BUILDING MAINTENANCE COST PLANNING AND ESTIMATING: A LITERATURE REVIEW

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There always exists budget constraint and competing priorities in maintenance needs for existing buildings. The purpose of this article is to conduct a critical literature review on: various maintenance types; and existing maintenance cost estimating models to develop a framework for maintenance budg*et al*location. A comparative study of current categories in maintenance works and maintenance cost models identified crucial factors that are considered in the decision-making of maintenance cost. Preventive and corrective are main strategies for building maintenance. Performance of these strategies suffers from the allocation of the maintenance budget. Cost estimation models for the different types of maintenance have not been developed yet since lack of a reliable data system. The findings highlight the importance of information system to support inspection building condition, monitor maintenance works and recorded data of building maintenance.

Keywords: cost estimating, cost planning, maintenance management

INTRODUCTION

Building maintenance is considered as a major activity in the construction industry because it is essential whether the buildings are large or small, simple or complex, located in urban or suburb. They must be well maintained to ensure their functionality and services during their life cycle. Traditionally, maintenance is defined as work on existing buildings undertaken to keep, restore or improve every part of a building, its services and surround to its original level and not to fall below the minimum acceptable level (British Standard 3811, 1993). Over the past, stakeholders of building asset have required the outcomes of building maintenance to meet certain criteria including re-instating physical condition to a specified standard; preventing further deterioration or failure; restoring correct operation within specified parameters; replacing components at the end of their useful/economic life with modern engineering equivalents; making temporary repairs for immediate health, safety and security reasons; and mitigation of the consequences of a natural disaster and assessing buildings for maintenance requirements (Queensland Government 2, 2017). Maintainability is an inherent characteristic of system design and installation with major maintenance implications as follows (Dell'lsola and Krik, 2003).

- The choice of exterior and interior finishes.

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- Selection of light fixtures, floor covering materials and interior elements.
- Plan for and implement a maintenance program.
- Perform most or all maintenance with full-time staff, or to contract for the services.

The quality of maintenance activities is significantly influenced by the amount of budg*et al*located. A common challenge is recognised in allocating maintenance budget with the argument during the process of formulating the maintenance funding (Lee and Scott, 2008). It is evidence that the cost of all maintenance works annually will exceed yearly budget and then the decision makers have to decide which tasks should take priority this year to maintain the building within the funds available and what could be delayed to the following year (NWS Heritage Office, 2004). Therefore, a proper maintenance cost plan would enable building owners to get optimal of maintenance outcome.

The cost plan will provide an available maintenance budget distribution among the elements, functions, or floor areas of the building resulting in providing a work breakdown structure and a cost breakdown structure that will help to control and monitor the maintenance cost (RICS, 2015). Cost estimation methods are vital components in determining the expenditures using in maintenance strategies and plans. Overestimation or underestimation of maintenance cost could affect negatively on decision making of the hierarchy of maintenance tasks as well as prevent using the maintenance budget effectively. However, preparing estimates for maintenance cost allocation is depending on various factors that makes the task to be complicated and challenging (Shah Ali, 2009). Although there are different approaches to estimate the cost, each method has its limitation to different types of maintenance works (Haroun, 2015; Raiborn, 2013; Maher *et al.,* 2011).

This study will analyse different methods to calculate maintenance cost to find out the better alternative for building maintenance costing. To achieve the aim, the paper tries to provide a systematic overview of maintenance work classification and existing cost models using in estimating maintenance cost. Based on an analytical comparison between these approaches, future work for cost planning and estimating for the maintenance is proposed appropriately.

LITERATURE REVIEW

Maintenance Work Types

Maintenance can be categorised according to answer questions why and when it happens. Figure 1 below present a summary of categorisation of maintenance work classification which enables organisations to provide consistent services to customers' satisfaction. There are two common terms of maintenance types: planned/preventive maintenance and corrective/unplanned maintenance with other categories as shown in Figure 1. Commonly, planned/preventive maintenance aims to prevent major breakdowns to ensure a building continues at peak efficiency through regular inspection and repair (Madureira *et al.,* 2017). Preventive maintenance is planned, based on cyclic maintenance actions such as cleaning, local repair and local replacement/treatment to prevent deterioration in advance (Ruparathna, Hewage and Sadiq, 2018; Queensland Government 2, 2017; EU Standard, 2009). Statutory maintenance, time-based, condition-based, predictive, reliability-centred maintenances are sub-categories of planned/preventive maintenance (Queensland Government 2, 2017; Ruparathna *et al.,* 2018; Wang *et al.,* 2014).

Although well-planned, maintenance work must always be ready to respond to unexpected breakdown. Corrective/unplanned maintenance consists of repair and replacement elements due to the failure of preventive maintenance or natural wear and tear that sometimes is called reactive maintenance (Ruparathna *et al.,* 2018; Queensland Government 2, 2017; EU Standard, 2009; Muyingo, 2009). There will be preventive and corrective maintenance work in any maintenance strategies. The planner should ensure that there is no conflict or duplication between reactive actions and planned operation. The proposed planning of maintenance activity should base on the estimated service life of building properties, cost rationalisation and users' satisfaction.

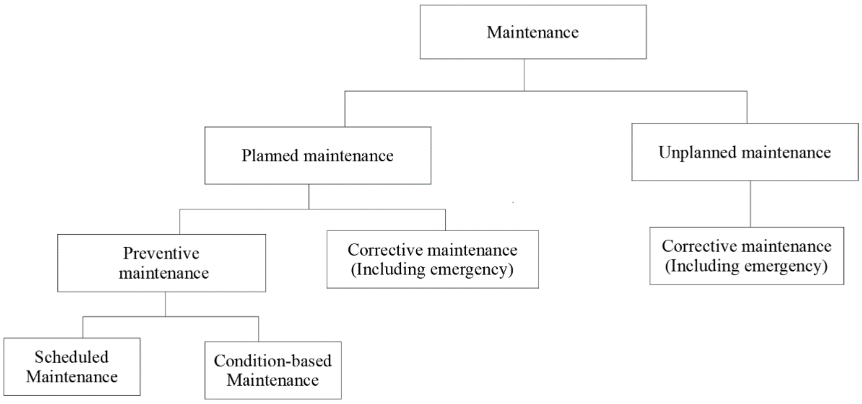

Figure 1: Types of maintenance (Chanter and Swallow, 2007).

The preventive maintenance is justifiable for health, safety and environmentally significant components/items for both items whose condition can or cannot be monitored. The corrective maintenance is appropriate for non-significant components/items and other items which the cost of applying time-based preventive maintenance is less than the cost of applying corrective maintenance (Horner, El-Haram and Munns, 1997). Based on the advantages and disadvantages of the above maintenance types, Table 1 categorises the maintenance hierarchy for building components/systems.

Table 1: Maintenance hierarchy for building components

Type of maintenance	Type of equipment
Corrective maintenance	Small parts and equipment.
	Noncritical equipment/item.
	Equipment unlikely to fail.
	Utility significant items whose condition cannot be monitored
Preventive maintenance	Equipment with known failure pattern.
	Recommended by the manufacturer.
	Consumable equipment.
	Equipment with subjected to wear

Source: Ruparathna et al., (2018).

The overall maintenance plan must provide information to allocate and prioritize sufficient resource and funds for the maintenance operations. The annual list of required maintenance with an estimated cost in the five-year programme usually follows. Alternatively, the repairs will be carried out in order of priority. Therefore, some maintenance will be deferred since the resource is limited. It should be noted that the buildings will require a certain of level of maintenance whatever the current economic situation.

Maintenance Cost Planning and Estimating

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, labours, equipment and tools as well as indirect costs such as administration, management and the inevitable overhead costs (El-Haram and Horner, 2002). When the demands of maintenance are identified, cost of the maintenance should be a prior estimate to measure resource availability and how much work should be scheduled in each period. Although cost estimates for building maintenance are normally prepared over the period to predict the likely cost of such works over the life of the buildings, they can be considered in a single annual maintenance programme. The main purposes of a cost plan for building maintenance are defined as listed below (RICS, 2015).

- Determine the target cost limit for maintaining programme works.
- Inform setting the annualised 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.

Like any program or plan, maintenance budgets will be subjected to change and adjustment and it must be based on forecasting or predicting aiming to best utilise fixed maintenance resource to meet the fluctuating maintenance workload (Al-Fares and Duffuaa, 2009). Total maintenance cost is the sum of the cost of preventive maintenance and corrective maintenance as shown in Figure 2. Having a proper preventive maintenance strategy can reduce corrective maintenance cost, leading to reach optimal maintenance zone. The optimal zone is where the two costs are balanced. Once funds are approved for the maintenance budget, efficient use of this money requires wise internal allocation of the funding at the operational level or locating this optimal zone.

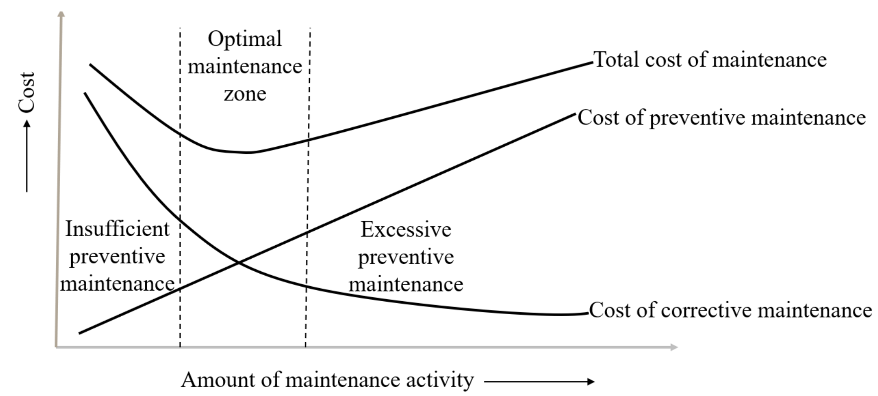

Figure 2: Total of maintenance cost (Douglas, 2017).

Douglas (2017) also summarised five stages in the optimisation process, that should be embedded in the design phase but will offer benefits to any state of a building lifecycle: (**1**) identify critical functions/elements/areas; (**2**) understand the failure models and effects; (**3**) evaluate existing maintenance; (**4**) apply predict maintenance technique; and (**5**) recommend changes to maintenance strategy according to findings of best practice.

Cost planning and estimating of maintenance work require detailed information such as maintenance requirements or the employer's brief for maintenance work throughout the life of the building over the short, medium and long-term. Some agreements remain as maintenance works can be challenging to cost accurately due to lack of reliable information required as listed below:.

- 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.

A limited number of the building components such as roofs, paintwork, woodwork and building services play a large part in maintenance cost (Straub, 2003). Therefore, identifying significant factors affecting the maintenance cost and the relationship between the factors such as building characteristics, tenant factors, maintenance factors, political factors might help to control the factors to optimise the maintenance cost. While planned maintenance works have different technical specifications resulting in differences in requirements for maintenance resource, leading to different approaches to calculating the costs for specific scheduled maintenance work (Mirghani, 2009), the unplanned maintenance costs usually are budget based on historical data showing by percentage of actual breakdown cost and total cost of maintenance.

Existing Cost Estimating Models for Maintenance

Table 2 presents a summary of cost estimating models for building maintenance, which is produced in recent years. Batalović *et al., (*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.

Li and 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 regression and a back propagation artificial neural network (BNP). Au-Yong, Ali and Ahmad (2013) established six significant characteristics that are correlated to the cost performance of high-rise office buildings. ASHRAE Owning and Operating database is a database of information on equipment service life and annual maintenance costs for a variety of building types and HVAC systems. The ASHRAE maintenance cost model is based on commercial office buildings in the US aiming at providing accurate and usable building owning and operating cost data to building owners and managers in respect of strategic decisions involving the life cycle and functionality of their buildings.

Table 2: Comparisons of Cost Estimating Models for Building Maintenance.

Project 1	Maintenance cost model for University buildings (Batalović *et al*., 2017)
Data Collection and Analysis	- A questionnaire survey was conducted to gather information of building characteristics, operational-usage characteristics: building age, number of stories, areas in each function, number of staff, number of students, number of shifts, time used for the purposes and reference period. - Historical maintenance and operation costs for 12 years: inspection cost, life cycle replacement costs, costs of periodic works and repairs, cost of reactive maintenance and operation costs. - The research applied statistical analysis and the application of regression analysis to form a database of independent and dependent variables
Significant variables	- building age - number of buildings stories - an overall hallway area
Models	MOC1 = 50356.55 + 101.21*H (€) MOC2 = 133475.30 + 18039 84 * S +89.86 * H (€) MOC3 = 58635.72 + 200.27* B +118.13* H (€) where B stands for building age, S stands for a number of buildings stories, and H is an overall hallways area of building expressed in m2.
Project 2	Cost prediction model of maintenance costs and budgeting for university buildings in Taiwan (Li and Guo, 2012)
Data Collection and Analysis	- Historical data on maintenance and repair from four university buildings over a 42-year period There were three assumed models used for estimation: - simple linear regression - multiple regression - back propagation artificial neural network (BPN): the maintenance and renovation costs of university buildings have a fluctuation and affected by the LCC, material prices and remedy cost value.
Significant variables	- building age; the number of floors; the number of classrooms - the elevators; the structure type; the total floor area
Models	A = 2.6388 + 35.25x - 26.678, where x is the age of a building, and A is total the maintenance costs over the years using simple linear regression B: maintenance cost models using multi-regression B1 = - 4957.1 + 147.84*building age + 774.3*floor + 35.1*class - 34.5*elevator B2 = - 2578.6 + 14.1*building age + 403.6*floor+ 314.3* elevator B3 = - 4812.8 + 147.6*building age + 742.3*floor + 34.4*class B4 = - 3677.7 + 142.9*building age + 683.1 *floor C: maintenance cost model using BPN with the basic structure of the network included hidden layers, an input layer and an output layer with parameters are hidden layers, nodes, loops, speed and momentum factors
Project 3	The findings of relationships between characteristics of scheduled maintenance and cost performance were analysed to obtain information for the prediction of maintenance performance (Au-yong *et al*., 2013).
Data Collection and Analysis	- This research was conducted using the triangulation approach, which included literature review, questionnaire survey that is recognised as the most appropriate method for data collection, and a semi-structured interview for validation of quantitative results - It was established that five characteristics are significantly correlated to the cost performance, the predictors of maintenance expenditure variance (MEV) included - skill and knowledge of labour (SKL), - level of spare part and material stock (LSP), - quality of spare parts and materials (QSP), - length of predetermined maintenance interval (LMI), - amount of maintenance and failure downtime (AMD). The multi-regression was analysed to produce the model
Significant variables	- Skill and knowledge of labour - Quality of spare parts and materials - Length of predetermined maintenance interval
Models	Maintenance expenditure variance (MEV) is produced as below: MEV1 = 7.704 – 0.380 SKL – 0.144 LSP – 0.361 QSP – 0.317 LMI – 0.085 AMD MEV2 = 7.286 – 0.423 SKL – 0.400 QSP – 0.324 LMI
Project 4	Maintenance cost model for building services (Ashrae, 2018)
Data Collection and Analysis	Various criteria were collected such as characteristics of buildings including location, age, size, height, a percentage of heated and cooled areas, functions, information of in-house maintenance and contract maintenance, and a proportion of preventive, predictive, and corrective maintenance cost - The indexes, base cost, and inflation index are identified from other ASHRAE research.
Models	Total maintenance cost in cents per square foot = [Base cost + (Age adjustment factor x Age in years) + Heating system adjustment factor + Cooling system adjustment factor + Distribution system adjustment factor)] x Inflation adjustment

All the cost estimation models discussed above have not considered the type of maintenance that limit the effectiveness of internal budg*et al*location. Once funds are approved for the maintenance budget, efficient use of this money requires wise internal allocation of the funding at the operational level.

Therefore, with different maintenance strategies, different cost estimation approaches should be applied to calculate more accuracy maintenance costs. According to the Figure 1 and Figure 2, annualised maintenance cost [AMC] can be calculated as:.

AMC = Corrective maintenance cost + Preventive maintenance cost [1].

Preventive maintenance cost can use traditional order costing to estimate the cost since the maintenance works are scheduled in time, resource and scale. A framework for costing planned maintenance can be referred to Mirghani (2001). Emergency preventive, predictive and corrective maintenance occur randomly, so recorded information about previous corrective maintenance cost plays a vital role to predict the cost for future. The dataset of information should be updated regularly to be used in statistical analysis or simulation such as Monte Carlo method to estimate the uncertain maintenance such as failure by natural disasters. In the scope of this study, there is not any cost model that has been developed for the uncertain maintenance types.

DISCUSSIONS AND FUTURE WORK

This paper has identified the most widely used approaches for maintenance classification of building maintenance. Many researchers pointed out that although corrective maintenance is rational when the impact of failure is rather than small, carrying out the corrective maintenance required performing immediately. Otherwise, higher costs than expected may be consequences when these faults happen in unexpected ways and at the wrong time, causing inconvenience to users and downtime independent components or systems. The authors also stated that preventive maintenance is justifiable if the consequence of fault is high about the cost of doing something that in advance reduces the risk for the fault (Lind and Muyingo, 2012). However, limitation of this maintenance approach is redundant tasks may be carried out or manufacturer's recommendation has limited local conditions and the actual process.

The literature review also indicates that to develop a rational maintenance plan requires both building inspection data and recording data on previous conservation works. Without this information, it is hard to decide on a maintenance policy or estimate the expenditure for a budget. Traditionally, to the asset, the building condition usually by visual only hardly to discover all problems. However, new methods and technologies such as a 3D scanner and Building Information Modelling have not been applied widely yet in the areas. Additionally, failures of maintenance sometimes have occurred since lack of communication between different management levels of maintenance and lack of previous maintenance knowledge of building manager and in-house staff whose responsible for maintenance activities in the building (Yin, 2008; Shah Ali, 2009). One idea can support the issue is knowledge management system which is discussed in Zavadskas *et al., (*2010). Key questions of the system are what components/systems should be monitor automatically and how to get lesson-learned from previous conservation and similar buildings.

The estimations will not only predict the cost of maintenance but also play an active role in shaping the role construction management which provides input for taking action (Georg and Tryggestad, 2009), The proposed framework for future research is developed by process mapping using IDEF0 method. Akasah *et al., (*2010) stated that IDEF0 is identified as the most appropriate technique for modelling a process that involves functions and activities as found in the maintenance management process of buildings.

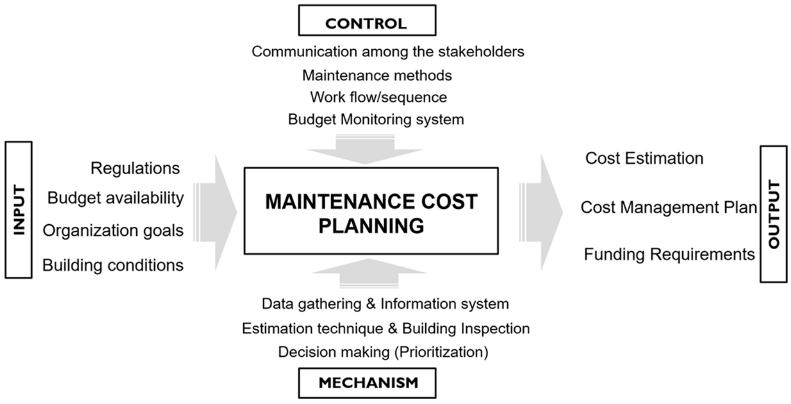

Figure 3: Proposed framework for future research.

In the method, maintenance cost planning is an activity, inputs are the data or objects to be transformed into outputs; outputs are data or objects produced by the activity; controls define conditions require to produce the correct output and mechanism are the means used to perform the activity (Erdogan, 2008). The elements in Figure 3 are proposed based on the literature review. The outputs of maintenance cost planning and estimating is the amount of maintenance cost that considers the dynamic and strategic role of building maintenance. The estimations will also propose cost management plan for maintenance work to get value for money. The cost plan is expected to adjust funding requirements since new and more users and functions/elements/areas can emerge during the service life of the building. Building conditions including innovation design and equipment; budget availability align with organisation goals and regulations such as building act or government strategy are the inputs of the cost plan. There are various factors control the maintenance cost planning and estimating. Well communication of building stakeholders will develop proper maintenance methods which are outsourcing service or in-house staff and maintenance workflow. A budget monitoring system will ensure the process standardised and transparent. Data needed including materials and labour costs, historical data and specifications should be gathered using innovation of information technology for knowledge management. Estimation technique and building inspection methods leading to the certain amount of maintenance cost will help the building owners make informed decisions. The framework aims to develop a cost plan for building maintenance in order to aid building owners to allocate the maintenance budget reasonably, thus allowing them to monitor/control the funding for maintenance in a standardised manner.

CONCLUSIONS

The literature review reveals that maintenance decisions made have a significant implication on maintenance cost. Good estimating of the anticipated cost of maintenance contributes to performing the tasks within the overall period of the budget. Especially in public sector, since almost public buildings use public funding, it requires that effective allocation practices be adopted to optimise the efficiency of the funds. However, lack of the needed data is considered as a reason to prevent the effectiveness. A framework should be developed to assist building stakeholders in inspecting the building, monitor the maintenance, collect and record the required information. Future research focuses on the development of case studies to test the proposed framework. Based on the information provided by the dataset and validated model, building owners and designers should pay more attention to the components/systems that have a significant maintenance cost and best practice to adjust the current maintenance strategy toward an optimised state.

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