **1** | 0.6 | 0.13 | 0.23 | 0.01 | 0.01 |
| **2** | 0 | 0.77 | 0.22 | 0.01 | 0 |
| **3** | 0 | 0 | 0.98 | 0.02 | 0 |
| **4** | 0 | 0 | 0 | 0.89 | 0.11 |
| **5** | 0 | 0 | 0 | 0 | 1 |

**Table 4.6:** Transition Matrix of Windows

| Condition | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **1** | 0.37 | 0.23 | 0.3 | 0.1 | 0 |
| **2** | 0 | 0.59 | 0.29 | 0.11 | 0.01 |
| **3** | 0 | 0 | 0.94 | 0.06 | 0.01 |
| **4** | 0 | 0 | 0 | 1 | 0 |
| **5** | 0 | 0 | 0 | 0 | 1 |

Once the transition matrices were derived, condition – transition curves and expected deterioration curves were developed based on the deterioration tables obtained for the asset components as cited in Table 4.7, Figure 4.3 and Figure 4.4.

**Table 4.7:** Deterioration Table - Commode with Cistern 01- Female Toilet 2

| Age (Years) | Change in Rating (Risk Rating) | | | | | Expected Overall Rating |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | |
| Initial | 0 | 1 | 0 | 0 | 0 | 2.000 |
| 1 | 0 | 0.77 | 0.22 | 0.01 | 0 | 2.240 |
| 2 | 0 | 0.593 | 0.385 | 0.021 | 0.001 | 2.430 |
| 3 | 0 | 0.457 | 0.508 | 0.032 | 0.003 | 2.583 |
| 4 | 0 | 0.352 | 0.598 | 0.043 | 0.007 | 2.706 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 5 | 0 | 0.271 | 0.663 | 0.054 | 0.012 | 2.807 |
| 6 | 0 | 0.208 | 0.71 | 0.064 | 0.018 | 2.891 |
| 7 | 0 | 0.16 | 0.741 | 0.073 | 0.025 | 2.962 |
| 8 | 0 | 0.124 | 0.762 | 0.082 | 0.033 | 3.024 |
| 9 | 0 | 0.095 | 0.774 | 0.089 | 0.042 | 3.078 |
| 10 | 0 | 0.073 | 0.779 | 0.096 | 0.052 | 3.126 |
| 11 | 0 | 0.056 | 0.78 | 0.102 | 0.062 | 3.170 |
| 12 | 0 | 0.043 | 0.777 | 0.107 | 0.073 | 3.210 |
| 13 | 0 | 0.033 | 0.771 | 0.111 | 0.085 | 3.248 |
| 14 | 0 | 0.026 | 0.763 | 0.114 | 0.097 | 3.283 |
| 15 | 0 | 0.02 | 0.753 | 0.117 | 0.11 | 3.317 |
| 16 | 0 | 0.015 | 0.742 | 0.12 | 0.123 | 3.350 |
| 17 | 0 | 0.012 | 0.731 | 0.122 | 0.136 | 3.382 |
| 18 | 0 | 0.009 | 0.719 | 0.123 | 0.149 | 3.412 |
| 19 | 0 | 0.007 | 0.706 | 0.124 | 0.163 | 3.443 |
| 20 | 0 | 0.005 | 0.694 | 0.124 | 0.176 | 3.472 |
| 21 | 0 | 0.004 | 0.681 | 0.125 | 0.19 | 3.501 |
| 22 | 0 | 0.003 | 0.668 | 0.125 | 0.204 | 3.529 |
| 23 | 0 | 0.002 | 0.656 | 0.124 | 0.218 | 3.557 |
| 24 | 0 | 0.002 | 0.643 | 0.124 | 0.231 | 3.584 |
| 25 | 0 | 0.001 | 0.631 | 0.123 | 0.245 | 3.611 |
| 26 | 0 | 0.001 | 0.618 | 0.122 | 0.258 | 3.638 |
| 27 | 0 | 9E-04 | 0.606 | 0.121 | 0.272 | 3.664 |
| 28 | 0 | 7E-04 | 0.594 | 0.12 | 0.285 | 3.689 |
| 29 | 0 | 5E-04 | 0.583 | 0.119 | 0.298 | 3.715 |
| 30 | 0 | 4E-04 | 0.571 | 0.117 | 0.311 | 3.740 |
| 31 | 0 | 3E-04 | 0.56 | 0.116 | 0.324 | 3.764 |
| 32 | 0 | 2E-04 | 0.549 | 0.114 | 0.337 | 3.788 |
| 33 | 0 | 2E-04 | 0.538 | 0.113 | 0.35 | 3.812 |
| 34 | 0 | 1E-04 | 0.527 | 0.111 | 0.362 | 3.835 |
| 35 | 0 | 1E-04 | 0.516 | 0.109 | 0.374 | 3.857 |
| 37 | 0 | 6E-05 | 0.496 | 0.106 | 0.398 | 3.902 |
| 38 | 0 | 5E-05 | 0.486 | 0.104 | 0.41 | 3.923 |
| 39 | 0 | 4E-05 | 0.476 | 0.102 | 0.421 | 3.945 |
| 40 | 0 | 3E-05 | 0.467 | 0.101 | 0.432 | 3.965 |
| 41 | 0 | 2E-05 | 0.458 | 0.099 | 0.443 | 3.986 |
| 42 | 0 | 2E-05 | 0.448 | 0.097 | 0.454 | 4.006 |
| 43 | 0 | 1E-05 | 0.439 | 0.096 | 0.465 | 4.026 |
| 44 | 0 | 1E-05 | 0.431 | 0.094 | 0.476 | 4.045 |
| 45 | 0 | 8E-06 | 0.422 | 0.092 | 0.486 | 4.064 |
| 46 | 0 | 6E-06 | 0.414 | 0.09 | 0.496 | 4.082 |
| 47 | 0 | 5E-06 | 0.405 | 0.089 | 0.506 | 4.101 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 48 | 0 | 4E-06 | 0.397 | 0.087 | 0.516 | 4.118 |
| 49 | 0 | 3E-06 | 0.389 | 0.085 | 0.525 | 4.136 |
| 50 | 0 | 2E-06 | 0.382 | 0.084 | 0.535 | **4.153** |

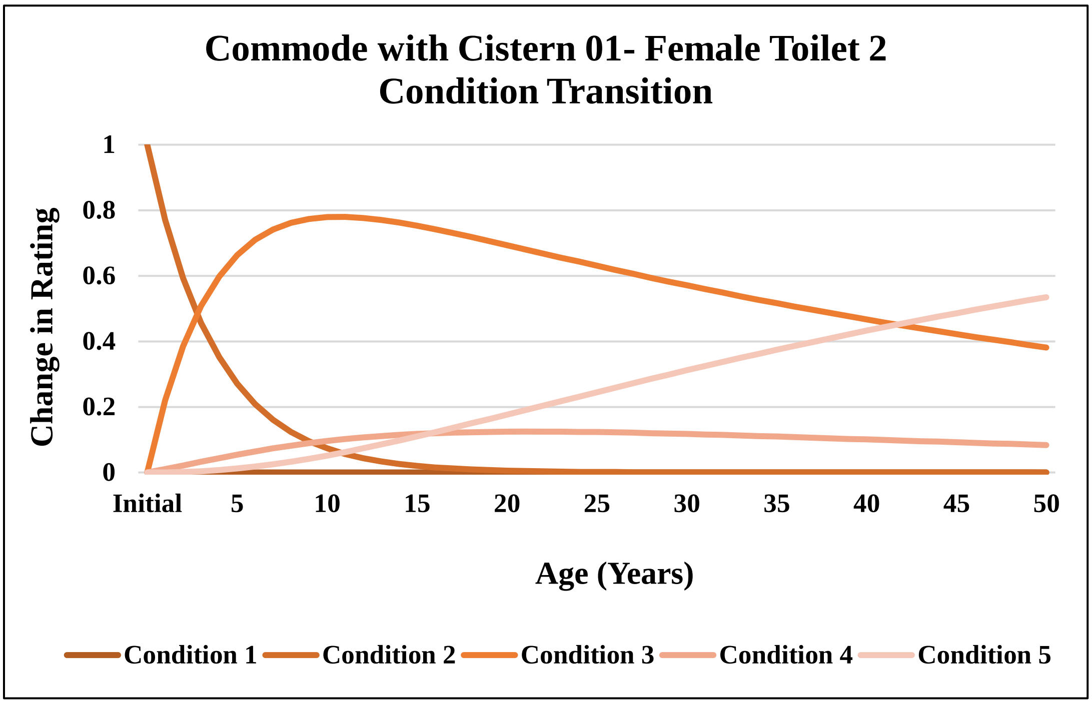



**Figure 4.3:** Transition Curve – Commode with Cistern 01 (Female Toilet 2)

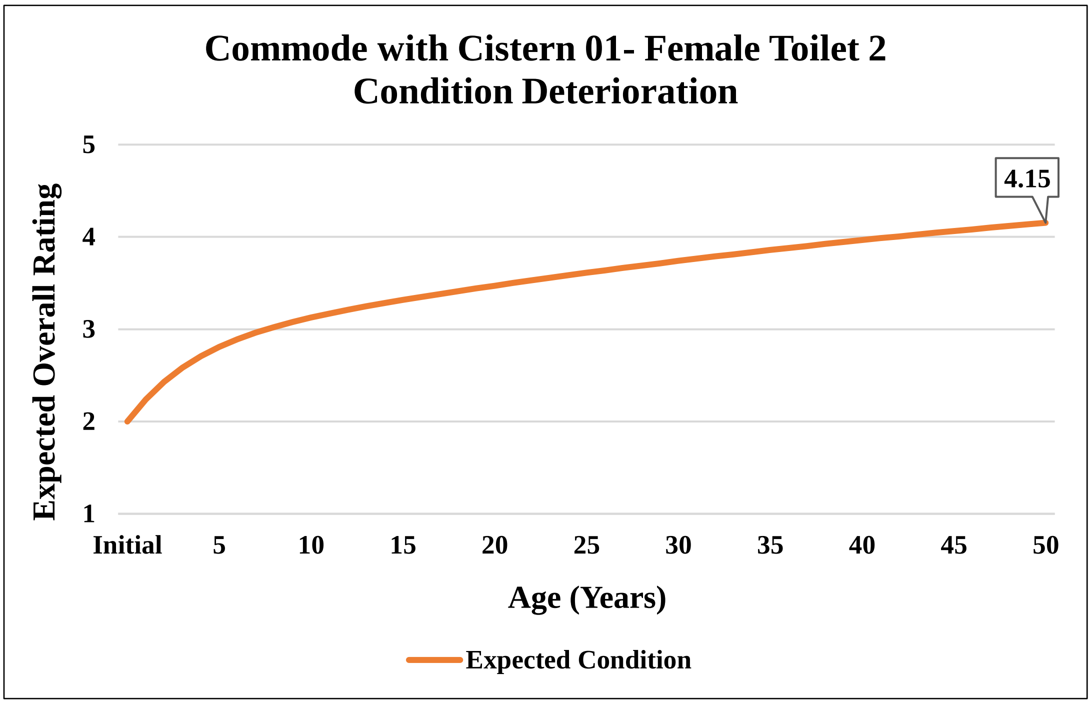
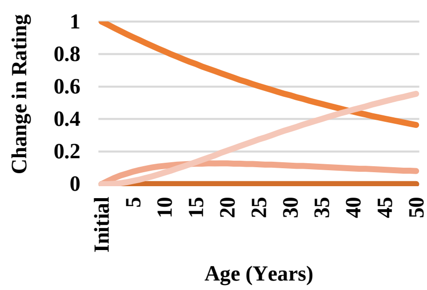
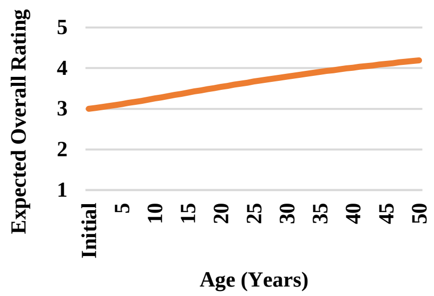
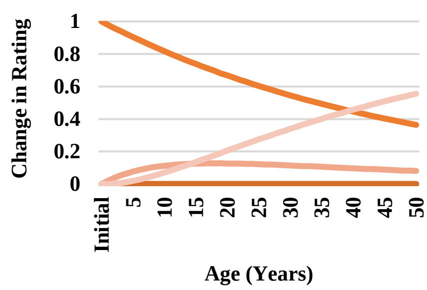
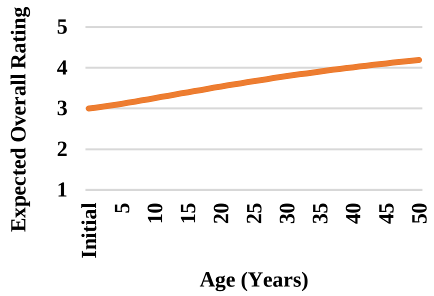
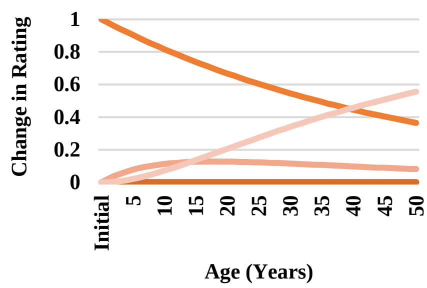
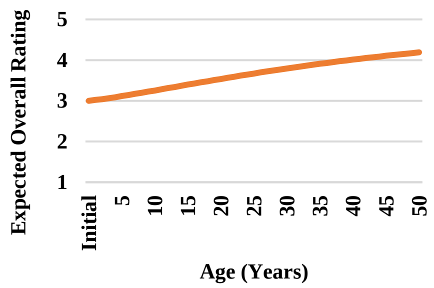
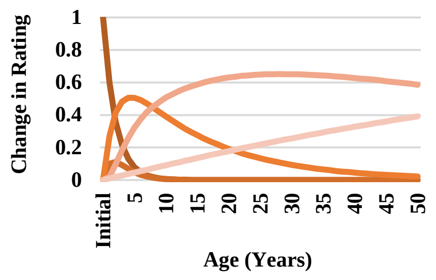
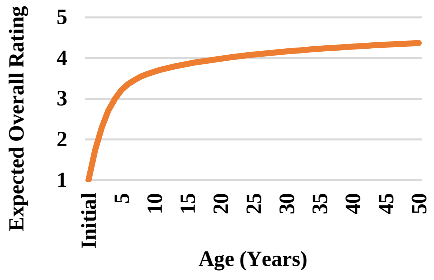
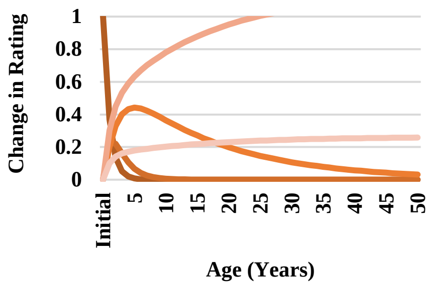
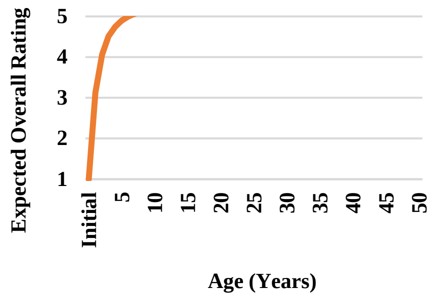
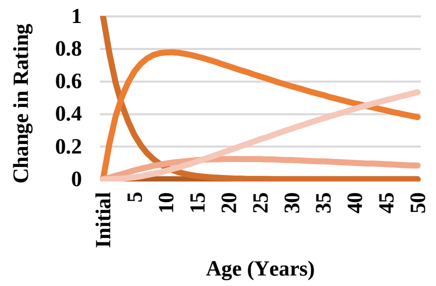
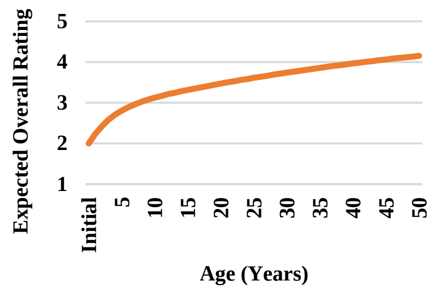
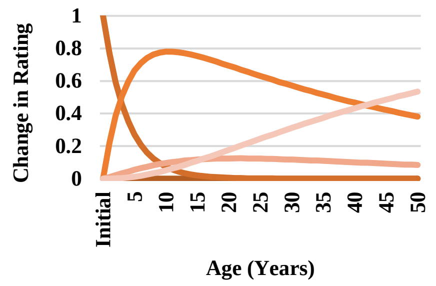
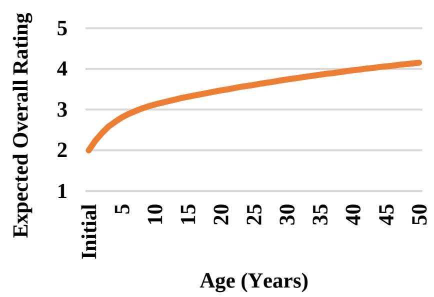


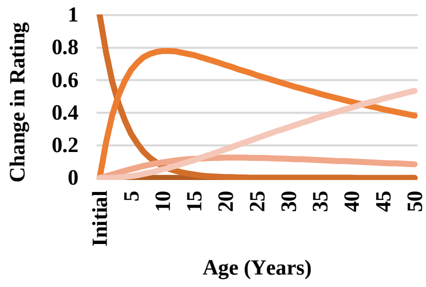
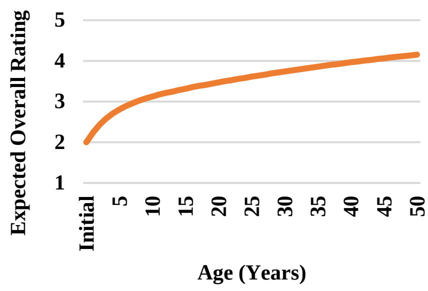
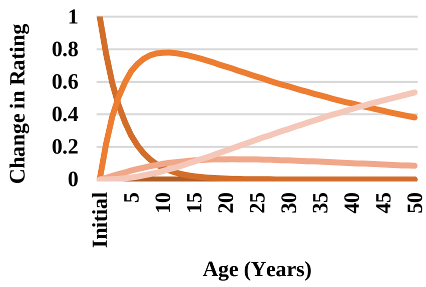
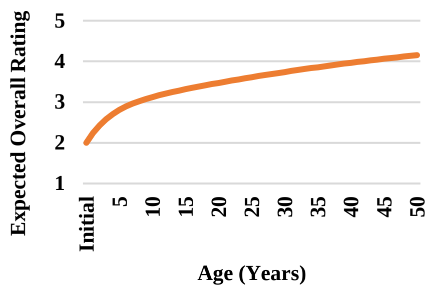
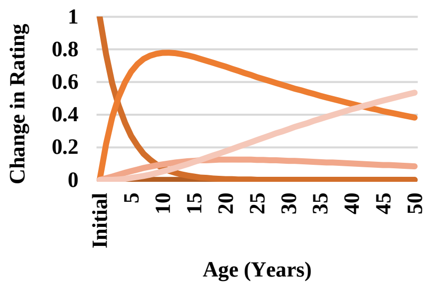
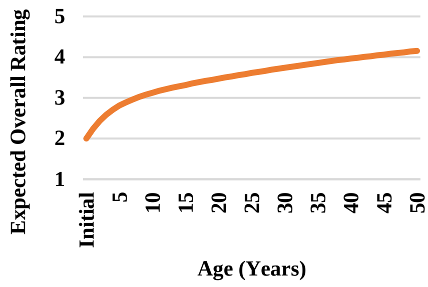
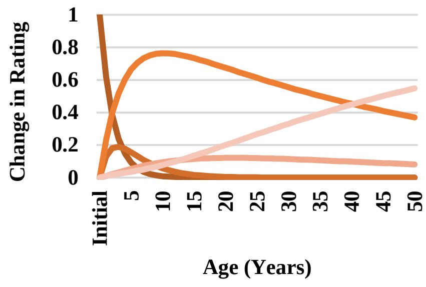
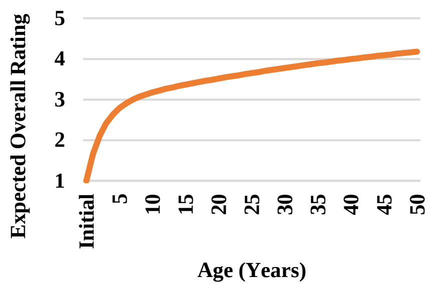

**Figure 4.4:** Deterioration Curve – Commode with Cistern 01 (Female Toilet 2)

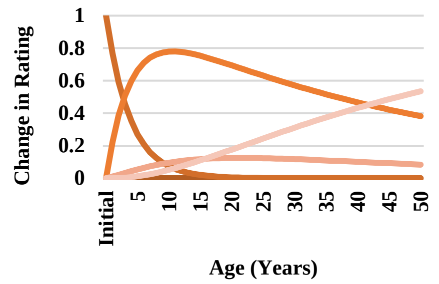
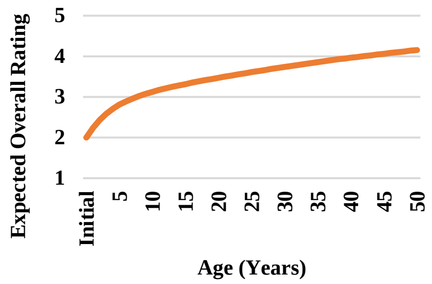
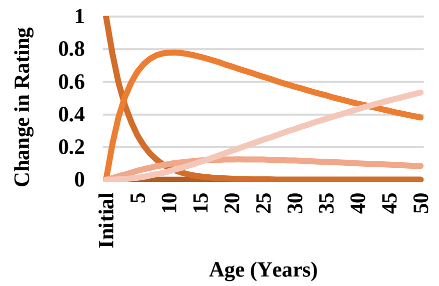
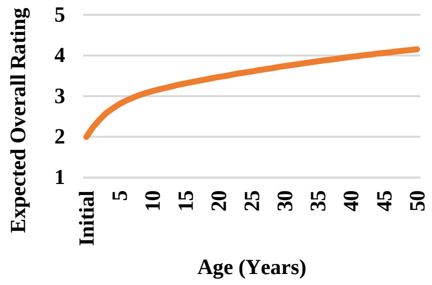
It is evident that after 15 years (Typical life span), likelihood of being in the same initial condition (Condition 2) of commode with cistern is a 2% probability whereas the probabilities of transferring to Conditions 3,4 and 5 are 75%, 12% and 11% respectively as in Figure 4.3 and the expected condition lies in between 3 and 4 as in Figure 4.4. Similarly, transition graphs and expected deterioration curves for other assets which have the calibrated transition matrices were derived as in Table 4.8 below. Here, the graphs represent the deterioration of the asset conditions without considering the asset maintenance since those calibrated transition matrices had derived without accounting that aspect.

Table 4.8: Sample of Derived Transition Graphs and Expected Deterioration Curves

| Asset | Transition Graph | Expected Deterioration Curve |
| --- | --- | --- |
| | 1 2 3 4 5 | Expected Condition |
| Squatting Pan with Cistern 01-Female Toilet 1 |  |  |
| Urinal 01-Male Toilet 2 |  |  |
| Bidet Spray 01-Female Toilet 1 |  |  |

<table>
<tr>
<td>Door 01- Female Toilet 1</td>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>Fanlight 01- Female Toilet 1</td>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>Air Conditioner Complete Set 01 - PTSA Office Building</td>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>Ceiling Fan 01- PTSA Office Building</td>
<td>
</td>
<td>
</td>
</tr>
</table>

<table>
<tr>
<td>LED Downlight 01 - PTSA Office Building</td>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>Generator (30KV) 01 - Generator Room</td>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>5A Socket Outlet 01 - Female Toilet 1</td>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>Two Gang Switch 01 - Female Toilet 1</td>
<td>
</td>
<td>
</td>
</tr>
</table>

| | | |
|---|---|---|
| Dry Powder Extinguisher 01 - Fire System |  |  |
| Hose Reel 01 - Fire System |  |  |

### 4.3.1. Conceptual Framework for Cost Projections

Maintenance policy of assets varies with the organization policy and the asset category whereas the derivation of the maintenance matrix is the initial step of developing the conceptual framework of cost projections. However, considering the unavailability of sample maintenance data, a conceptual framework in cooperating a maintenance matrix which had assumed with reference to the early findings as shown in Table 4.9.

**Table 4.9:** Maintenance Matrix

| **Condition** | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| **1** | 1 | 0 | 0 | 0 | 0 |
| **2** | 0 | 1 | 0 | 0 | 0 |
| **3** | 0 | 0.1 | 0.9 | 0 | 0 |
| **4** | 0 | 0.1 | 0 | 0.9 | 0 |
| **5** | 0.1 | 0 | 0 | 0 | 0.9 |

Accordingly, this matrix was based on a 10% pre-determined maintenance policy (Yahaya, et al., 2018) which interprets that for elements in any condition, 10% will be rehabilitated to the respective better condition (Table 4.10) whereas Condition 3 was taken as the threshold condition. As elaborated in Table 2.4 in section 2.4, a typical cost breakdown for Commode with Cistern was developed as in Table 4.11.

**Table 4.10:** Rehabilitation Conditions

| Condition | Rehabilitation Condition |
|---|---|
| **1** | - |
| **2** | - |
| **3** | 2 |
| **4** | 2 |
| **5** | 1 |

**Table 4.11:** Cost Breakdown Estimation – Commode with Cistern

| Maintenance Action | Intervention State | Activity | Estimated Cost (LKR) |
|---|---|---|---|
| Condition assessment | 3,2,1 | Annual routine monitoring | 3% from new unit |
| Minor work | 4 | Component parts restoration | 20% from new unit |
| Major work | 5 | Replacement | 30,500.00 (new unit) |

Accordingly, maintenance cost distribution in each of the conditions for the respective years was calculated using the Equation (2) as in Table 4.11. Here,

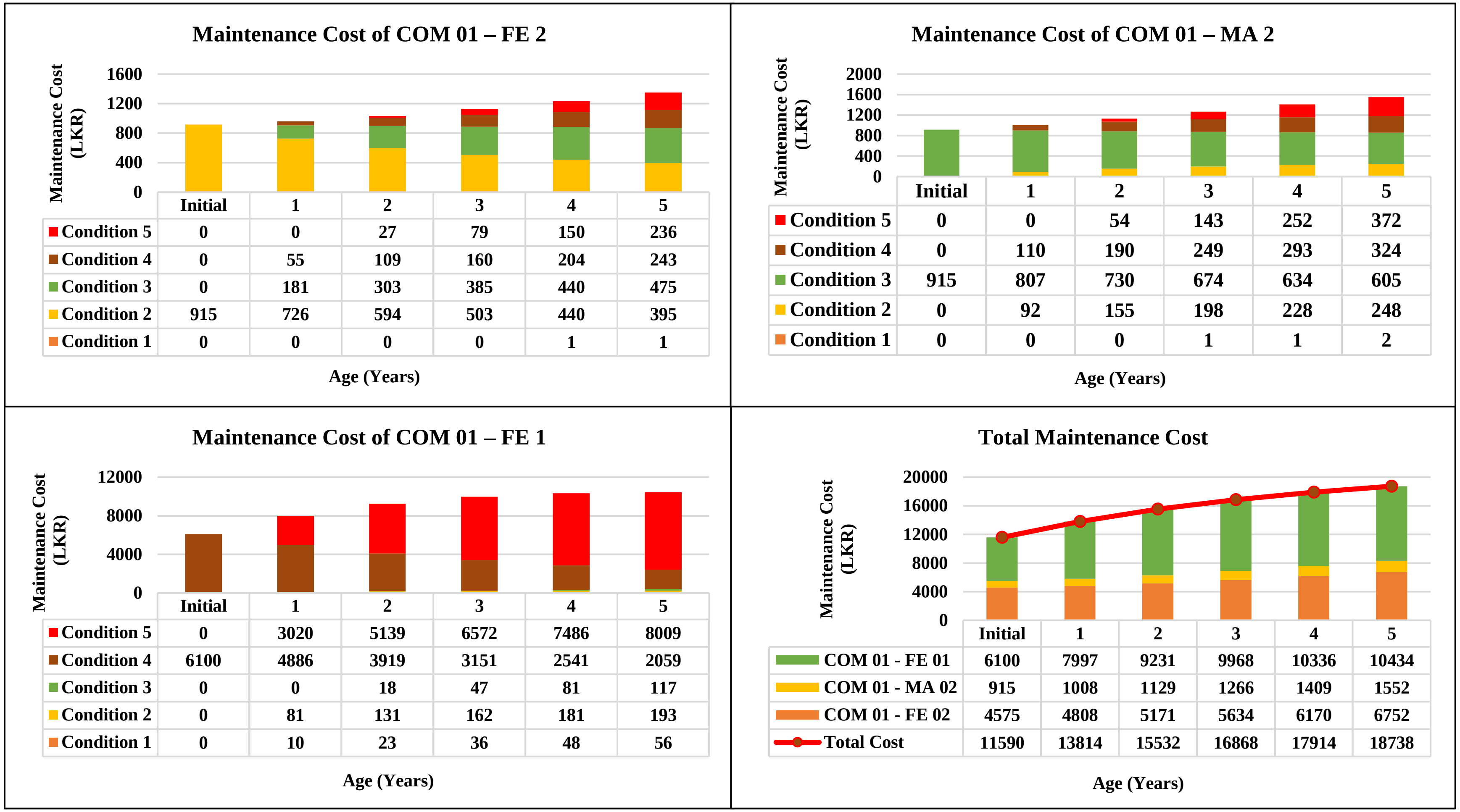
- Maintenance cost for a time period of 5 years were calculated as the sample calculation
- Since the condition of 7 commodes with cistern were evaluated total number of assets were taken as 7
- Initial conditions of these 7 assets are illustrated in Table 4.12 whereas the deterioration of assets having same initial condition was assumed to be same. Since the total cost of all assets with same initial condition were accounted as the times of the number of such assets (Here 5 times)
- Following abbreviations were used for the convenience of graphical representation
    - ✓ Commode with Cistern 01 – Female Toilet 2 (COM 01 – FE 2)

- ✓ Commode with Cistern 01 – Male Toilet 2 (COM 01 – MA 2)
- ✓ Commode with Cistern 01 – Female Toilet 1 (COM 01 – FE 1)

**Table 4.12:** Initial Conditions of Assets

| Asset | Initial Condition | | | | | Number of Assets |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | |
| COM 01 – FE 2 | 0 | 1 | 0 | 0 | 0 | 5 |
| COM 01 – MA 2 | 0 | 0 | 1 | 0 | 0 | 1 |
| COM 01 – FE 1 | 0 | 0 | 0 | 1 | 0 | 1 |

Maintenance cost distributions can be illustrated as in Figure 4.5.




**Maintenance Cost of COM 01 – FE 2**

| | Initial | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Condition 5 | 0 | 0 | 27 | 79 | 150 | 236 |
| Condition 4 | 0 | 55 | 109 | 160 | 204 | 243 |
| Condition 3 | 0 | 181 | 303 | 385 | 440 | 475 |
| Condition 2 | 915 | 726 | 594 | 503 | 440 | 395 |
| Condition 1 | 0 | 0 | 0 | 0 | 1 | 1 |

**Maintenance Cost of COM 01 – MA 2**

| | Initial | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Condition 5 | 0 | 0 | 54 | 143 | 252 | 372 |
| Condition 4 | 0 | 110 | 190 | 249 | 293 | 324 |
| Condition 3 | 915 | 807 | 730 | 674 | 634 | 605 |
| Condition 2 | 0 | 92 | 155 | 198 | 228 | 248 |
| Condition 1 | 0 | 0 | 0 | 1 | 1 | 2 |

**Maintenance Cost of COM 01 – FE 1**

| | Initial | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Condition 5 | 0 | 3020 | 5139 | 6572 | 7486 | 8009 |
| Condition 4 | 6100 | 4886 | 3919 | 3151 | 2541 | 2059 |
| Condition 3 | 0 | 0 | 18 | 47 | 81 | 117 |
| Condition 2 | 0 | 81 | 131 | 162 | 181 | 193 |
| Condition 1 | 0 | 10 | 23 | 36 | 48 | 56 |

**Total Maintenance Cost**

| | Initial | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| COM 01 - FE 01 | 6100 | 7997 | 9231 | 9968 | 10336 | 10434 |
| COM 01 - MA 02 | 915 | 1008 | 1129 | 1266 | 1409 | 1552 |
| COM 01 - FE 02 | 4575 | 4808 | 5171 | 5634 | 6170 | 6752 |
| Total Cost | 11590 | 13814 | 15532 | 16868 | 17914 | 18738 |

**Figure 4.5:** Distribution of Asset Maintenance Cost

### 4.4. Disaster Assessment Method

Disaster assessment applicable to assets were developed under two aspects as pre and post which was developed as a conceptual framework considering the limited availability of data related to passenger terminals. However, the assessment was a hybrid of semi-quantitative approaches and expert judgements.

#### 4.4.1. Pre-Disaster Assessment

For the pre-disaster assessment, an empirical method of using risk score value was adopted in developing the framework. Disaster risk score was formulated using the Equation (5) and the risk assessment rating scales are illustrated in Table 4.13, Table 4.14 and Table 4.15. These scales were developed based on the historical data records and the scales provided in the contemporary studies.

Disaster Risk Score = (Risk Score of disaster Likelihood)*(Risk Score of asset exposure)*(Risk Score of asset vulnerability) (5)

**Table 4.13:** Scale Rating - Disaster Likelihood

| Scale | Frequency | Probability (% chance) |
|---|---|---|
| 1 | No record of disaster in the past | - |
| 2 | Expected to occur less than once every 100 years | Annual Chance < 1 |
| 3 | Expected to occur about once every 51-100 years | 1 ≤ Annual Chance < 2 |
| 4 | Expected to occur about once every 11-50 years | 2 ≤ Annual Chance < 10 |
| 5 | Expected to occur about once every 3-10 years | 10 ≤ Annual Chance < 50 |
| 6 | Expected to occur once every 2 years or more frequently | Annual Chance ≥ 50 |

Source: (Tomlinson, Daman, & Dawson, 2019)

**Table 4.14:** Scale Rating - Asset Exposure

| Scale | Asset Exposure |
|---|---|
| 1 | No damage |
| 2 | Up to 5% damage of the asset |
| 3 | Up to 10% damage of the asset |
| 4 | Up to 25% damage of the asset |
| 5 | Up to 50% damage of the asset |
| 6 | Up to 100% damage of the asset |

**Table 4.15:** Scale Rating - Asset Vulnerability

| Scale | Asset Vulnerability |
|---|---|
| 1 | Very high resistance |
| 2 | High resistance |
| 3 | Medium resistance |
| 4 | Low resistance |
| 5 | Very low resistance |
| 6 | No resistance at all |

Here, Maximum Risk Score = 6 x 6 x 6 = 216

Minimum Risk Score = 1 x 1 x 1 = 1

**Table 4.16:** Scale Rating – Degree of Risk

| Scale | Degree of Risk |
|---|---|
| 1 – 72 | Low risk |
| 73 – 144 | Medium risk |
| 145 – 216 | High risk |

On the other hand, if the same asset gets affected by different disaster incidents, disaster risk of the asset can be calculated by the summation of Equation (5).

Although, this method provides a useful measure of the risk, the scores should be interpreted as best estimates and not absolutes since the semi-quantitative approaches incorporate certain degree of subjectivity that cannot be completely eliminated.

### 4.4.2. Post-Disaster Assessment

Similar to the pre assessment, an empirical method for calculation of the disaster damage on asset was adopted. Here, framework was developed to compute only the immediate damage using the repair/rehabilitation costs whereas long-term losses were not accounted for. However, depreciated asset values are recommended to use when estimating the asset damage instead of using the replacement asset values since the replacement values overestimates the asset damage. If flood losses were evaluated at full replacement costs, "values at risk" would systematically higher than the ones presented in the national accounts (Merz, Kreibich, Schwarze, & Thieken, 2010).

In overall, except to the semi-quantitative approaches adopted above for both the assessment aspects, framework was in cooperated with the expert judgements.

Considering the pre-assessments, risk score will be calculated by a group of experts and the final score value will be taken for accounting the mitigatory measures. On the other hand, for the post-assessments, it is expected to evaluate asset damages via experienced surveyors or assessors to reduce the subjectivity of perceptions as well as to have more a consistent and reliable assessment. Accordingly, conceptual framework for disaster assessment can be illustrated as in Figure 4.6.

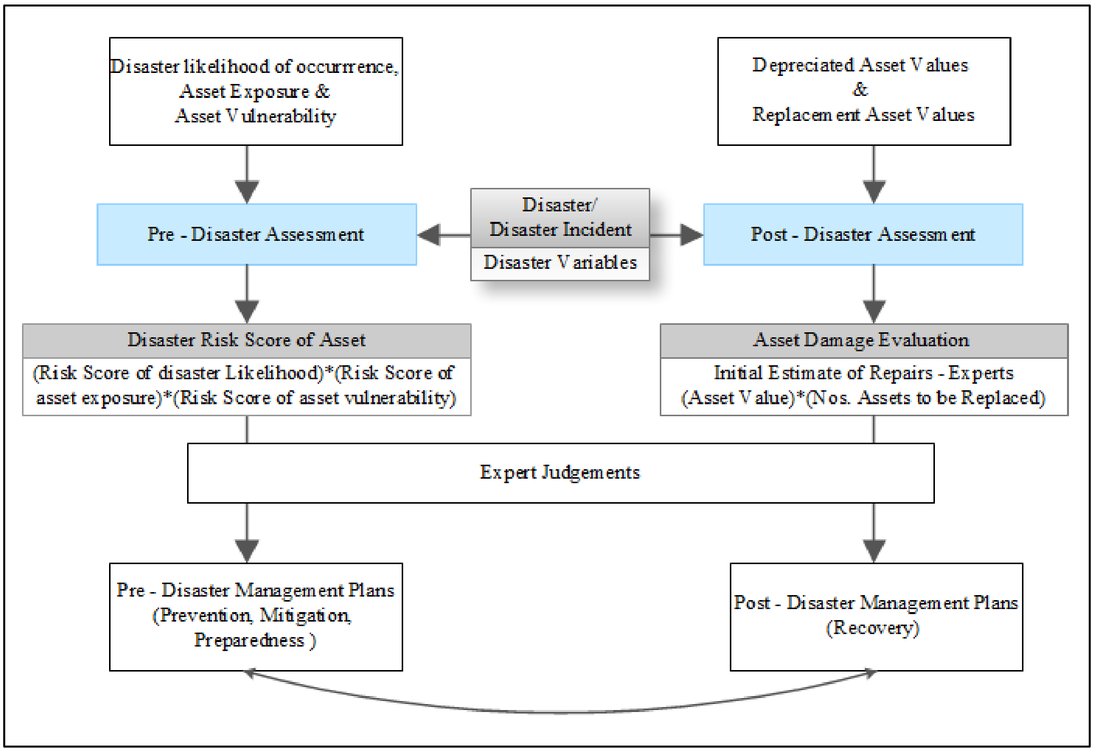



**Figure 4.6:** Disaster Assessment Conceptual Framework

<u>Demonstration Example: Cyclonic Storm Roanu</u>

According to the Sri Lankan Disaster Management Centre (DMC),

- Cascading disaster incidents: Heavy rainfall, Floods, Landslides
- Formed: 19 May 2016 and Dissipated: 23 March 2016
- Heaviest record rainfall after 18 years

Let the disaster likelihood is 18 years and the roof with a medium resistance is subjected to a damage of 10% (Minor exposure),

Pre-Disaster Assessment,

Disaster Risk Score = 4 x 3 x 3 = 36 Hence, Dispaly unit has a low risk

Accordingly, experts can propose disaster mitigation strategies, risk transfer options and disaster improvement plans considering the vulnerability of the assets.

Post-Disaster Assessment,

Assessors can estimate the asset damage depending on its condition; repair or replacement.

However, it is essential to formulate disaster management plans considering all the dependencies of the assets that are vulnerable to disasters such that those critical assets can function post-disaster without any disruptions. Alternative routings or relocations and feasibility of backup systems (backup generators during a power outage) within the budget can be cited as such contingency plans.

Integration of Asset Management with Disaster Management

Here, both the asset management and disaster management assessment methods were developed based on the risk rating. Since it promises of being that both the assessment methods can be integrated through the concept of risk.

## 4.5. Summary

Risk score value was the basic principle applied in developing assessment method for both predictive maintenance of assets and the disaster management of assets in the passenger terminals. Nevertheless, Markov Chain for the asset maintenance and cost projections and simple semi-quantitative approach for the disaster management were adopted. However, expert judgments were in cooperated for all the assessments. Due to the inadequate availability of data related to passenger terminals, only a conceptual framework was developed for the asset cost projections and disaster management through this chapter whereas the limitations and future research directions are elaborated within the next chapter.

# 5. CONCLUSIONS AND RECOMMENATIONS

## 5.1. Introduction

This chapter summarizes the findings of this research and recommendations connecting to the research objectives whereas the findings of this study are discussed under two aspects as the key findings from the literature review and findings of the research. Further, the future research areas ae identified and proposed in this chapter.

## 5.2. Findings from the Literature Review

According to the early findings, condition evaluation makes the foundation for a proper asset maintenance management. This basically deals with the condition evaluation mechanism by introducing a condition rating scale to assess the existing conditions of the assets and cooperate the preventive and predictive maintenance of assets for the future endeavors. Nevertheless, literature introduces the condition scale ratings defined in the early research works and most of them have incorporated the five-point rating scale. On the other hand, most of the early works in worldwide had been focused on the predictive maintenance of assets and their future cost projections as a proactive approach for decision making method instead of existing reactive approach.

Accordingly, literature introduces several predictive modelling methodologies and techniques in which the applicability depends on the data availability, accuracy level and the degradation mechanism of the assets. Also, these models vary in the range of starting from log-based approaches to the advanced simulations through comprehensive software like MATLAB and Simulink through probabilistic approaches. In addition, literature introduces different data collection and monitoring techniques with respect to the asset categories. However, considering the different perspectives, Markov Chain was selected as the most possible approach for this study as the assessment method for predictive maintenance of assets as well as for the cost projections whereas the data was collected through visual inspections. Further, Markov Chain approach was amalgamated with the expert judgements to reduce the subjectivity of the outputs.

Consequently, infrastructure asset management related to the public transport terminals bear the consequences of the disasters in many aspects, yet this area has not been elaborated in many of the early research works. However, for this study, method was proposed to carry out the disaster assessments under two aspects; pre-disaster assessment and post-disaster assessment.

## 5.3. Findings of the Research

Findings of this study are discussed with respect to the objectives of the research as elaborated below.

In this study, Markov Chain was used as the assessment method for the predictive maintenance of assets in KMTT. This asset maintenance assessment method accounts not only the physical condition but also the performance condition, criticality and come up with a risk rating scale. Accordingly, risk score values derived from the condition evaluations were used as the initial distribution matrix of each asset with respect to the condition rating scale illustrated in Table 4.2. However, derivation of the transition matrix was the most challenging part of applying the Markov concept to this study since a reasonable data set is required to derive a validated matrix. But this study had only the present conditions of the assets since the validated matrices developed in a contemporary research were used for this study. However, transition matrices of that study had been developed only for limited asset categories. Since, Markov Chain was used for those evaluated assets that had transition matrices in that study. Accordingly, results of those assets showed the transition probabilities of deterioration of the assets and the expected condition of the assets after the respective time period.

Nevertheless, it should be noted that the transition matrices of that study was developed as an overall matrix for all the assets in the respective asset category (i.e., Transition matrix for services include plumbing, electrical, mechanical and fire services). As a result of this, assets with the same initial distribution matrix shows the same degradation curve and the expected condition. Since expert judgement was in cooperated with the Markov Chain so that it would support for decision making processes. Further, it should be pinpointed that those transition matrices had been derived with respect to the normal deterioration of the assets without considering the maintenance of the assets. Since the assessment method proposed in this study results the predictive conditions of assets with respect to the normal deterioration.

On the other hand, in achieving the secondary objective; cost predictions of assets was also developed based on Markov Chain. But due to the limited availability of maintenance data, a conceptual framework was developed applying a maintenance matrix used in a contemporary research. However, this conceptual framework results expected maintenance cost of the asset for a particular year as well as the derived graphical representations illustrates the cost transition with respect to the condition transition of assets.

Disaster assessments method was also developed as a conceptual framework under two aspects. Similarly, to the asset maintenance, pre-disaster assessment method was too based on the disaster risk score value of the asset whereas the post-disaster assessment method was a simple approach of calculation of asset damage. However, expert judgments were proposed to integrate to both the methods in decision making process of planning mitigatory measures and estimating of the asset repair/rehabilitation cost.

Considering the optimizations of the processes, two workshops were held with expertise of the field (18 participants) and with the stakeholders of the KMTT project. According to their feedback, processes were aligned.

### 5.4. Contribution

This research is the initial attempt to address the gap in knowledge of the lack of methods for predicting the deterioration of assets in the passenger terminals as well as for the disaster management of assets thereby integrating those aspects. Accordingly, this study evaluated conditions of around one thousand assets in KMTT proposed assessment method was applied to a limited number of assets. Nevertheless, the proposed assessment methods and conceptual frameworks can be integrated and developed further to use as a user-friendly software for the assessors and the end-users in the passenger terminals. On the other hand, proposed frameworks can be applied to any passenger terminals in both local and global context. However, a reasonable data collection within respective maintenance intervals of assets is required for effective executions and to have accurate results.

### 5.5. Limitations

Like other research, this study too had encountered limitations specially related to the data collection. Although, condition evaluations were carried out, a reasonable data set for deriving the transition matrices were not available. Also, maintenance data and disaster data related to passenger terminals were not documented properly for in cooperating to the proposed assessment methods and frameworks. Further, the assets that were not able to inspect (Building structure) were proposed to assess as an overall replacement.

### 5.6. Recommendations

Since this study is the initial step of addressing the gap in knowledge and proposing the assessment methods, following recommendations were proposed.

- Expertise judgments – It is recommended to in cooperate more expert judgements and experiences for specifying the condition parameters, condition ratings of the physical and performance conditions and the assigned weightages of the assets as well as for specifying the cost estimations and disaster management plans. This will further reduce the subjectivity of the study through the different perspectives of the experts and optimize the framework.
- Robust data set – Since this is the initial data set, it is suggested to gather at least three robust data sets including condition and maintenance evaluations for derivations of the transition matrices respective to each asset so that the proposed assessment method can be validated. This is applicable for the disaster data related to the passenger terminals.
- Use of GIS software for exposure analysis – Considering the post-disaster assessments, it is recommended to model vulnerability functions (damage functions) in GIS in order to calculate the asset damage for the respective disaster.

- Training to assessors and end-users – It is recommended to administer the training on technical aspects and familiarize the assessors and the end-users if the proposed framework is developed as a user-friendly software tool.

## 5.7. Areas for Future Research

Following can be pinpointed as new approaches to future research areas with respect to the findings of this study.

Considering the limited condition data availability with one time field survey, this study used transition matrices derived in a contemporary study to demonstrate the predictive model. But within a one-time survey as well, a range of data can be collected if the assets are in different age groups (asset 1: 1yr of life, asset 2: 4 yrs. of life, asset 3: 6 yrs. of life etc.) such that the transition matrices can be derived using them. Accordingly, snapshot survey concept can be proposed to capture the deteriorations of the asset conditions with a spectrum of data for developing the predictive models so that the future research can be optimized with limited time surveys.

In this study, criticality for both the physical and performance conditions were assumed as an overall effect with compared to the other similar assets of the same asset subcategory to prioritize the maintenance order. In the sense, criticality for physical condition was assumed as the criticality for the performance condition of the asset. But, in practical scenarios, the assumption may not hold good always whereas the criticality for the physical condition may not be as same as of performance condition. An asset with physical deteriorations yet performing smoothly can be cited as an example. Since, it opens up a new way for the future research to identify the preciseness of predictive results by accounting different criticality values for both the conditions instead of taking it as an overall.

Considering the disaster assessment method, future researchers are suggested to develop the proposed disaster assessment method such that it can be used to calibrate the pre-disaster assessment and further for validating the outcomes.

This study was limited to the passenger terminals focusing the assets in KMTT. However, future researchers are expected to extend the research area by experimenting the applicability of this proposed framework and/or amended advanced framework with other industrial sectors such as construction, health, power, and telecommunication etc.

### 5.8. Conclusion

In overall, it can be concluded that the Markov Chain is the best possible approach that can be developed based on the present condition of the assets although calibration of transition matrices is challenging. However, presence of a robust data set (collected through a continuous cycle of condition monitoring) for both the asset maintenance and disaster management is essential to have better predictions and plannings so that the reactive nature of decision-making processes can be minimized.

## References


[1] (n.d.). Retrieved September 2021, from https://www.lce.com

[2] (IAM), I. o. (2008). *PAS 55-1:2008.* BSI.

[3] A, S. (2003). Using a Condition Dependent Approach to Maintenance to Control Costs and Performances. *Journal of Facilities Management*, 380 – 395.

[4] Abuzayana, K. M., Whyte, A., & Bell, J. (2014). Asset-management framework(s) for infrastructure facilities in adverse (post-conflict/disaster-zone/high-alert) conditions. *4th International Conference on Building Resilience, Building Resilience* (pp. 304 – 311). Salford Quays, United kingdom: Elsevier B.V.

[5] ADB. (2017, November). Disaster Risk Assessment for Project Preparation. Manila, Philippines: Asian Development Bank.

[6] Ahluwalia, S. S. (2008). *A framework for efficient condition assessment of the building infrastructure.* Waterloo, Ontario, Canada.

[7] Awang, N. A., Chua, S. J., & Ali, A. S. (2017). Building Condition Assessment Focusing on Persons with Disabilities' Facilities at Hospital Buildings. *Journal of Design and Built Environment*, 73-84.

[8] Besiktepe, D., Ozbek, M. E., & Atadero, R. A. (2021). Condition Assessment Framework for Facility Management Based on Fuzzy Sets Theory. *Buildings 2021*.

[9] Dalia, S., & Elwakil, E. (2019). Asset Condition Assessment Model Framework for Healthcare Facilities. *School of Construction Management.* West Lafayette, USA.

[10] *deloitte*. (2022). Retrieved January 15, 2022, from deloitte web site: https://www2.deloitte.com/br/en/pages/finance/solutions/asset-management-optimization.html

[11] *ezofficeinventory*. (2022, January 19). Retrieved February 5, 2022, from ezofficeinventory web site: https://blog.ezofficeinventory.com/why-use-an-asset-tracking-software-for-disaster-management/

[12] Fiix. (2022). The Short Guide to Preventive Maintenance. Canada.

[13] Fiix. (n.d.). The Short Guide to Preventive Maintenance. Canada.

[14] *GE Digital*. (2022). Retrieved January 15, 2022, from GE Digital Web site: https://www.ge.com/digital/blog/repair-vs-replace-how-assess-true-lifecycle-cost-your-assets-part-2

[15] Goins, J., & Moezzi, M. (2012). *Links between Occupant Complaint Handling and Building Performance.* Berkeley, CA, USA: Center for the Built Environment.

[16] Halliwell, E. (2019, June 6). *Servicechannel*. Retrieved January 15, 2022, from Service channel Web site: https://servicechannel.com/blog/balance-replacement-asset-value-maintenance-cost/

[17] Haster, T., Freese, P. E., & Nichols. (2016). Development of a Sustainable Asset Management and CIP Program. Cathleen Reed. Retrieved from https://slideplayer.com/slide/12565405/

[18] *International Infrastructure Management Manual* (3rd ed.). (2006). Thames, N.Z.: Association of Local Government Engineering N.Z. Inc (INGENIUM), National Asset Management Steering (NAMS) Group.

[19] Inya, N., & Omar, S. (2021). A Risk Management Database Framework Implementation for Transportation Asset Management. *CivilEng*, 193-213.

[20] J, R. (1993). Condition Assessment Surveys. *Facilities* , 11-13.

[21] Keshavarzrad, P. (2015, March). Optimising Asset Management of Community Buildings.

[22] Kohler, A., Jülich, S., & Bloemertz, L. (2004, June). *Preventionweb.* Retrieved January 15, 2022, from Preventionweb Web site: https://www.preventionweb.net/files/1085_enriskanalysischs16.pdf

[23] Lavy, S. (2008). Facility management practices in higher education buildings. *Journal of Facilities Management*, 303–315.

[24] Lee, S.-Y., Chung, S.-H., & Oh, J.-K. (2004). Demand Forecasting based Infrastructure Asset Management. *KSCE Journal of Civil Engineering*, 165-172.

[25] Linggar, S., Aminullah, A., & Triwiyono, A. (2018). Analysis of building and its components condition assessment. *MATEC Web of Conferences.*

[26] Merz, B., Kreibich, H., Schwarze, R., & Thieken, A. (2010, August 18). Assessment of economic flood damage. Germany: Copernicus Publications.

[27] Mohseni, H., Setunge, S., Zhang, G., & Wakefield, R. (2017). Markov Process for Deterioration Modeling and Asset Management of Community Buildings. 1-12.

[28] N, S. (2004). Making the Case for Facility Condition Assessment. *CEFPI 2004 Annual, International Conference.* Burgess Carter, U.S.A.

[29] Okoh, C., Roy, R., Mehnen, J., & Redding, L. (2014). Overview of Remaining Useful Life Prediction Techniques in Through-Life Engineering Services. *6th CIRP Conference*, 158-163.

[30] Ramli, M. W., Alias, N. E., Yusop, Z., & Taib, S. M. (2020). Disaster Risk Index: A Review of Local Scale Concept and Methodologies. *IOP Conference Series: Earth and Environmental Science* (pp. 1-11). Malaysia: IOP Publishing.

[31] Robery, P. C. (2014). Keynote: Role of Asset Management in Monitoring Durability Changes to Minimize Safety Risks to Infrastructure. *3rd international Conference of Service Life Design for Infrastructure.* Zhuhai, China.

[32] Robielos, R. A., Lin, C. J., Senoro, D. B., & Ney, F. P. (2020). Development of Vulnerability Assessment Framework for Disaster Risk Reduction at Three Levels of Geopolitical Units in the Philippines. *Sustainability*, 1-27.

[33] Ruben, S., Dmitriy, F., Fabian, M., & Zhuang, W. (2014). Log-based Predictive Maintenance. *Sipos, Ruben & Fradkin, Dmitriy & Moerchen, Fabian & Wang, Zhuang. (2014).Proceedings of the ACM SIGKDD International Conference on Knowledge Discovery and Data Mining*, 1867–1876.

[34] Sahaduta, L., Akhmad, A., & Andreas, T. (2019). Analysis of building and its components condition assessment case study of dormitory buildings. *MATEC Web of Conferences.* Yogyakarta, Indonesia: EDP Sciences.

[35] SEM, C. (2014). *weebly*. Retrieved January 2022, from weebly web site: https://mem-maintenance.weebly.com

[36] Sharabah, A., & Setunge, S. (2008). A Reliability Based Approach for Management of Council Owned Buildings in Australia - Building Resilience. *CIB International Conference on Building Education and Research*, (pp. 914-923). Heritance Kandalama, Sri Lanka.

[37] Simmons, D. C. (2017). *Understanding disaster risk: risk assessment methodologies and examples.*

[38] Solanki, K. (2022, May 21). *toppers4u.* Retrieved from toppers4u web site: https://www.toppers4u.com/2022/05/markov-chain-analysis-properties.html

[39] Stapelberg, & Frederick, R. (2006). *Australian infrastructure and industry assets management survey : preliminary literature review and survey analysis report.* Brisbane, Australia.

[40] *StudyFinance*. (2022). Retrieved January 15, 2022, from StudyFinance Web site: https://studyfinance.com/maintenance-to-fixed-assets/

[41] Taguchi, R., Tanoue, M., Yamazaki, D., & Hirabayashi, Y. (2022). Global-Scale Assessment of Economic Losses Caused by Flood-Related Business Interruption. *Water*, 1-20.

[42] *The Health and Safety Consultancy*. (2022). Retrieved from The Health and Safety Consultancy: http://www.thehealthandsafetyconsultancy.co.uk/guides/riskrating.asp

[43] *The MathWorks.* (2020). Retrieved from The MathWorks Web site: https://www.mathworks.com

[44] Tomlinson, M., Daman, R., & Dawson, A. (2019). *Hazard, Risk and Vulnerability Analysis (HRVA).* Regional District of Nanaimo, Town of Qualicum Beach, City of Parksville

[45] Washington, U. (2022). *rems.ed.* Retrieved from rems.ed.: https://rems.ed.gov/docs/repository/00000454.doc

[46] Westen, C. v. (2005). *cdema.* Retrieved January 20, 2022, from cdema Web site: https://cdema.org/virtuallibrary/index.php/charim-hbook/methodology/5-risk-assessment/5-5-risk-assessment-methods

[47] Wickramasinghe, V. (2019). A reliability-based approach for predicting degradation of building assets.

[48] Yahaya, M. S., Azis, N., Selva, A. M., Kadir, M. Z., Jasni, J., Jawad, E., . . . Ghazali, Y. Z. (2018). A Maintenance Cost Study of Transformers Based on Markov Model Utilizing Frequency of Transition Approach. *Energies*, 1-14.