PREDICTION COST MAINTENANCE MODEL OF OFFICE BUILDING BASED ON CONDITION-BASED MAINTENANCE

1. Introduction

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 [25]. Planned maintenance is the predetermined tasks that are well organised and performed in advance so as to reduce or to prevent any damages to the components or items. It is subdivided into scheduled maintenance and condition-based maintenance. On the other hand, 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 [1].

Moreover, planned maintenance should be the major activity in building maintenance compared to unplanned maintenance. Otherwise, unplanned maintenance will result in frequent breakdown or downtime, and subsequently, high maintenance cost for repair and replacement works [7]. Thus, condition-based maintenance, as a strategy of planned maintenance, should be recommended to achieve the optimal maintenance expenditure.

This paper aims to establish the relationship between the characteristics and the performance through inferential analysis; then, to develop a regression model for prediction purpose. Taking into cognizance of the advantages and disadvantages of condition-based maintenance, this paper focuses on the characteristics of condition-based maintenance towards maintenance performance as shown in Figure 1.

![Fig. 1. Relationship between characteristics of condition-based maintenance and maintenance performance](image-url)
2. High-Rise Office Building

In Malaysia, high-rise building is defined as building of more than 7 storeys (or the top floor of the building is more than 60 feet) [8]. This definition is in accordance with the Uniform Building By-Laws 1984. Despite the increasing concerns on the maintenance of buildings in Malaysia, there are few researches on the facilities and maintenance management of high rise office building.

Office buildings usually have their own maintenance management teams managed by the maintenance or the building managers to preserve the conditions of the buildings [30]. Generally, the services provided by the building managers in office buildings are cleaning, landscaping, general maintenance, lighting, heating, ventilating and air conditioning (HVAC), lift or escalator, mechanical and electrical, sanitary and plumbing, access, signage, parking and others [22]. These services are significant for office buildings as they provide functions, safety, health and comfort to the building users in daily activities.

However, building satisfaction surveys indicated that most building users were not satisfied with the building services [30]. The building users’ dissatisfaction was mainly due to issues such as lack of maintenance staff, lack of expertise, lack of tools and technology, insufficient allocations and inappropriate maintenance strategies. These issues are more evident in medium-sized high-rise office building, which is equipped with more sophisticated systems, such as fire detection and protection systems, central heating, ventilating and air conditioning system, escalators and others [15].

Therefore, this study focuses on the issue related to the building users’ dissatisfaction in high-rise office buildings through the examination of the characteristics of condition-based maintenance strategy towards maintenance performance.

3. Characteristics of Condition-Based Maintenance

Condition-based maintenance is defined as the maintenance initiated as a result of knowledge of the condition or significant deterioration of an item or component through continuous monitoring and routine inspection to minimise the total cost of repairs [11, 12, 17, 19, 25]. This maintenance strategy is aimed to minimise the total maintenance cost by collecting and gathering the condition data of the building systems, especially those critical components. However, the maintenance strategy might not be applicable to all building systems or assets in terms of the availability of such maintenance technology and cost effectiveness [17]. The characteristics of condition-based maintenance toward maintenance performance are stated below:

3.1. Skilled Manager

This maintenance strategy requires rigorous analysis on the data and information of systems condition and reliability, as well as financial maintenance data. Meanwhile, building managers must have proper understanding on the failure modes and rates, asset criticality, and other significant factors while implementing condition-based maintenance [11]. In order to perform condition-based maintenance effectively, there must be qualified maintenance personnel with related experience, skill and knowledge. High level of training is required for the supervisors and technicians to carry out the maintenance works include condition monitoring, routine inspection, as well as repair and replacement [6, 27]. In this circumstance, skilled manager should be able to provide or conduct training session for the maintenance personnel improve their skill and knowledge. Thus, satisfactory level of skill and knowledge of manager is required to ensure the success of the maintenance strategy.

3.2. Monitoring Equipment and Technique

According to Edward et al. [10], there is a wide range of techniques to examine the condition of specific items or assets, such as oil analysis, vibration monitoring, thermography and so on. Specific measuring and monitoring equipments are required by expertise to perform the maintenance tasks. The tools might be complicated and costly for an organisation [6]. Due to the technical complexity of building systems and the level of sophistication of monitoring tools increases, the maintenance management must be able to train and develop the skill of maintenance personnel for adaptation of new maintenance technology. Therefore, the criteria that should be taken into consideration for condition-based maintenance include:

- Availability of monitoring equipment and technique.
- Capability to adopt the monitoring technology.

3.3. Acquisition of Data and Information

Bevilaqua and Braglia [5] argued that the data and information acquisition systems are the necessary applications to perform condition-based maintenance. The documentation and record of information are essential to ensure the reliability of information about the conditions and remaining lifetime of system components. Ali [2] further explained that the conditions of buildings and systems must be considered to allocate adequate maintenance cost. Thus, the maintenance personnel should acquire the data and information regarding the conditions of building system components. In order to achieve the success of condition-based maintenance, the reliability of data and information regarding system conditions must be taken into consideration.

3.4. Frequency of Monitoring and Inspection

Condition-based maintenance can only be implemented with proper system monitoring and inspection. Tsang [28] found that the frequency of inspection must be determined, either the components are monitored continuously or inspection is performed with fixed interval, so that action can be taken in time to prevent the failures or breakdowns occur. The maintenance personnel need to identify an optimal frequency or interval of inspection to avoid over-inspection or under-inspection. Then, Hameed et al. [16] demonstrated that planning of appropriate maintenance activities prior to failure and maintenance cost is greatly influenced by the ability to monitor and inspect the condition of systems. Thus, it is necessary to identify the optimal frequency of monitoring and inspection, so that condition-based maintenance can improve the performance in term of cost-effectiveness.

4. Maintenance Performance

The development of performance measurement in management aims to improve the quality and service, as well as to meet cost parameters [4]. The measurement of maintenance performance is an assessment that helps to identify the strengths and weaknesses of the maintenance activities. In addition, the result of performance measurement indicates the effectiveness of the existing strategy. Consequently, the management team is able to plan and make appropriate decision for future maintenance strategy [13].

The measurement of performance can be obtained through the level of success or failure in terms of schedule, cost and functionality [18, 26]. Acknowledging that the rising maintenance cost is one of the major concerns of the industry and public, this study chose cost performance as the dependent variable. The cost or expenditure for building maintenance is often used in measuring the performance of buildings. The maintenance performance is calculated using the variance of actual expenditure and planned cost for building maintenance activities [2]. However, accuracy of planned cost reflects the credibility of maintenance performance. Therefore, it is vital for top management to identify the planned maintenance cost at the planning stage.

For the purpose of this study, a comparison between the actual and the planned cost was made to identify the level of maintenance
performance. For example, maintenance performance of a building system is deemed below expectation when the actual expenditure for maintenance tasks exceeds the planned cost. In contrast, high performance level is achieved when the total expenditure is below the planned cost for maintenance works.

5. Research Methodology

This research adopted a mixed method approach that was adopted by Ali [3] and Nik Mat [23] to study maintenance-related topics. The approach comprises literature review, questionnaire survey, semi-structured interviews, and case study. This approach allows researchers to address more complicated research questions and achieve higher reliability and validity of the research [29]. The research was divided into stages and conducted sequentially. Firstly, the characteristics of condition-based maintenance were identified through literature reviews and subsequently; questionnaires were drafted.

Secondly, simple random sampling was adopted in the questionnaire survey to identify the relevant respondents who have been or were involved in office building maintenance management during the period of this research. This method ensures the sample accuracy by selecting the respondents at random and by considering all elements in the population[24]. Population criteria included building requirements, which were high-rise office buildings (7-storey and above) located in Klang Valley, Malaysia and must have been completed for more than two years. 338 (research population) sets of the questionnaire were sent out by post and 100 sets were returned, which gave a return rate of 30 percent. The respondents were maintenance management staff working in the office buildings (see Figure 2). Based on the data obtained during the survey, some of the respondents, included in the category of “others”, were either managing directors of a property management firm, or mechanical and electrical engineers. 85 percent of the respondents were building manager, building supervisor and executive specialising in the planning and the execution of maintenance management activities. They are considerably expert in the planning and implementation of maintenance strategies, and thus able to provide accurate and reliable answers towards the questions.

Job Title (N = 100)

![Job Title Distribution](image)

Fig. 2. Respondents’ Profile

Subsequently, the survey result was converted and analysed through Statistical Package for Social Science (SPSS) software. Reliability analysis was conducted for the condition-based maintenance characteristics variables to enhance the reliability of the data. The purpose of this analysis was to check the consistency of the scale of data [20]. Cronbach’s alpha test showed a coefficient of 0.888. A coefficient of more than 0.70 indicates good reliability.

A correlation test was suitable to measure the relationship between the characteristics of maintenance strategy [9]. It helped to indicate the influence of the maintenance characteristics on the maintenance expenditure. This was performed through the SPSS software. The Pearson product-moment correlation was employed for the analysis. The correlation test was calculated using the following formula:

\[
 r = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sqrt{\sum (x - \bar{x})^2 \sum (y - \bar{y})^2}}
\]

Where,

\( (x - \bar{x}) \) = the deviation of variable X from its mean;
\( (y - \bar{y}) \) = the deviation of variable Y from its mean.

The findings on the relationships between condition-based maintenance characteristics and cost performance were used as the basis for the prediction of maintenance performance. The predicted value of a dependent variable from the value of an independent variable is called regression [14]. In this study, there were more than one significant independent variables identified. Thus, a multiple linear regression was used to analyse the collective and the separate contributions of two or more independent variables to the variation of the dependent variable. The multiple linear regression is formulated as:

\[
 Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \ldots + \beta_kX_k + \epsilon
\]

Where,

\( Y \) is the dependent variable (\( Y = \) maintenance expenditure variance);
\( X_1, X_2, \ldots, X_k \) are the independent variables (\( X_1 = \) skill and knowledge of manager; \( X_2 = \) availability of monitoring equipment and technique; \( X_3 = \) capability to adopt the monitoring technology...);
\( \beta_0, \beta_1, \beta_2, \ldots, \beta_k \) are the parameters of the model;
\( \epsilon \) is the random error

In order to validate the questionnaire results, building managers were interviewed at the third stage. In the interview sessions, the interviewees were required to answer the interview questions and to provide further explanation about the implementation of the maintenance strategy. Thus, the building manager with more than five years’ experiences and expertise in office building maintenance was the minimum requirement as the interview respondent. The interviewees were selected from the questionnaire respondents who fulfil the requirement. 76 respondents who met the requirement were identified. However, only 15 of them agreed to participate in the interview session. Semi-structured interviews were conducted to obtain further details and understandings about the significant characteristics of condition-based maintenance determined through the correlation analysis. For example, one of the interview questions was "Does the level of manager skill and knowledge significantly influence the cost performance? How does it influence the cost performance?" This type of interview allows the researcher to explore and uncover the respondents’ views in detail [21].

Then, a case study was carried out on a 27-storey office building located in Kuala Lumpur. The building is thirteen years old, with total floor area of 324,000 square feet, privately owned and managed under the in-house maintenance and management team. The purpose of the case study was to test the applicability of the developed regression model. Relevant information about the significant predictor was collected. The data was applied into the regression model for calculation of the ratio of maintenance expenditure variance. Consequently, the ratio was compared to the exact scenario of the office building.
6. Finding and Discussions

6.1. Relationship between Characteristics of Condition-Based Maintenance and Cost Performance

The findings revealed the relationship between characteristics of condition-based maintenance and cost performance as shown in Table 1. The dependent variable of this study was cost performance, which was determined by maintenance expenditure variance whilst the independent variables were the five variables discussed earlier. SPSS considers variables with the significance value of 0.05 or below to be significantly correlated. Four out of the identified five independent variables were determined to be significantly correlated to the maintenance expenditure variance. The variables are as follows:

- Skill and knowledge of manager
- Availability of monitoring equipment and technique
- Capability to adopt the monitoring technology
- Reliability of maintenance data and information

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Maintenance Expenditure Variance</th>
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<tbody>
<tr>
<td>Skilled Manager-Skill and Knowledge</td>
<td>-0.276**</td>
</tr>
<tr>
<td>Equipment and Technique-Availability</td>
<td>-0.350**</td>
</tr>
<tr>
<td>Equipment and Technique-Capability to Adopt</td>
<td>-0.240*</td>
</tr>
<tr>
<td>Acquisition of Data-Reliability</td>
<td>-0.394**</td>
</tr>
<tr>
<td>Monitoring and Inspection-Frequency</td>
<td>-0.138</td>
</tr>
</tbody>
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*: Correlation is significant at the 0.01 level (2-tailed)
**: Correlation is significant at the 0.05 level (2-tailed)

6.2. Regression Model of Maintenance Cost Performance

Since there were four characteristics found to be significantly correlated to the cost performance, the predictors of maintenance expenditure variance (MEV) included skill and knowledge of manager (SKM), availability of monitoring equipment and technique (AET), capability to adopt monitoring technology (CAT), as well as reliability of maintenance data and information (RDI). The regression model for the research was produced as follows (see also Table 2):

Model 1 (Enter Method)

MEV = 6.686 – 0.162 SKM – 0.392 AET + 0.272 CAT – 0.513 RDI  (3)

Coefficient of multiple regression, \( R^2 = 0.186 \) (18.6%)

However, the analysis result determined that three predictors were not significant with p-value of more than 0.05. So, another regression model that eliminated the non-significant predictors was developed as follows (see also Table 3). This model was determined appropriate and accurate to estimate the maintenance expenditure variance.

Model 2 (Stepwise Method)

MEV = 6.281 – 0.665 RDI  (4)

Coefficient of multiple regression, \( R^2 = 0.148 \) (14.8%)

In order to ensure that the regression models were not violated, the validity of the regression models was checked. Data tabulated in Table 2 and Table 3 had proven that there was no problem of multicollinearity for Model 1 and Model 2 respectively. Whereby, the tolerance value should not be less than 0.1 and variance inflation factor, VIF should not be greater than 10.
The measurement unit score of the predictor was inserted into the regression model for calculation as follows:

\[ \text{MEV} = 6.281 - 0.665 \times \text{RDI} \]

As a result, the prediction of maintenance expenditure variance that was calculated through the regression model matched the exact scenario of the studied case. So, the applicability of the regression model in practical was validated and confirmed. The result also summarised that very high degree of concern towards the reliability of maintenance data is a must to eliminate the issue of over-budget.

7. Conclusion

The findings revealed that the characteristics of condition-based maintenance directly influenced the cost performance. Therefore, it is important to understand the influences of condition-based maintenance characteristics in the maintenance process, from planning to the outcome of maintenance. Skill and knowledge manager, availability of monitoring equipment and technique, capability to adopt monitoring technology, as well as reliability of maintenance data and information were highlighted as the characteristics that significantly influencing the maintenance performance. Model 2 developed from stepwise regression analysis highlighted reliability of maintenance data and information as the significant predictor in condition-based maintenance strategy. Using the prediction model, practitioners can predict the variance of maintenance expenditure from the level of concern towards the reliability of maintenance data. Thus, they may decide how much of concern towards the reliability of maintenance data is required in order to achieve optimal maintenance expenditure. Several measures were recommended to improve the maintenance characteristics. The measures include provision of training to maintenance personnel, effective communication between maintenance personnel and clients, planning of maintenance interval based on priority of building services and safety level to occupants, and the collaboration with the service providers. In conclusion, it is vital for the building maintenance practitioners to incorporate the identified significant characteristics and measures for improvement in planning and executing condition-based maintenance with optimum maintenance cost performance. Nevertheless, further research should be conducted on measures to improve the maintenance strategy and outcome.
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References