Post-print version: Au-Yong, C. P., Ali, A. S., & Ahmad, F. (2013). Significant Characteristics of Scheduled and Condition-Based Maintenance in Office Buildings. *Journal of Performance of Constructed Facilities, 28*(2), 257-263.
http://dx.doi.org/10.1061/(ASCE)CF.1943-5509.0000432

Significant Characteristics of Scheduled and Condition-Based Maintenance in Office Buildings

Cheong Peng Au-Yong (Corresponding Author)
PhD Candidate
Centre for Construction, Building and Urban Studies,
Faculty of Built Environment,
University of Malaya,
50603 Kuala Lumpur, Malaysia.
Email Address: auyongcp@um.edu.my

Azlan Shah Ali
Associate Professor
Centre for Construction, Building and Urban Studies,
Faculty of Built Environment,
University of Malaya,
50603 Kuala Lumpur, Malaysia.
Email Address: asafab@um.edu.my

Faizah Ahmad
Senior Lecturer
Centre for Construction, Building and Urban Studies,
Faculty of Built Environment,
University of Malaya,
50603 Kuala Lumpur, Malaysia.
Email Address: faiz@um.edu.my

Significant Characteristics of Scheduled and Condition-Based Maintenance in Office Buildings

Cheong Peng Au-Yong, Azlan Shah Ali, and Faizah Ahmad

ABSTRACT

Sustainability of buildings is one of the main aims in the construction industry. In achieving sustainability, maintenance of building and its facilities which include planning, implementation and outcome of maintenance activities become an important criterion. This paper aims to identify the significant characteristics of scheduled and condition-based maintenance in office buildings through reviews of relevant literature and questionnaire survey. The significance of the characteristics was identified through ranking analysis. Semi-structured interview was conducted to obtain further details on the characteristics and measures to enhance efficiency of the characteristics. The findings reveal that the dominant characteristics for scheduled maintenance include quality of spare part and material, the level of labor skill and knowledge, and budget allocation for maintenance labor whilst for condition-based maintenance; the dominant characteristics are the level of manager skill and knowledge, reliability of maintenance data, and financial allocation for the maintenance manager. The study concludes that these dominant characteristics should be considered in the implementation of maintenance strategies.

Keywords: Maintenance strategies; characteristics; scheduled maintenance; condition-based maintenance; maintenance performance; office building.

INTRODUCTION

Sustainable buildings ensure buildings and services are in good condition for living, working, and other daily activities. Building maintenance is vital in ensuring buildings sustainability. Maintenance is defined as a combination of actions carried out to retain an item in, or restore it to, an acceptable condition under BS 3811:1984 and ISO 15686-1 (ISO2000) (Lee & Wordsworth 2001; Flores-Colen et al. 2010).

Generally, building maintenance is divided into planned maintenance and unplanned maintenance under BS3811 (Seeley 1987). Planned maintenance is the predetermined tasks that are well-organized and performed in advance. The maintenance actions reduce or prevent any failure or damage to the components or items. On the other hand, unplanned maintenance is carried out in the event of emergency or contingency maintenance without any predetermined plan. The maintenance actions are carried out after failure or damage detected.

Planned maintenance should be the major activity in building maintenance. Frequent breakdown or downtime is more likely to occur, and high maintenance cost is required by unplanned maintenance for repair and replacement works (Chareonsuk et al. 1997). Thus, unplanned maintenance should be minimized to achieve optimal maintenance expenditure.

According to Horner et al. (1997), several strategic options are available to management and many alternative decisions should be considered for maintaining a building in proper aspect. Consequently, the study of the maintenance strategies is necessary to control the maintenance performance, especially the maintenance cost.

Background

Lee & Scott (2009) identify three (3) basic maintenance strategies namely scheduled maintenance, corrective maintenance and condition-based maintenance. Scheduled maintenance is defined as the preventive maintenance carried out in accordance with predetermined time interval, number of operations, mileage and others to ensure such components perform in good condition (Seeley 1987; Horner et al. 1997; Nilsson 2007; Flores-Colen & De Brito 2010). Conversely, corrective maintenance is defined as the repair or replacement work implemented after failure has occurred and intended to restore such item to its required performance function. Condition-based maintenance is defined as the maintenance initiated based on knowledge of the condition or significant deterioration of an item through continuous monitoring and routine inspection, thus reducing the total cost of repairs (Seeley 1987; Horner et al. 1997; Ellis 2008; Flores-Colen & De Brito 2010).

Building maintenance costs are rising rapidly (El-Haram & Horner 2002). The total spending on building maintenance in the UK increased 66% over the last 10 years in the 1990s (BMI 1996). Therefore, the selection of planned maintenance strategy to minimize building maintenance cost becomes an important decision in construction and building industry.

Forster & Kayan (2009) argued that scheduled maintenance is deemed to be an optimal strategy for building maintenance. Conventionally, the best way to optimize the performance of the building and the services or facilities fixed within it, was by servicing, overhauling or replacing them according to the predetermined plan with fixed interval (Horner et al. 1997; Flores-Colen & De Brito 2010).

However, Edward et al. (1998) argued that scheduled maintenance might incur the unnecessary costs of replacement of parts, as those parts are occasionally fit to use. Moreover, routine inspection or scheduled maintenance may ignore the invasive undertakings that massively upset the stability of a system (Moubray 2007). Consequently, scheduled maintenance may induce unpredictable impact, and cause the failure.

On the other hand, Ugechi et al. (2009) posited that condition-based maintenance is the most advantageous compared to other maintenance strategies. They further argued that the implementation of condition-based maintenance allows sufficient lead time to organize, schedule and carry out necessary repairs before any failure occurs. Thus, major breakdowns and costly downtime can be avoided.

However, to achieve the full advantage of condition-based maintenance, the condition of an item must be monitored (Horner et al. 1997). The statement is supported by Ellis (2008) who argued that condition-based maintenance is not applicable to all maintenance assets or services. Thus, condition monitoring techniques or equipment is required prior to implementation of the condition-based maintenance practices.

Taking into cognizance the advantages and disadvantages of both maintenance strategies, this paper aims to identify the dominant characteristics of condition-based and scheduled maintenance, as well as the measures to enhance efficiency of the characteristics that influence the maintenance performance. Understanding the importance of the characteristics of both maintenance strategies ensures successful planning and implementation of the maintenance strategies.

PREVENTIVE MAINTENANCE

Preventive maintenance is an effective approach to enhance the reliability and quality of a system and its components. Preventive maintenance is divided into

scheduled maintenance and condition-based maintenance strategies (Seeley, 1987; Yang, 2004), and each maintenance strategy has its own characteristics.

Characteristics of Scheduled Maintenance

Hameed et al. (2010) pointed out that maintenance activities performed at fixed time intervals are meant to reduce the probability of failures and breakdowns. However, scheduled maintenance is deemed as not cost effective, whereby the replacement of components is often performed regardless of the condition. The performance of the scheduled maintenance relies on the criteria such as:

- Skilled labor
- Spare part and material
- Predetermined interval for maintenance
- Cost allocation for failure or downtime

Since scheduled maintenance is carried out in a fixed time interval, it requires permanent maintenance staff or technicians to perform the tasks. Groote (1995) argued that the qualification of the maintenance labor force affects the maintenance outcome. For instance, some of the scheduled maintenance works are determined by an experienced and skilled technician who observes the wear and tear of the parts or components. Thus, the technicians should not limit their capability only in replacing and overhauling system components, but they must be able to identify the need for scheduled maintenance. Horner et al. (1997) argued that skilled labor is highly demanded for scheduled maintenance activities. Thus, skilled labor is one of the main characteristics to be considered for implementation of scheduled maintenance.

According to Horner et al. (1997), the requirement for spare part and material is higher for scheduled maintenance compared to other maintenance strategies. Some parts of building systems or services need to be replaced with a new one in a fixed interval as determined in the maintenance program schedule, regardless whether the parts are damaged or not. Basically, management of spare parts and materials includes the study of spare part required, efficiency of spare parts reordering, level of stocks of spare parts, and storage of spare parts (Groote 1995). Tsang (1995) argued that accurate spare parts identification and stocking helps control and reduce the operation and maintenance costs. In addition, the quality of spare part and material always has an impact towards maintenance performance (Ali et al. 2010). Thus, the selection of spare part and material should consider cost saving as well as the quality of spare part and materials.

The interval of maintenance activities has critically influenced the maintenance outcome. Chen et al. (2003) argued that performing appropriate maintenance tasks at the right time prolongs the service life of a system. Moreover, Narayan (2003) posit that delay to perform the maintenance task at the right time may cause further damages to the system components. On the other hand, Yang (2004) argued that scheduled maintenance programs might not be able to avoid the risk of failure occurring on system components before the fixed replacement time. This problem occurs due to the unknown condition of the system components. Direct maintenance cost with a tight scheduled maintenance; while downtime cost due to system breakdown may be expensive with a loose scheduled maintenance (Chareonsuk et al. 1997). Hence, an adequate maintenance interval must be identified and performed to enhance the effectiveness of scheduled maintenance.

Acknowledging that scheduled maintenance is not able to prevent the risk of failure, financial allocation of the cost of failure should be considered when planning the maintenance approach. According to Zuashkiani et al. (2011), breakdown may cause collateral damage in a particular system. Relatively, additional cost will be incurred for the failures occurred before the predetermined maintenance time. Furthermore, downtime involves the time required for detection, repair or replacement and restarting the system (Bevilacqua & Braglia 2000). The occurrence of downtimes is likely to affect the activities of core business such as loss of production. Hence, the cost allocation for failure and downtime must be taken into consideration in the planning and execution of scheduled maintenance activities.

Characteristics of Condition-Based Maintenance

Condition-based maintenance aims to minimize the total maintenance cost by collecting and gathering the condition data of the building systems, especially the critical components. However, this maintenance strategy might not be applicable to all building systems or assets in terms of cost-effectiveness and the availability of such maintenance technology (Horner et al. 1997). The characteristics of condition-based maintenance affecting maintenance performance include:

- Skilled manager
- Monitoring equipment and technique
- Acquisition of data and information
- Frequency of monitoring and inspection

Condition-based maintenance requires vigorous analysis on the data and information of system's condition and reliability, as well as financial maintenance data. In order to execute this maintenance strategy effectively, building managers must be able to allocate adequate staff and training on the appropriate methods for monitoring tools, data acquisition and processing, as well as data interpretation (Mann et al. 1995). Moreover, condition-based maintenance requires building managers to have a proper understanding on the failure modes and rates, asset importance, and other significant factors (Ellis 2008). Thus, the success of the maintenance strategy is directly related to the skilled manager. The support of a skilled manager is highly required to plan, manage, organize, supervise, and monitor the implementation of condition-based maintenance in various aspects.

According to Mann et al. (1995), condition monitoring technology has matured at an explosive rate. The technology assists the maintenance staff in determining the condition of building systems and allows them to predict a mechanical breakdown (Davies 1995; Edward et al. 1998). Edward et al. (1998) highlighted a wide range of techniques to examine the condition of specific items or assets, such as oil analysis, vibration monitoring, thermograph and others. Specific measuring and monitoring equipment are required with expertise to perform the maintenance tasks. However, Carnero (2006) argued that the tools might be complicated and costly for an organization. Therefore, the availability of monitoring equipment and capability of the maintenance staff to use the equipment should be taken into consideration for condition-based maintenance.

Bevilacqua & Braglia (2000) argued that the data and information acquisition systems are the necessary to perform condition-based maintenance. The maintenance data needed for the maintenance strategy include a failure or replacement data, inspection data, maintenance action data, and installation data (Tsang et al. 2006). The documentation and record of information are essential to ensure the reliability of information about the conditions and the remaining lifetime of system components. Similarly, analysis of collected data and information on the conditions of the building and systems is vital for the maintenance staff to set up maintenance tasks. Ali (2009) further argued that the conditions of buildings and systems must be considered to ensure sufficient maintenance cost. Thus, the maintenance staff should acquire the data and information on the conditions of building system components.

Condition-based maintenance can only be implemented with proper monitoring and inspection system. Hameed et al. (2010) demonstrated that planning of appropriate maintenance activities prior to failure and maintenance cost is directly

influenced by the ability to monitor and inspect the condition of the systems. Tsang (1995) argued 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. In addition, maintenance staff needs to identify an optimal frequency or interval of inspection to avoid over-inspection and/or wastage of resources. Thus, the identification of optimal frequency of monitoring and inspection can improve the performance of condition-based maintenance in terms of cost-effectiveness.

The above reviews highlighted four main characteristics of scheduled maintenance are skilled labor, spare part and material, predetermined interval for maintenance, and cost allocation for failure and downtime. On the other hand, four main characteristics of condition-based maintenance are a skilled manager, monitoring equipment and technique, acquisition of data and information, as well as frequency of monitoring and inspection. The characteristics are significant in planning and implementation of both maintenance strategies. However, the priority of the characteristics has not been discussed. The practitioners could improve the efficiency in planning and implementation of the maintenance strategies by prioritizing the characteristics. Therefore, this paper aims to rank the importance of the characteristics of the scheduled and condition-based maintenance.

RESEARCH METHODOLOGY

This research adopts a mixed method approach comprises of literature review, questionnaire survey, and semi-structured interviews. This approach allows researchers to address more complicated research questions and achieve higher reliability and validity of the research (Yin, 2009). The research was divided into three stages and conducted sequentially. Firstly, the characteristics of scheduled and condition-based maintenance were identified through literature reviews and subsequently; questionnaires were drafted (see Figure 1).

Secondly, simple random sampling was adopted in the questionnaire survey to identify the relevant respondents who have been or are currently involved in office building maintenance management. This method ensures the sample accuracy by selecting the respondents at random and all elements in the population are considered (Saris & Galhofer, 2007). Population criteria included building requirements, which were high-rise office buildings (7-storey and above) located in Klang Valley, Malaysia and must be completed more than two years. 398 sets of the questionnaire were sent out and 120 sets questionnaire was returned, which gave a return rate of 30 percent. The respondents were maintenance management staff

working in the office buildings (see Figure 2). 83 percent of the respondents were building manager, building supervisor and executive specializing in the planning and execution of maintenance management activities.

QUESTIONNAIRE

SECTION A – Respondent's Particular

1. What is your job title?
   [ ] Building Manager [ ] Building Executive/ Supervisor
   [ ] Building Technician [ ] Others, please specify _____

2. How long have you involved in the building maintenance industry?
   [ ] Less than 5 years [ ] 6 - 10 years [ ] 11 - 15 years [ ] More than 15 years

SECTION B – Maintenance Information

1. Type of maintenance strategy adopted by the management.
   [ ] Scheduled maintenance (Please answer Question 1 in Section C)
   [ ] Condition-based maintenance (Please answer Question 2 in Section C)
   [ ] Both (Please answer all the questions in Section C)

SECTION C – Characteristics of Scheduled and Condition-Based Maintenance

Please rate the level of importance of the variables in maintenance tasks by using the scales:
1=Very low degree; 2=Low degree; 3=Average; 4=High degree; 5=Very high degree

1. Characteristics of Scheduled Maintenance

		1	2	3	4	5
1.1	Skilled labour					
	(a) Budget allocation					
	(b) Skill and knowledge					
	(c) Number of labours					
1.2	Spare part and material					
	(a) Budget allocation					
	(b) Level of stock					
	(c) Quality					
1.3	Predetermined interval for maintenance					
	(a) Budget allocation					
	(b) Length of the interval					
1.4	Cost of failure and maintenance downtime					
	(a) Budget allocation					
	(b) Amount of downtime					

2. Cost Characteristics of Condition-Based Maintenance

		1	2	3	4	5
2,1	Skilled manager					
	(a) Budget allocation					
	(b) Skill and knowledge					
2.2	Monitoring equipment and technique					
	(a) Budget allocation					
	(b) Availability of equipment					
	(c) Capability to adopt the technique					
2.3	Acquisition of data and information					
	(a) Budget allocation					
	(b) Reliability of data information					
2.4	Monitoring and inspection					
	(a) Budget allocation					
	(b) Frequency of inspection					

Figure 1: Questionnaire sample

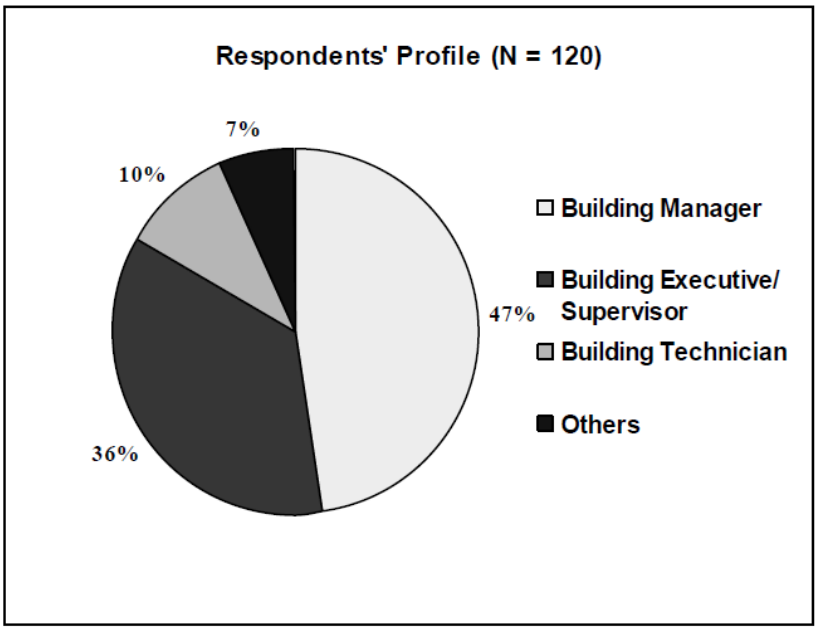

Figure 2: Respondents' profile

Reliability analysis was conducted for the scheduled and condition-based maintenance characteristics variables to enhance reliability of the data. The purpose of this analysis was to check the consistency of the scale of data (Leech et al., 2011). Cronbach's alpha coefficient tests shows the coefficients for characteristics of the scheduled maintenance and condition-based maintenance were 0.741 and 0.888 respectively. Coefficient of more than 0.70 indicates good reliability.

Furthermore, mean and standard deviation were used to measure the variables in ranking analysis. Mean is known as a measure of average or arithmetic average of the scores in a distribution. Standard deviation is used as a measure of average when the mean is being used (Sekaran & Bougie, 2009). Generally, standard deviation indicates the size of the residuals, which is the difference between a particular observation and the mean. Thus, the larger is the standard deviation, the greater is the spread of data.

Table 1 shows the ranking analysis of the characteristics of scheduled maintenance and Table 2 shows the ranking analysis of the characteristics of condition-based maintenance. The mean score (with 1 – very low degree to 5 – very high degree) was used to rank the level of importance of the characteristics. The main purpose of ranking analysis was to indicate the differences in the level of importance among the characteristics.

In order to validate the questionnaire results, building managers with more than five years' experiences in office building maintenance were interviewed on the

third stage. The interviewees were selected from the questionnaire respondents who fulfill the requirement. Semi-structured interviews were conducted to obtain further details and understandings about the characteristics of both maintenance strategies. For example, one of the interview questions was "*Is quality of spare part an important characteristic for scheduled maintenance? Why is it important for this maintenance strategy?*" The interview allows the researcher to explore and uncover the respondents' views in detail (Marshall & Rossman, 2006).

Table 1: Ranking of characteristics of scheduled maintenance

Rank	Variable	Mean (N=101)	Std. Deviation
1	Spare Part and Material-Quality	3.53	.944
2	Skilled Labor-Skill and Knowledge	3.41	.982
3	Skilled Labor-Budget Allocation	3.32	.871
4	Spare Part and Material-Budget Allocation	3.19	.880
5	Predetermined Maintenance Interval-Length of Interval	3.16	.914
6	Predetermined Maintenance Interval-Budget Allocation	2.98	.787
7	Spare Part and Material-Level of Stock	2.83	.861
8	Skilled Labor-Number of Labors	2.83	.873
9	Failure and Maintenance Downtime-Budget Allocation	2.78	.867
10	Failure and Maintenance Downtime-Amount of Downtime	2.74	1.163

Table 2: Ranking of characteristics of condition-based maintenance

Rank	Variable	Mean (N=100)	Std. Deviation
1	Skilled Manager-Skill and Knowledge	3.71	.808
2	Acquisition of Data-Reliability	3.46	.915
3	Skilled Manager-Budget Allocation	3.43	.807
4	Acquisition of Data-Budget Allocation	3.34	.901
5	Equipment and Technique-Budget Allocation	3.28	.900
6	Equipment and Technique-Capability to Adopt	3.25	.796
7	Monitoring and Inspection-Frequency	3.23	.874
8	Equipment and Technique-Availability	3.09	.911
9	Monitoring and Inspection-Budget Allocation	3.04	.777

76 respondents were identified as meeting the interviewee's requirement, however, only 15 of them agreed to participate in the interview session. Unlike the questionnaire survey, the interviewees were required to answer the interview questions and provide further explanation of the implementation of both maintenance strategies.

FINDINGS AND DISCUSSIONS

Table 1 ranks the characteristics of scheduled maintenance based on the mean scores. Quality of spare part and material ranked the highest with a mean score of 3.53. Meanwhile, the standard deviation value of 0.944 indicated the widespread of data and eliminated the issue of biased data. The quality of the spare part was identified as the most important characteristics in executing scheduled maintenance. This finding supported that the quality of spare part and material is essential and directly affecting the maintenance performance (Ali et al., 2010). Moreover, the replacement interval of the parts could be extended as the parts and materials usually have longer lifespan. One interviewee's stated that:

> "… use of good quality materials or spare parts is cost saving in long-term aspect, as they maximize the service life of a system."

Skill and knowledge of maintenance labor was ranked second with a mean score of 3.41, thus indicating its significance in scheduled maintenance. The data are normally distributed with the standard deviation value of 0.982. Error and mistake occurred during maintenance works could be reduced or minimized. Furthermore, the skilled labor would be able to detect abnormal condition of a system when executing the maintenance tasks. The result confirmed the importance of labor qualification in building maintenance (Groote, 1995). Moreover, one of the interviewees highlighted the significance of skilled labor:

> "… skilful or experienced staff would make sure the maintenance work is done according to the requirements or standard operation procedures."

In order to employ skillful and knowledgeable maintenance labor, budget allocation for labor recruitment becomes an important aspect. Generally, the salary of a labor is positively proportional to his level or skill and knowledge. Thus, the finding demonstrated that the budget allocation for skilled labor was ranked third with the mean score of 3.32, and standard deviation value of 0.871. The finding verified that large amount of budget allocation is required for skilled labor (Carnero, 2006). An interviewee said:

> "… definitely we cannot expect skillful and responsible staff with low salary payment."

Table 2 ranks the characteristics of condition-based maintenance based on the mean scores. In Malaysia, condition-based maintenance is a newly adopted strategy in building maintenance management. Thus, skill and knowledge of building manager towards condition-based maintenance are necessary to promote this strategy to the management team. The skill and knowledge of building manager were ranked highest in the survey result, with the mean score of 3.71. The data were

proven to be normally distributed with the standard deviation value of 0.808. This finding supported that building managers must have adequate skill and knowledge of the aspects of condition-based maintenance (Ellis, 2008). In fact, building managers must be able to plan, monitor and coordinate the overall process of this maintenance strategy such as adopted technique, required equipment and software, as well as the type of training provided. One interviewee said:

> "… a building manager must be able to supervise and train the staff as condition-based maintenance is a new concept in facilities management in Malaysia."

Reliability of data on system condition was ranked second with a mean score of 3.46 and standard deviation value of 0.915, which demonstrated the widespread of data and eliminated the issue of biased data. As argued by Qingfeng et al., 2011, the success of condition-based maintenance is highly dependent on the reliability of the condition and maintenance data. The need for maintenance tasks always relies on the system condition, which could be observed and monitored through the data recorded through monitoring techniques. Accurate data would ensure the success of condition-based maintenance. On the other hand, inaccurate data would lead to breakdown or failure as quoted by one of the interviewees:

> "… incorrect data implicate the adequacy of maintenance execution. In this situation, damage tends to occur."

Similar to scheduled maintenance, budget allocation for building manager is one of the significant characteristics of condition-based maintenance. The finding reveals that the budget allocation for building manager is ranked third with the mean score of 3.43. Generally, an experienced, skillful and knowledgeable manager demands a high salary for his job. Therefore, the level of experience, skill and knowledge would determine the salary. Therefore, the budget allocation for recruiting a skilled manager must be optimal. The result was validated by an interviewee:

> "… you get what you pay. Every qualified and experienced manager expects a better salary."

In semi-structured interview session, the respondents were asked about the ranking analysis result. All the interviewees acknowledged the importance of the three dominant characteristics of scheduled maintenance and another three for condition-based maintenance. The interviewees further stressed the importance of the characteristic as shown in Table 3 for scheduled maintenance and Table 4 for condition-based maintenance.

Since all the interviewees acknowledged the six dominant characteristics and even provided the importance of the characteristics while planning and implementing

the particular maintenance strategies, the results obtained from ranking analysis were validated. Furthermore, the interviewees suggested various measures to improve the effectiveness of both maintenance strategies, such as the provision of training, knowledge-sharing and communication platform, as well as clients' commitment to allocate sufficient maintenance budget.

Table 3: Importance of dominant characteristics of scheduled maintenance: interviewees' feedback

Characteristics	Importance
Spare Part and Material-Quality	• Ensure the effectiveness of system. • Guarantee better lifespan. • Reduce frequency of breakdown.
Skilled Labor-Skill and Knowledge	• Ensure parts installed according to the requirement. • Proper maintenance works performed. • Reduce human error
Skilled Labor-Budget Allocation	• Provide good workmanship. • Increase the initiation, motivation, and morale of workers. • Employ and retain skilful and experienced labor

Table 4: Importance of dominant characteristics of condition-based maintenance: interviewees' feedback

Characteristics	Importance
Skilled Manager-Skill and Knowledge	• Ensure all the maintenance works run smoothly and accordingly to the requirement. • Lead to the success of condition-based maintenance. • Able to supervise and train the staffs (as condition-based maintenance is new in Malaysia).
Acquisition of Data-Reliability	• Ensure proper maintenance work is performed by reviewing the obtained data about the system condition. • Reliable data indicates the need of maintenance works accurately.
Skilled Manager-Budget Allocation	• Qualification of maintenance manager is positively proportionate to the amount of salary.

CONCLUSION

This paper demonstrated the importance of appropriate maintenance strategies to improve maintenance performance. The reviews of the literature revealed ten characteristics of scheduled maintenance and nine characteristics of condition-based maintenance as significant characteristics in implementing those maintenance strategies. Therefore, understanding the impact of these characteristics in the maintenance process is vitally important. The study reveals that the quality of spare part and material, the level of labor skill and knowledge, and budget allocation for maintenance labor as the dominant characteristics of scheduled maintenance. On

the other hand, the level of manager skill and knowledge, reliability of maintenance data, and budget allocation for the maintenance manager is highlighted as the dominant characteristics of condition-based maintenance. In addition, the study suggested several measures to enhance the efficiency of the maintenance strategies as follows:

- Provision of training for maintenance staff.
- Provision of knowledge-sharing and communication platform among clients, maintenance team, and users.
- Clients' commitment in allocating sufficient maintenance budget.

In conclusion, maintenance staff or organizations of office buildings in Klang Valley, Malaysia, or even other areas, should be aware of the appropriate maintenance strategies to improve the maintenance performance of an office building. Planning and implementation of maintenance strategies should take into account the characteristics of the selected management strategies.

REFERENCES

Ali, A. S. (2009). Cost Decision Making in Building Maintenance Practice in Malaysia. *Journal of Facilities Management, 7* (4), 298-306.

Ali, A. S., Kamaruzzaman, S. N., Sulaiman, R., & Au Yong, C. P. (2010). Factors Affecting Housing Maintenance Cost in Malaysia. *Journal of Facilities Management, 8*(4), 285-298.

Bevilacqua, M., & Braglia, M. (2000). The Analytic Hierarchy Process Applied to Maintenance Strategy Selection. *Reliability Engineering and System Safety, 70*, 71-83.

BMI. (1996). *Building Maintenance Information, Report 253*: Building Cost Information Services Ltd.

Carnero, M. C. (2006). An Evaluation System of the Setting up of Predictive Maintenance Programmes. *Reliability Engineering and System Safety, 91*, 945-963.

Chareonsuk, C., Nagarur, N., & Tabycanon, M. T. (1997). A Multicriteria Approach to the Selection of Preventive Maintenance Intervals. *International Journal of Production Economics, 49*, 55-64.

Chen, D.-H., Lin, D.-F., & Luo, H.-L. (2003). Effectiveness of Preventative Maintenance Treatments Using Fourteen SPS-3 Sites in Texas. *Journal of Performance of Constructed Facilities 17*(3), 136-143.

Davies, R. (1995). Gearing up for Effective Maintenance. *The Plant Engineer, 39*(2), 26-29.

Edward, D. J., Holt, G. D., & Harris, F. C. (1998). Predictive Maintenance Techniques and Their Relevance to Construction Plant. *Journal of Quality in Maintenance Engineering 4*(1), 25-37.

El-Haram, M. A., & Horner, M. W. (2002). Factors Affecting Housing Maintenance Cost. *Journal of Quality in Maintenance Engineering, 8*(2), 115-123.

Ellis, B. A. (2008). Condition Based Maintenance. *The Jethro Project*, 1-5.

Flores-Colen, I., & De Brito, J. (2010). A Systematic Approach for Maintenance Budgeting of Buildings Facades Based on Predictive and Preventive Strategies. *Construction and Building Materials, 24*, 1718-1729.

Flores-Colen, I., de Brito, J., & Freitas, V. (2010). Discussion of Criteria for Prioritization of Predictive Maintenance of Building Façades: Survey of 30 Experts. *Journal of Performance of Constructed Facilities, 24*(4), 337-344.

Forster, A. M., & Kayan, B. (2009). Maintenance for Historic Buildings: A Current Perspective. *Structural Survey, 27*(3), 210-229.

Groote, P. D. (1995). Maintenance Performance Analysis: A Practical Approach. *Journal of Quality in Maintenance Engineering, 1*(2), 4-24.

Hameed, Z., Ahn, S. H., & Cho, Y. M. (2010). Practical Aspects of a Condition Monitoring System for a Wind Turbine with Emphasis on its Design, System Architecture, Testing and Installation. *Renewable Energy, 35*, 879-894.

Horner, R. M., El-Haram, M. A., & Munns, A. (1997). Building Maintenance Strategy: A New Management Approach. *International Journal of Quality in Maintenance, 3*(4), 273-280.

Lee, H. H. Y., & Scott, D. (2009). Overview of Maintenance Strategy, Acceptable Maintenance Standard and Resources from a Building Maintenance Operation Perspective. *Journal of Building Appraisal, 4*(4), 269-278.

Lee, R., & Wordsworth, P. (2001). *Lee's Building Maintenance Management* (4th ed.). Oxford: Blackwell Science Ltd.

Leech, N. L., Barrett, K. C., & Morgan, G. A. (2011). *IBM SPSS for Intermediate Statistics: Use and Interpretation* (4th ed.). New York: Taylor and Francis Group, LLC.

Mann, L., Saxena, A., & Knapp, G. M. (1995). Statistical-Based or Condition-Based Preventive Maintenance? *Journal of Quality in Maintenance Engineering, 1*(1), 46-59.

Marshall, C., & Rossman, G. B. (2006). *Designing Qualitative Research* (4th ed.). California: Sage Publication, Inc.

Moubray, J. (2007). Maintenance Management - A New Paradigm Retrieved 6 January, 2011, from http://www.maintenanceresources.com/referencelibrary/rcm/maintparadigm.htm

Narayan, V. (2003). *Effective Maintenance Management: Risk and Reliability Strategies for Optimizing Performance*. New York: Industrial Press Inc.

Nilsson, J. (2007). Reliability and Cost Centered Maintenance Methods: Nuclear Power and Reliability Centered Maintenance (RCM). *Maintenance Management in Power Systems*.

Qingfeng, W., Wenbin, L., Xin, Z., Jianfeng, Y., & Qingbin, Y. (2011). Development and Application of Equipment Maintenance and Safety Integrity Management System. *Journal of Loss Prevention in the Process Industries, 24*, 321-332.

Saris, W. E., & Gallhofer, I. N. (2007). *Design, Evaluation, and Analysis of Questionnaires for Survey Research*. New Jersey: John Wiley & Sons Inc.

Seeley, I. H. (1987). *Building Maintenance* (2nd ed.). New York: Palgrave.

Sekaran, U., & Bougie, R. (2009). *Research Methods for Business: A Skill Building Approach* (5th ed.). West Sussex: John Wiley & Sons Ltd.

Tsang, A. H. C. (1995). Condition-Based Maintenance: Tools and Decision Making *Journal of Quality in Maintenance Engineering, 1*(3), 3-17.

Tsang, A. H. C., Yeung, W. K., Jardine, A. K. S., & Leung, B. P. K. (2006). Data Management for CBM Optimization. *Journal of Quality in Maintenance Engineering, 12*(1), 37-51.

Ugechi, C. I., Ogbonnaya, E. A., Lilly, M. T., Ogaji, S. O. T., & Probert, S. D. (2009). Condition-Based Diagnostic Approach for Predicting the Maintenance Requirements of Machinery. *Engineering, 1*, 177-187.

Yang, S. K. (2004). A Condition-Based Preventive Maintenance Arrangement for Thermal Power Plants. *Electric Power Systems Research, 72*, 49-62.

Yin, R. K. (2009). *Case Study Research: Design and Methods* (4th ed. Vol. 5). California: SAGE Publication, Inc.

Zuashkiani, A., Rahmandad, H., & Jardine, A. K. S. (2011). Mapping the Dynamics of Overall Equipment Effectiveness to Enhance Asset Management Practices. *Journal of Quality in Maintenance Engineering, 17*(1), 74-92.