



FRAMEWORK FOR OPERATIONS AND MAINTENANCE COST MODEL OF HOSPITAL BUILDING

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Abstract: Hospitals play a vital role in delivering healthcare services to communities. Hospitals are unique facilities that rely on numerous specialized and sometime complex systems to deliver healthcare services to patients. Indian hospitals are run by the private sector as well as the government sector, although there is lack of cost information from the hospitals. Costs of operations and maintenance (O&M) are important part of the Life cycle costs. This research describes framework for development of model for predicting Annual costs of Operations and Maintenance Cost for Hospital Building. It is essential for managers, to recognizing the O&M cost of Hospitals. The framework would be beneficial for the hospital administrators to have an understanding of their cost structures, control over their expenditure in the area of O&M expenses and also help in efficient functioning of the facilities. With this process of developing a cost prediction model, the predictions and the budgeting for the upcoming years during the operational period of hospital will become easier. The framework is applied on various Private Hospitals in India to check the suitability and applicability of the study.

Index Terms - Maintenance, Operations, Cost Modelling, Hospital Building

1.INTRODUCTION

1.1. Background

Buildings undergo deterioration and damage to the building with the age of the building. "The most important factor for maintaining the building's function and value depends on construction quality, a long-term maintenance plan and maintenance management" (Li, et al., 2010). Through various studies, it has been observed that the facility operations and maintenance (O&M) cost is greatly influenced by the decisions made in the early planning and design phase. However, during practice, there is limitation to assessing the financial impact due to lack of prediction of the O&M cost of the building influenced by the decisions made in the project planning phase. (Tu & Huang, 2013)

Maintenance management is one of the most challenging and costly elements in hospitals ((Chotipanich, 2004; Shohet, 2006) as cited in (Yousefli, et al., 2017)). It supports the functioning and continuity of care facilities and services of hospitals as critical as emergency and lifesaving care facilities (Shohet et al., 2003). Maintenance might also affect many non-core activities of hospitals such as food storage and supply, cleaning, and security of buildings ((CHFM, 2016) as cited in (Yousefli, et al., 2017)). The cost information is needed to inform decisions regarding policies, allocation of cost to various facilities and services, to introduce or set user fees, to determine budgets to run health services and also to assess the efficiency of healthcare services across settings (Chatterjee, et al., 2013).

Hospitals are very different from traditional commercial organizations or office buildings. They are unique and critical because of the various complexities involved at infrastructural level, manpower and operational level. Hospital buildings in India are widely varied in terms of their facility provided based on which they belong to whether it is Private Sector or Government Sector. Life cycle cost of the building includes the operation as well as maintenance cost. It is observed that the 60-80% of the life cycle cost. It is essential for the designer, client and the user to determine the cost of O&M (Carr, 2017). In case of hospitals, recognizing the O&M cost of per bed is a critical issue to the hospital administrations.

Hospitals when compared with other facilities are unique in nature because of the complexity of their systems and service. (Salah, et al., 2018). It is difficult to forecast hospital requirements into the future. The problem is while briefing, designing and cost analysis stages of new building mostly there is no participation of the facility managers (Shohet & Lavy, 2004). Shohet, et al., (2003) states health facilities tend to operate 24 hours a day making facilities performance function particularly is very critical. When compared to other facilities hospitals are considered complex due to the presence of several specialty systems that work together in delivering the required services (Salah, et al., 2018).

1.2. Research Objectives

The aim of the research is to develop a framework for O&M cost of hospital building. The principle objectives of the research presented in this paper are:

1. To analyze the maintenance practices and identify the factors affecting O&M cost in hospital building
2. To identify O&M cost attributes and developing a framework for cost prediction model
3. To demonstrate the application of the developed framework.

1.3 Research Methodology

The research was carried out in four stages. The first stage includes literature review based on the keywords such as O&M, Hospital Buildings, Cost Modelling. The outcome of the first stage was to identify the various factors that affect the O&M cost in hospital building. The second stage is to identify various attributes which contributes towards O&M cost of hospital building through literature study. The attributes were then tested through pilot study to check its viability in Indian hospital buildings. The third stage includes development of framework to develop cost prediction model for O&M cost of hospital building. The final stage to demonstrate the application of the framework on hospital buildings in India.

1.4. Literature Review

A. Operations and Maintenance of Building

Maintenance by NBC (Part 12, 2016,p.7) is defined as “An intervention on an asset to improve its operation or ensure its continued good operation (It is also the combination of all technical and associated administrative actions during the service life to retain a building, or its parts, in a state in which it can perform its required functions.” Bureau of Indian Standards (2016) has stated through its finding that the cost to run a building over its lifetime is more than the cost to build it. Maintenance is often not the given the significance it requires, but to maintain a building is expensive. Through the literature study conducted by (Yousefli, et al., 2017) it was concluded that the operational phase of the building contributes to the biggest amount of expenditure that occur during the service life of the building.

B. Operations and Maintenance Elements of Hospital Building

Boussabaine, et al. (2012) has mentioned responsive (emergency and normal) maintenance and programmed (preventative and renovation (here the major works of replacement are not included) maintenance on building and their parts (lift, auto transport, fire protection system, heating, ventilation and air condition system (HVAC), and electricity generator, etc.) as the variables for maintenance cost. The variables taken into account for operation cost comprises of water bills, electricity for (medicals equipment, lighting, computers, office equipment, heating, ventilation, air conditioning, etc.), oil, gas, and fuel. The rate of beds dedicated to every kind of healthcare activity is a significant driver of the O&M cost of a healthcare facility.

The hospital services are taken in the four key areas such as operating rooms (OR), intensive-care units (ICUs), emergency rooms (ERs) and regular rooms (RRs). As per study of Salah, et al. (2018) the systems that are critical for provision of healthcare services include Medical gases, Elevator systems, HVAC systems. The largest impact is due to Medical-gas systems in case of failure, followed by elevators, primary HVAC, and finally secondary HVAC. (Salah, et al., 2018) The main reason for cost planning for building maintenance are defined as listed below (RICS, 2015) as cited in (Le, et al., 2018)

- “ Determine the target cost limit for maintaining programme works.
- Inform setting the annualized maintenance budgets and available funding constraint.
- Provide cost information to assist decision makers to make informed decisions.
- Inform what asset investment are funded or not funded and then revise life cycle cost plan.
- Ensure the employer is provided with best value for money from maintenance spent.”

Yousefli, et al.(2017) has stated the following research work on O&M cost of hospital:

“Umeh (1994) developed a model consisting of the O&M cost of hospitals. He identified the source of financing and measured its impact on rising cost of maintenance in hospitals. Stolavs Hospital in Norway was examined to determine factors affecting its operating cost (Nesje, 2002). It is advocated that the rate of occupancy per bed, age, scale, and morphology of hospitals are the factors with greater impact on maintenance costs.”

C. Cost Modelling

The process framework plays a significant role in maintaining consistency during the model development process. To develop cost model, it is crucial to acquire previous cases while constantly obtaining new cases. To ensure that the model is improved and modified continuously, a framework should be chosen that has a cycle, such as the Plan, Do, Check, and Act (PDCA) cycle. Since most of the cost models are based on historical data, it is important to acquire sufficient data for estimation (Ji, et al., 2019).To provide cost estimates for maintenance work it is essential to have detailed information regarding the planning of the maintenance work. The information required consists of the brief of the work over the short, medium and long-time span of the building. Usually such information is provided by the user/manager/owner of the building (Le, et al., 2018). Some agreements remain as maintenance works can be challenging to cost accurately due to lack of reliable information required as listed below: (Le, et al., 2018)

- Type of buildings/asset/facility and the functional usage.
- Occupancy details: tenure detail, hours of operations, usage of space.
- A statement of building/asset/facility (age of the building, last major refurbishment, etc.).
- Location and building description.
- Aims of the maintenance programme, maintenance strategy.

Li & Guo (2012) developed research to show how to establish a cost prediction model of maintenance for university buildings in Taiwan that used historical data on maintenance to predict the model, using three different methods: simple linear regression (SLR), multiple linear regression (MLR) and a back propagation artificial neural network (BNP). Krstić & Marenjak (2017) produced the models basing on historical data of buildings in the University of Osijek to predict maintenance cost models over the periods, which used multiple-regression and Stepwise analysis to identify the relationship between the variables resulting in three models. El-Haram, et al. (2002) has proposed data structure for collecting whole life cost data for buildings. In which under the section of Facility Management costs the cost related to O&M life cycle are also considered. This framework will help in understand the elements of buildings that need to be considered for the breakdown of the cost variable of O&M of a building. Since this framework is generalized for a building, its suitability for hospital can be assessed in the study.

D. Attributes and Techniques for predicting O&M Cost

The literature has stated various different methods to develop a cost prediction model for O&M costs in various types of building. The study on condominium properties of Taiwan, Tu & Huang (2013) developed a cost prediction model to identify the average monthly O&M cost through Regression Analysis and Artificial Neural Network (ANN). The two various methods assessed for their accuracy with the actual cost data. For hospital buildings, Sliteen (2011) developed the relationship of the O&M cost with the gross floor area, number of beds, occupancy rate. It also analysed sub-costs of the O&M such as the total utilities cost and staff cost using Regression Analysis. Krstić & Marenjak (2017) developed various equations through Regression Analysis. The set of independent variables included building age, number of storeys, classroom area, teacher's area etc. and the dependent variable as Annual Maintenance and Operation Cost of the University Building. Studies other studies on hospital building used similar variables and developed ways to predict O&M cost using Regression Analysis as a technique. The most important cost elements for O&M include the cost of human resources, energy costs, costs for consumables and spare parts required in the repetitive service and repair of equipment, and charges for various services (e.g. municipal waste and waste water disposal). Considerable investments will also be needed periodically for major retrofits (e.g. refurbishment of external finishes and indoor redecoration) and the replacement of worn-out plant and equipment. (Yik & Lai, 2005) Maintenance cost includes all costs of keeping the building up to an acceptable standard. It relates to the direct cost of maintenance such as spares, labour, equipment and tools as well as indirect costs such as administration, management and the inevitable overhead costs ((El-Haram and Horner, 2002) as cited in (Le, et al., 2018)) Sliteen, et al.(2011) states "The optimal provision operations and maintenance (O&M) costs of buildings must be sought to obtain both economic and managerial objectives. In order for this requirement to be implemented, it must be considered during building design and construction processes."

2. BUILDING MAINTENANCE AND OPERATIONS

2.1. Objectives of Maintenance

The objectives of building maintenance are: (Yong, et al., 2013)

- to ensure that the buildings and their associated services are in a safe condition,
- to ensure that the buildings are fit for use,
- to ensure that the condition of the building meets all statutory requirements,
- to carry out the maintenance work necessary to maintain the value of physical assets of the building stock, and
- to carry out the work necessary to maintain the quality of the building

2.2 Categories of building maintenance work

Building maintenance is the combination of technical and administrative actions to ensure the items and elements of a building are of an acceptable standard to perform their required functions. Generally, building maintenance is divided into planned maintenance and unplanned maintenance under BS3811.

Planned maintenance is the predetermined tasks that are well organized and performed in advance so as to reduce or to prevent any damages to the components or items. Planned maintenance, which includes planned preventive maintenance and shutdown maintenance. It is subdivided into condition-based maintenance, reliability centred maintenance (RCM) and total productive maintenance (TPM). (Bureau of Indian Standards, 2016)

Unplanned maintenance is carried out in the event of contingency maintenance without any predetermined plan after failure or damage was detected. It is subdivided into corrective maintenance and emergency maintenance. It is divided into three types: (Bureau of Indian Standards, 2016)

1) Corrective maintenance: Maintenance initiated as a result of the observed or measured condition of plant, equipment, systems, elements, before or after a functional failure, can be used to resolve the problem and ensure correct functional performance. This work can be planned or unplanned.

2) Breakdown maintenance: Breakdown maintenance relates to the task of restoring an asset so that it can fulfil its original function after failure. This method may result in high replacement costs over the lifetime of the asset, but has a low initial maintenance resource requirement. It is sometimes used for simple facilities that have few operatives and no critical environments to support.

3) Emergency maintenance: This maintenance method results from a sudden, unforeseen occurrence requiring immediate corrective work to be carried out to restore to function and to avoid potentially serious consequences.

2.2 Factors Affecting Operations and Maintenance Cost

It was observed through the study of various authors (Omari, 2011; Ali.et.al., 2010; Rupani et.al.,2017; Jandali and Sweis, 2018; Perera et. al., 2016) the contributing factors affecting the operations and maintenance Cost are categorized in technical, managerial, financial and design phase categories. The highlighted factors represent the maximum occurrence in the works of the mentioned authors.

Table 1 : Factors Affecting Maintenance Cost

Technical	Managerial
Design problems	Maintenance management factors
Faulty maintenance	Resource management factors
Building characteristics	Duration of the maintenance contract
Building Age	Poor administration of maintenance management
Building height	Lack of documentation on the maintenance work
Building area or size	Absence of form of planned maintenance program
Type of structure	Lack of preventive maintenance method
Building Services	Building energy management system
Building materials	
Poor quality control	
Site conditions	

Financial	Design Phase
Insufficient budget allocated for maintenance activities	Absence of maintainability analysis
Poor financial control	Failure to consider life cycle costing analysis
Budget Constraint	Selection and specification of inferior quality materials
Delay in Payment	Errors conducted during the design phase
Inflation of maintenance cost	Lack of feedback from the maintenance group to design team
Failure to forecast maintenance expense	

3. Operations and Maintenance Cost

A building will continue to be a valuable asset only if it is properly operated and maintained. It requires maintenance to keep up its structural integrity, water-tightness and aesthetic appearance, both inside and outside. The services systems also require proper O&M to ensure that indoor environmental conditions can be kept under proper control and that people are well facilitated to move in and out to work, to get the goods and services they want or to enjoy the amenities inside the building. The economic rent of a building will diminish when such qualities are reduced. The following table provides a brief description of the O&M cost. This will help in determining the various attribute that are to be accounted for the study.

Table 2: Description of the cost attributes

Cost Attributes	Description
Operating costs	All costs related to facility operation, such as insurance, air conditioning, ventilation, overhead and wages, energy, fire protection, lifts and escalators, repair and maintenance, security, cleaning and garbage, sundries, and other expenses and fees.
Utilities Costs	Utility costs are associated with the provision of electrical power, potable water, central heating and cooling and sewage service. The utility categories provided were those most commonly used: electricity, fuel oil, natural gas, chilled water, steam, water and sewage. Mostly sewage costs are embedded in water costs, as it were unable to separate the two. Here utility costs are broken out by square meters and adjusted discharges. For utilities, electricity remained as the biggest contributor to the total cost of utilities. (IFMA, 2013)
Maintenance Cost	Annual maintenance costs, also broken out by square meters and adjusted discharges, include all repair, preventive, materials, direct labor and contract costs. This survey indicates that demand maintenance, repairs, and breakdown maintenance increase as a building age. This is consistent with increases in the total costs of utilities as a building ages. (IFMA, 2013) Costs for labor (in-house or contracted-out) and materials required for building monitoring, inspection, repairs, maintenance, and response to service requests are included in maintenance cost.

3. Healthcare in India

The Indian healthcare delivery segment is largely driven by private sector players who occupy a major share of nearly 80% of the country's total healthcare market. They also account for almost 74% of the country's total healthcare expenditure. The private sector has done a commendable job in creating pockets of excellence and has been able to realize significant value. The enduring success has led to the emergence of multiple players and spawned industry diversification and deep specialization enhancing verticalization and reach of offerings. Today, the Indian Healthcare industry has become a preferred Sector for strategic and financial investments. (Apollo, 2018)

3.1. Hospital Expenditure

The hospital expenditure is split into 2 categories; operational and non-operational expenditure. The operational expenditure includes the maintenance expenses. Following is the breakdown of the expenses into each of the 2 categories:

3.2. O&M Cost Attributes of Hospital

Healthcare facilities, be it either small clinics or large hospitals, these are important building assets which are complex to operate, manage and maintain (Lavy & Shohet, 2009). The hospital administration has to run the hospital on a day to day basis to render patient care, which is their primary objective of the hospital, with the personnel, finance, accounts, technical and supportive services. In order to do this the hospital administration has to create a functional organization that will be effective and efficient in order to achieve the hospital objective.

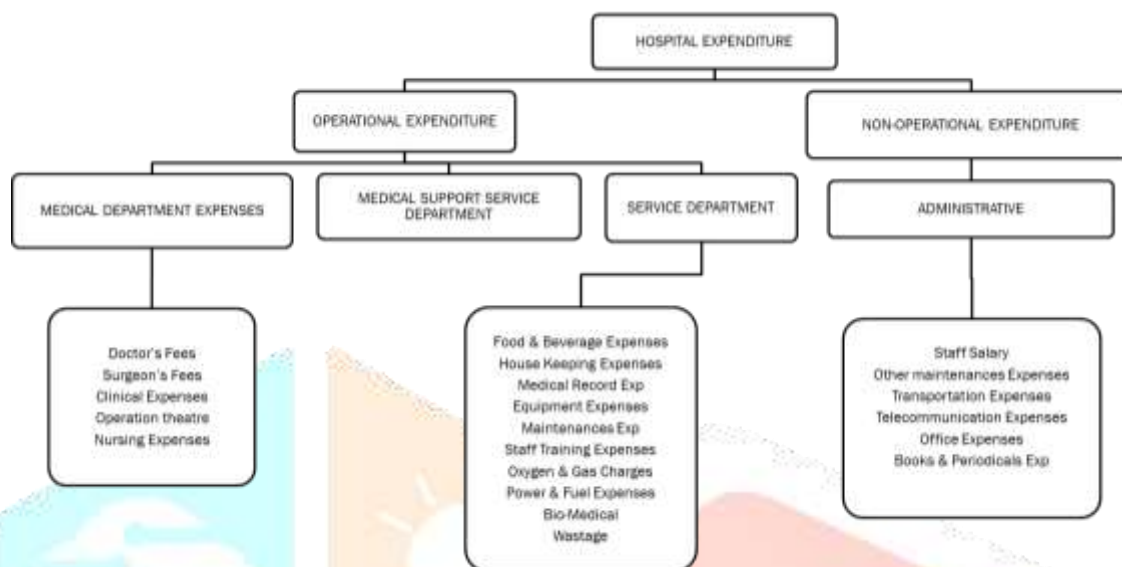


Figure 1 : Hospital Expenditure Breakdown (ICAI,2015)

Table 3 : O&M Cost Attributes

Maintenance Cost Attributes	Operations Cost Attributes
Building Maintenance Cost	Safety and Security Cost
Plant and Machinery Maintenance Cost	Power and Fuel Cost
Housekeeping Cost	Water Cost
Maintenance Cost of Manifold System	Sewerage Cost
Maintenance Material Cost	Clinical Waste Disposal Cost
Equipment Replacement Cost	Domestic Waste Disposal Cost
Outsourced Maintenance Cost	Meal provision Cost
	Laundry and Linen Services Cost
	Patient transport Cost
	Medical Record Cost
	Sterile Services Cost
	Doctor and Nurse Wages
	Manifold System Operating Cost
	Drugs and Medical Supplies Cost

4.1. Operations and Maintenance Cost Model

The cost of O&M work depends on many factors, which include: (Tu & Huang, 2013)

- The range, scale and complexity of services systems to be operated and maintained;
- The quality of services to fulfil user's requirements;
- The competence of the in-house team and the contractor, both in technical knowledge and skills and in organization and management;
- The budget that can be made available for O&M of services systems; and
- The transaction costs associated with the contractual arrangements.

4.2. Purpose of Cost Model

The purpose of cost models generally, is to support at least one of the following tasks:

- Forecasting the total price which the client will have to pay for the building, at any stage in the planning phase.
- To develop a model to assist in the client in budgeting of the O&M, which can also help in deriving alternatives for services to be provided in the hospital.
- It will also help in optimization of cost.
- It will help in appropriate allocation of budgets to the required areas of maintenance and cost of hospital.

4.3. Theoretical framework to develop O&M cost models

The framework is to develop O&M cost model. The framework will consist of input such as the historical cost data of hospitals. The data collected will be then processed through mechanism of Regression Analysis to generate output, i.e., O&M cost models. The below Figure 3 describes the overall diagram of the framework used to develop O&M cost model.

4.4. Data Collection and Data Analysis

For the development of cost model's, data from various hospitals can be collected based on the attributes selected from the literature. The data collection also included the collection of hospital characteristics such as built up area, age, patient beds and bed-occupancy. The model will be developed based on the framework to determine the future O&M cost for the hospital building. As observed in literature, majorly the authors have considered the occurrence of O&M cost annually. The annual consideration of O&M cost would make it easier for the user to monitor and assess the changes in strategies to optimize the O&M cost.

The data was grouped according to the major components for cost models. The operation cost has a major sub component i.e., Utilities Cost. The maintenance cost has two of the major sub-components. The first sub-component is housekeeping cost, and the second is repair and maintenance cost. The elements can be combined as per the individual need of the user and building.

4.5 Cost Modelling Technique

Regression analysis and neural networks are two of the modelling techniques, identified by Newton 1991, which have been used to develop models to estimate the cost of buildings. However, predominantly, these models rely on the use of historic but recent cost data.

4.5.1. Multiple Linear Regression (MLR)

Multiple Linear Regression (MLR), also known simply as multiple regression, is a statistical technique that uses multiple independent variables to predict the outcome of a dependent variable. Multiple linear regression (MLR) models the linear relationship between the independent variables and dependent variable.

4.5.2. Multiple Linear Regression: Assumptions

1. There is a linear relationship between the adjacent dependent variables and the independent variables.
2. The independent variables are not highly correlated with each other.
3. Y_i observations are selected independently and randomly from the population.
4. Residuals should be normally distributed with a mean of 0 and variance.

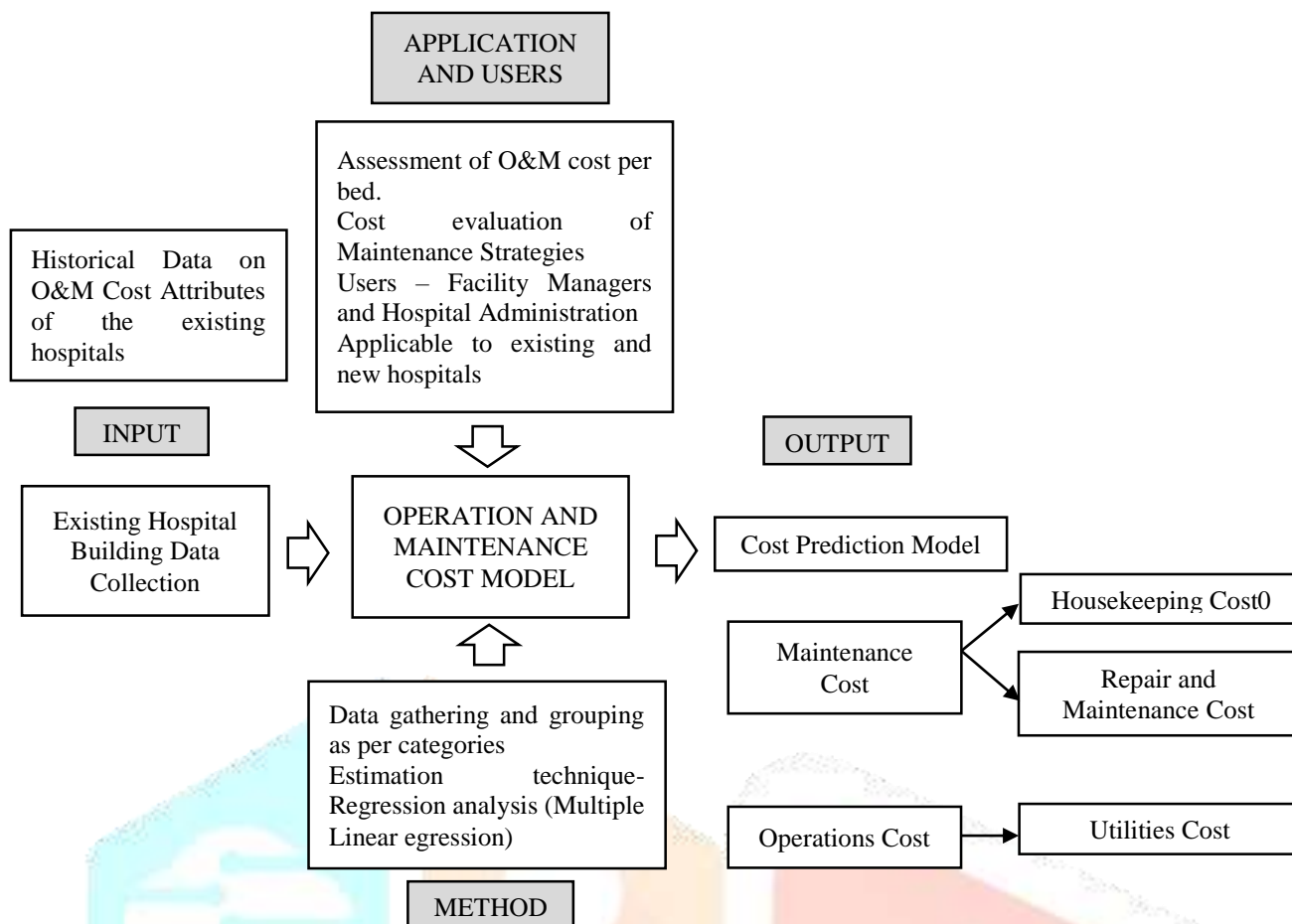


Figure 2: Framework for O&M Cost Model Development (Adapted from Le, et al., 2018)

4.6. Independent and Dependent Variables

The independent variables are the input variables in the cost prediction model and the dependent variable is the dependent variable. The hospital characteristics are considered as independent variable. The dependent variables are O&M cost and their sub components. As seen in previous studies the O&M cost is dependent majorly on the characteristics of the building. The various elements of the O&M cost are grouped together to fit into a regression model. The grouping of the cost attributes can be altered according to the requirement of the cost model. The grouping selected for the study is as stated below in Table 4.

Table 4 : Grouping of O&M Cost Attributes for Cost Model

Cost attributes	Categories	
Equipment Replacement Expenditure	Repair and Maintenance Cost	Maintenance Cost
Plant and Machinery Expenditure		
Building Maintenance Expenditure		
Outsourced Maintenance Expenditure		
Maintenance Expenditure of Manifold System		
Housekeeping Expenditure	Housekeeping Cost	Operations Cost
Sewerage Expenditure	Utilities Cost	
Power and Fuel Expenditure		
Water Expenditure		
Clinical and Domestic Waste Disposal Expenditure		
Safety and Security Expenditure	Operating Cost	
Meal provision Expenditure		
Laundry and Linen Services Expenditure		
Administrative Expenditure		
Doctor and Nurse Wages		
Drugs and Medical Supplies Expenditure		
Operating Cost of Manifold Services		

literature states the factor which affects the O&M cost and those are the building characteristics. Hence, it is selected as independent variables for the development of cost model. The list of independent and dependent variables is as follows:

Independent variables	Dependent variables
Built Up Area	Annual Repair and Maintenance Cost
Building Age	Annual Housekeeping Cost
Patient Beds	Annual Maintenance Cost
Bed Occupancy Rate	Annually Utilities Cost
	Annually Operations Cost

5. Application of Framework: Development of Cost Model

The O&M expenditure data was collected from 4 different private hospitals. The data was collected for various time period of the hospital building constituting of 11 training samples for development of cost model.

Table 5: The data distributions of the dependent and independent variables of the 11 training samples

	Minimum	Maximum	Average	S.D.
Built Up Area	6264	55741	46173.7	18231.94014
Building Age	6	28	20	5.966573556
Patient Beds	108	718	603.7	220.1109225
Bed Occupancy Rate	0.6	0.88	0.78	0.086171077
Annual Maintenance Cost	15387786	235799611.00	145443365.18	65743437.29
Annual Operations Cost	575873402	5218158156	3738743050	1693522564

Regression Analysis is performed on the above training samples. The P-value and the R-square values were assessed along with the normality curve. The residual analysis is performed through P-P plot. The best results for the selected combination of independent variables is chosen to formulate the equations.

The O&M cost models developed for private hospitals through the developed framework are as follows:

Annual Repair and Maintenance Cost

$$M_1 = 43979.9 b_1 + 18109984 b_2 - 3774726.5 b_3 + 18826437.8 \quad (1)$$

Annual Housekeeping Cost

$$M_2 = -93.6 b_1 + 848782.9 b_2 + 243455.8 \quad (2)$$

Annual Maintenance Cost

$$M_3 = 44223.09 b_1 + 19064456.3 b_2 - 3805623.1 b_3 + 19767560.19 \quad (3)$$

Annual Utilities Cost

$$O_1 = 9741.8 b_1 - 506641 b_3 - 11215823.8 \quad (4)$$

Annual Operations Cost

$$O_2 = 421966.1 b_1 - 7726898.6 b_4 - 21360913.1 b_3 + 768143021.2 \quad (5)$$

6. Conclusion

Hospitals are very different from traditional commercial organizations or office buildings. They are unique and critical because of the various complexities involved at infrastructural level, manpower and operational level. The study presents methods to predict O&M cost of Hospital Building. The O&M cost of ranges between 70 per cent to 80 per cent of the overall life cycle cost of a building. The significance of whole-life costs for building operation and maintenance (O&M) is well known. The causes of ill-budgeted O&M resources, however, are often uncertain. This paper contributes to the 'cost modelling' research field, from the project management and Life Cycle Cost Analysis perspectives, by developing an effective framework to develop prediction model in predicting buildings' future O&M costs in the project planning phase and operational phase. With this decision support tool, it is expected that the operational feasibility or affordability of proposed design schemes can be ensured in the project planning phase, and unexpected operational problems, such as budgeting of funds for O&M or shortage of fund can be catered by determining the budget required for the upcoming years through cost prediction model. The study analysed which factors can affect operations maintenance and costs. Presented results can indicate importance of those factors already at the planning phase of new buildings. Consideration of those factors could lead to the rationalization of operations and maintenance costs of buildings with similar purpose.

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