The current issue and full text archive of this journal is available on Emerald Insight at:
www.emeraldinsight.com/1355-2511.htm

Enhancing building maintenance cost performance with proper management of spare parts

Cheong Peng Au-Yong, Azlan Shah Ali and Faizah Ahmad
Faculty of Built Environment, University of Malaya, Kuala Lumpur, Malaysia

Received 14 January 2015
Revised 29 April 2015
Accepted 1 September 2015

Abstract

Purpose – Scheduled building maintenance requires appropriate and adequate spare parts to replace existing parts on a regular basis. Management of spare parts is seen as an important criterion to ensure the efficiency of scheduled maintenance. The purpose of this paper is to identify the contributors of spare parts management and investigate the relationship between these contributors and maintenance cost performance.
Design/methodology/approach – This research adopted a quantitative approach, which utilised questionnaire surveys to study the relationship between the contributors of spare parts management and maintenance cost performance. The data were analysed through descriptive analysis, correlation, and regression analysis. Additionally, a case study was examined to validate the results obtained from the survey.
Findings – The results of this research demonstrated that the quality of spare parts (QSP), budget allocation for acquisition of spare parts, and level of stocks were significantly correlated to the maintenance cost variance (MCV). Moreover, the results of the regression analysis indicated that the QSP was the significant predictor of MCV.
Originality/value – This research highlights the importance of spare parts management in building maintenance. It recommends that maintenance management set up a spare parts management department for updating stocks frequently. Meanwhile, the management should avoid ad-hoc acquisition of spare parts, as this is always more expensive. The management should also select spare parts based on quality instead of lowest cost. In addition, building managers should also apply the developed regression model in practice to predict and improve maintenance performance.

Keywords Quality, Maintenance, Inventory, Cost performance, Spare parts management

Paper type Research paper

1. Introduction

High building maintenance cost has become a common issue in construction industry nowadays (El-Haram and Horner, 2002). The main reason for this is the low service quality of maintenance management in Malaysia (Kamaruzzaman and Zawawi, 2010; Ruslan, 2007). This poor maintenance performance is primarily due to the lack of preventive maintenance measures. Thus, the introduction and implementation of preventive maintenance measures is highly recommended to solve the problem of high maintenance costs.

One preventive maintenance strategy that has been suggested for improving building maintenance costs is scheduled maintenance (Forster and Kayan, 2009). This is defined as preventive maintenance that is carried out in accordance with certain criteria, such as predetermined intervals of time, number of operations, and mileage,

The authors gratefully acknowledge the financial support of the University of Malaya Research Grant (UMRG), Grant No. RP007A/13SUS established at the University of Malaya, Sustainability Science Research Cluster.

Journal of Quality in Maintenance Engineering
Vol. 22 No. 1, 2016
pp. 51-61

1355-2511
DOI 10.1108/JQME-01-2015-0001

so as to ensure that building components remain in good condition (Flores-Colen and De Brito, 2010; Horner *et al.*, 1997; Nilsson, 2007; Seeley, 1987).

Scheduled maintenance involves the regular replacement of parts to retain the functionality of the building and its components (Horner *et al.*, 1997). Notably, the cost of spare parts, number of stocks, and lifespan of maintenance parts or items have been proven to be factors that influence maintenance performance (Groote, 1995). As a result, the effectiveness of scheduled maintenance can be greatly influenced by the quality of spare parts (QSP) management.

For instance, inadequate stocking of spare parts (SSP) may lead to extended system deterioration and failure, while maintaining excessive spare parts may lead to extensive carrying costs (Wang, 2012). In other words, the unavailability of spare parts affects scheduled maintenance operations and jeopardises the quality of systems. On the other hand, oversupply of spare parts requires more storage space, which is uneconomical.

Given this scenario, efficient spare parts management should aim to optimise spare parts provisioning costs in an environment that maintains the normal operation of the organisation or system (Kranenburg and van Houtum, 2008). Taking into cognisance the importance of spare parts management towards maintenance performance, this paper aims to identify the contributors of spare parts management that should be considered in maintenance management, and investigate the relationship between these contributors and maintenance cost performance.

2. Management of spare parts

Scheduled maintenance requires the availability of appropriate and adequate spare parts to replace existing parts on a regular basis (Au-Yong *et al.*, 2013). Replacement tasks are meant to restore the conditions of buildings and systems to their original state of functionality by overcoming the effect of wear and tear (Bevilacqua and Braglia, 2000). Consequently, these tasks help in reducing the probability of a building or system breakdown (Hameed *et al.*, 2010).

Spare parts are defined as all parts, equipment, and expandable assets that operate in a system for certain period of time (Assaf *et al.*, 2011). Every part or component in a system has its own lifetime. It needs to be replaced when it reaches the end of its lifetime. It is important to have spare parts available for replacement to ensure a system operates consistently. For example, preventive maintenance requires several categories of spare parts, including exchange parts, lubricants, and other materials for maintenance such as rags and cleaning solvents (Salonen and Deleryd, 2011; Swanson, 2001).

Maintenance management is a process that allocates and coordinates resources such as spare parts, to enhance aspects of maintenance performance such as reliability, safety, function, cost, comfort, and convenience (Idrus *et al.*, 2009). One important strategy to improve maintenance performance is the proper management of spare parts. In general, management of spare parts includes the study of spare part needs, efficient spare parts reordering, noting the level of stocks of spare parts, and storage of spare parts (Groote, 1995). Thus, proper management of spare parts is essential to improve maintenance performance.

2.1 Previous studies

Based on a review of the literature, the contributors of spare parts management are shown in Figure 1.

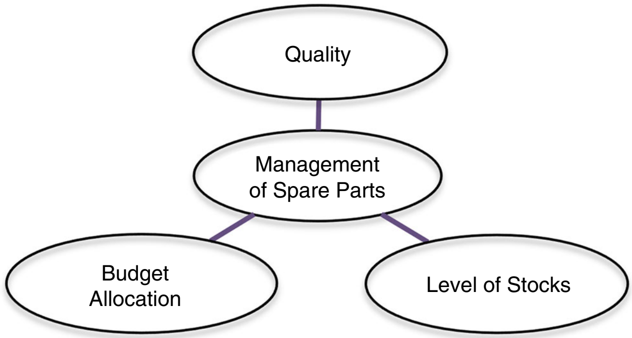

Figure 1. Contributors of spare parts management

Figure 1 indicates that budget allocation is an important contributor in the management of spare parts. For example, Yik and Lai (2005) pointed out that the cost for spare parts required in scheduled maintenance is one of the major costs in building services maintenance. Accurate spare parts identification and stocking help to control and reduce operation and maintenance costs (Tsang, 1995). On the other hand, the allocation of spare parts can be limited by budget constraints (Costantino *et al.*, 2013). Thus, Hassan *et al.* (2014) argued that effective spare parts management requires an acceptable balance between budget allocation for spare parts and stock-out costs.

Level of stocks (refer to Figure 1) is another significant contributor of spare parts management. Indeed, spare parts are much required for scheduled maintenance compared to other maintenance strategies (Horner *et al.*, 1997). Some parts of building systems or services need to be replaced with new ones at a fixed interval depending on the maintenance programme schedule, whether or not the items are damaged. Thus, the availability of spare parts is of high concern in scheduled maintenance as it can affect the maintenance performance (Parida and Kumar, 2006). Eti *et al.* (2006) noted that a good maintenance manager should be able to allocate adequate spare parts for maintenance programs at minimum cost without jeopardising the quality of systems. Nevertheless, maintaining appropriate levels of stocks for different spare parts requires reliable forecasting techniques over a specific time period to identify priorities in spare part storage (Hassan *et al.*, 2014).

The QSP also has an impact on maintenance performance (Ali *et al.*, 2010). Obviously, selection of good quality spare parts can reduce the maintenance budget and downtime loss (De Silva and Ranasinghe, 2010). On the other hand, poor quality spare parts have a shorter service lifespan compared to good spare parts, leading to more defects in a system (Zuashkiani *et al.*, 2011). In some circumstances, poor quality items might be damaged before the predetermined replacement schedule and this would affect the whole system's operation. As a result, repair work would need to be carried out and additional maintenance costs would be incurred. The sourcing of spare parts is also critical as it involves risk of variations in quality Roda *et al.* (2014). Therefore, the QSP is another essential contributor to be taken into consideration, as the selection of spare parts and suppliers should not only be driven by cost saving. This way, the systems' lifespans and their operations will be respectively prolonged and enhanced (Au-Yong *et al.*, 2014).

3. Maintenance cost performance

In management, development of performance measurement is usually conducted to improve quality and service, as well as to meet cost parameters (Amaratunga and

Baldry, 2002). The aspect of cost or expenditure for building maintenance is mostly used in measuring the performance of buildings. Commonly, maintenance cost performance is calculated using variance of actual expenditure and planned cost for building maintenance activities (Ali, 2009). A comparison between actual and planned cost is usually made to identify the level of maintenance performance. For instance, the maintenance performance of a building system is deemed below expectation when the actual spending for maintenance tasks is more than the planned cost. In contrast, a high performance level is achieved when the total expenditure is less than the planned cost of the maintenance works. Since rising maintenance costs are of major concern to the industry and public, this research is concerned with improving cost performance.

4. Research methodology

This research investigated the relationship between management of spare parts and maintenance cost performance. A quantitative approach using a survey questionnaire was utilised with reference to research undertaken by Ali (2009), who used questionnaire surveys to study the relationship between uncertainties in refurbishment design processes and project performance. Additionally, this research carried out a case study to validate the results obtained from the survey questionnaire.

The questionnaire survey used in this research was targeted at collecting data on the contributors of spare parts management and the cost performance of maintenance management in office buildings. In order to obtain a high response rate, the questionnaire was constructed in a short and simple manner so that it would not take up too much of the respondents' time. The questionnaire was constructed using close-ended questions in five-point Likert scales and multiple choices. Simple random sampling was adopted to identify relevant respondents who were previously or currently involved in building maintenance management in the area of Klang Valley, Malaysia. Furthermore, respondents were required to answer questions based on their experience or involvement in maintenance management for high-rise office buildings. Meanwhile, the criteria for buildings were that they must have a minimum of seven storeys and be at least two years old.

Questionnaire surveys require a minimum response rate of 30 per cent to produce reliable and convincing results (Hoxley, 2008). In this research, a total of 300 questionnaires were distributed to building managers, building executives, supervisors, technicians, and other maintenance personnel within the Klang Valley. Out of 113 responses, 101 were found to be useful and valid for analysis. The remaining 12 questionnaires were incomplete or invalid for some reasons. Therefore, a response rate of 38 per cent was achieved. The demographic profile of respondents is shown in Table I. 83 per cent of the respondents were building managers, executives, and supervisors. They had considerable expertise in the planning and implementation of maintenance strategies. 10 per cent of the respondents were building technicians, while the remaining 7 per cent were categorised as "others" (which referred to mechanical and electrical engineers).

Table I.
Demographic profile of the respondents

Position	Percentage ($n=101$)
Building manager	50
Building executive/supervisor	33
Building technician	10
Others	7

In order to validate the questionnaire's results, a case study was carried out on a 32-storey office building located in Kuala Lumpur. The building was seven years old, with a total floor area of 493,000 square feet, and privately owned and managed under the in-house maintenance and management team. The purpose of the case study was also to test the applicability of the developed regression model. Relevant information about the significant predictor was collected. The data were applied into the regression model for calculation of the maintenance cost variance (MCV) ratio. Consequently, the ratio was compared to the exact scenario of the office building.

5. Findings and discussion

5.1 Ranking analysis

Ranking analysis is commonly used to determine the relative importance of variables in research. The mean score (with 1 – not important at all, to 5 – very important) indicates the different levels of importance of the various spare parts management contributors in maintenance management (refer to Table II).

It was found that "QSP" achieved the highest ranking, with a mean score of 3.53. Meanwhile, the standard deviation value was 0.944, indicating that the data were widespread and not biased. Essentially, the QSP was identified as the most important characteristic in executing scheduled maintenance. This finding supports the statement of Ali *et al.* (2010) that the QSP is crucial, as it always has an impact on maintenance performance. By having good quality spare parts, building systems can operate effectively with minimal breakdowns or failure. Additionally, the replacement interval of the parts can be extended, as quality parts usually have a longer lifetime. In order to acquire good quality spare parts, selection of reliable suppliers is significant (Roda *et al.*, 2014).

The results also showed that the "budget allocation to acquire spare parts" ranked second, with a mean score of 3.19 and standard deviation value of 0.880. Indeed, adequate budget allocation is vital, as it ensures that resources are available to acquire parts needed to perform replacement tasks on time. Additionally, a sufficient budget allows for a bulk order of spare parts that is usually sold at cheaper cost. On the other hand, insufficient funds may lead to acquisition of poor quality parts that cause more maintenance issues in the future. Hence, optimal budget allocation ensures the availability of spare parts, efficient spare parts reordering, adequate stocks of spare parts, and good quality spare parts (Groote, 1995). In addition, the balance between budget allocation for purchasing spare parts and the consequences of stock-out cannot be ignored (Hassan *et al.*, 2014).

The variable found to rank lowest in this analysis was stock levels of spare parts, with a mean score of 2.83, which is below 3.00. Data are normally distributed with a standard deviation value of 0.861. This result indicates that excessive stocks of spare parts may jeopardise effective maintenance management. This is because extra storage space is required to keep and store these spare parts. Meanwhile, extensive care is

Table II. Importance level of the contributors of spare parts management

Rank	Variable	Mean ($n = 101$)	SD
1	Quality	3.53	0.944
2	Budget allocation	3.19	0.880
3	Level of stocks	2.83	0.861

required to ensure the upkeep of the spare parts, especially fragile parts like fluorescent tubes and light bulbs. Thus, this result confirms that accurate spare parts identification and stocking help to control and improve the effectiveness of maintenance management (Tsang, 1995). As suggested by Hassan *et al.* (2014), decision making in prioritising the level of stocks for different spare parts is critical.

5.2 Reliability analysis

The reliability of data for the various contributors of spare parts management was then examined through Cronbach's α analysis. The Cronbach's α coefficient for the contributors was 0.756. A coefficient number above 0.70 indicates acceptable reliability (Leech *et al.*, 2011). Therefore, the scale and data obtained in this research were confirmed to be reliable.

5.3 Correlation analysis

Following this, an associative test using Spearman rank correlation coefficient analysis was conducted to establish the relationship between the contributors of spare parts management and maintenance cost performance (refer to Table III). Higher concern for the contributors is likely to reduce the cost variance. Therefore, a negative correlation between the contributors and cost variance was expected in the analysis outcome.

In an associative test, the null hypothesis is rejected at a significance level of 0.05. In other words, the probability of error in rejecting the null hypothesis is 5 per cent. The null (*H0*) and alternative (*H1*) hypotheses of this study are stated as follows:

H0. There is no significant correlation between the contributors of spare parts management and maintenance cost performance.

H1. There is a significant correlation between the contributors of spare parts management and maintenance cost performance.

The correlation analysis results (Table III) indicated that the QSP was significantly correlated to the cost variance with a correlation coefficient of −0.327 (p-value less than 0.01). This indicates that good quality spare parts optimise maintenance expenses by minimising defects and failures. Poor quality spare parts and materials are likely to become damaged and cause unwanted failure to building systems. Thus, additional repair and replacement work would be needed, which incurs extra maintenance cost.

The results also found that budget allocation for acquisition of spare parts was significantly correlated to the cost variance, with a correlation coefficient of −0.232 (p-value less than 0.05). Budget allocation for spare parts allows for the storing of spare parts at an adequate level. Furthermore, better quality spare parts are obtained when there is less budget limitation. In some circumstances, organisations refuse to allocate an adequate budget for acquiring spare parts. As a result, maintenance personnel face

Table III. Correlation matrix between the contributors of spare parts management and maintenance cost variance

Variable	Cost variance
Quality	−0.327**
Budget allocation	−0.232*
Level of stocks	−0.255*

Notes: *,**Correlations are significant at the 0.05 and 0.01 levels, respectively issues of poor stock management and reduced QSP, which are factors that lead to delayed maintenance tasks and unwanted damages. This is especially pertinent because extra maintenance incurs cost.

The level of stocks was significantly correlated to the MCV with a correlation coefficient of −0.255 (p-value less than 0.05). This indicates that proper management of spare parts ensures the availability of adequate spare parts for maintenance tasks. The maintenance expenditure also increases under inefficient management of spare parts. For example, the maintenance staff will be urged to order a small number of spare parts to carry out maintenance tasks when there are no spare part stocks available. It usually costs more to order a small number of spare parts instead of a large number. Consequently, maintenance expenses will increase.

Based on these results, the null hypothesis was rejected and the alternative hypothesis was accepted. These findings confirm that the higher the concern towards the quality, budget, and stock of spare parts, the lower the variation of maintenance cost. In other words, building managements can optimise maintenance costs if they are able to effectively manage the quality, budget, and stock of the spare parts.

5.4 Regression analysis

Subsequently, a regression analysis was performed to produce a prediction model of the strength of the relationship between the variance of maintenance cost and the contributors of spare parts management. According to the correlation analysis result, the predictors of MCV included QSP, budget allocation for management of spare parts (BSP), and SSP. The regression model for this research is produced below:

Model 1 (enter method):

$$\text{MCV} = 6.308 - 0.490\ \text{QSP} - 0.184\ \text{BSP} - 0.031\ \text{SSP}$$

Coefficient of multiple regression, $R^2 = 0.126$ (12.6 per cent).

Nevertheless, the results of the analysis identified that two predictors were not significant with a p-value of more than 0.05 (see Table IV). Therefore, another regression model was produced to eliminate the non-significant predictors, as follows (see Table V):

Model 2 (stepwise method):

$$\text{MCV} = 5.949 - 0.580\ \text{QSP}$$

Coefficient of multiple regression, $R^2 = 0.116$ (11.6 per cent).

	Unstandardised coefficients		Standardised coefficients			95.0 % Confidence interval for B		Collinearity statistics	
Model	B	SE	β	t	Sig.	Lower bound	Upper bound	Tolerance	VIF
1 Constant	6.308	0.686		9.194	0.000	4.946	7.670		
QSP	−0.490	0.195	−0.289	−2.511	0.014	−0.878	−0.103	0.682	1.467
BSP	−0.184	0.212	−0.101	−0.868	0.388	−0.604	0.237	0.666	1.501
SSP	−0.031	0.233	−0.017	−0.134	0.893	−0.493	0.430	0.578	1.731

Note: Dependent variable: maintenance cost variance

Table IV. Coefficient of model 1 (enter method)

The assumptions of the multiple regression analysis were then examined. It was found that no multicollinearity problem occurred, where all the tolerance and VIF values of the predictors were more than 0.1 and less than 5, respectively.

These results indicate that only one contributor of spare parts management was a significant predictor in Model 2, namely, QSP ($\beta = -0.341$, $p < 0.05$). Meanwhile, it was found that 11.6 per cent of the maintenance cost variation could be predicted by the QSP. The regression analysis results therefore prove that the QSP is the most influential contributor in maintenance cost performance. Consequently, the selection of good quality spare parts must be emphasised in the maintenance and repair of buildings and services. Building managers are recommended to apply the regression model in planning maintenance strategies. This is because the regression model is able to predict the maintenance cost performance before the implementation of maintenance strategies.

5.5 Testing the applicability of the regression model in practical life

Since Model 2 was identified as an appropriate model for estimating the cost performance, a case study on a selected office building was conducted to collect data on the QSP and MCV. The respondents' level of concern towards the QSP was reflected by the criteria of acquiring spare parts as shown in Table VI; while the MCV was reflected by the ratio of actual maintenance cost to planned maintenance cost, as shown in Table VII.

In this case study, the management team of the building had a very high degree of concern regarding the QSP. The management spent 50 per cent of total maintenance costs on acquiring spare parts with a lifespan of at least two years, achieving a measurement unit score of 4 (refer to Table VI). Meanwhile, the actual and planned annual maintenance costs of the building were 175,000 and 160,000 Malaysian

Table V. Coefficient of model 2 (stepwise method)

	Unstandardised coefficients		Standardised coefficients			95.0 % Confidence interval for *B*		Collinearity statistics	
Model	*B*	SE	*β*	*t*	Sig.	Lower bound	Upper bound	Tolerance	VIF
2 Constant	5.949	0.587		10.140	0.000	4.785	7.114		
QSP	−0.580	0.160	−0.341	−3.613	0.000	−0.898	−0.261	1.000	1.000

Note: Dependent variable: maintenance cost variance

Table VI. Measurement units of the predictor

Criteria of acquiring spare parts	Level of concern towards quality of spare parts	Measurement unit
Lowest acquisition cost without considering lifespan of spare parts	Very low degree	1
Lower acquisition cost with little concern on lifespan of spare parts	Low degree	2
Lower acquisition cost with moderate concern on lifespan of spare parts	Average	3
Optimal acquisition cost with high concern on lifespan of spare parts	High degree	4
Longest lifespan without considering acquisition cost	Very high degree	5

Ringgit, respectively. Therefore, the ratio of the MCV was 1.09, with a measurement unit score of 4 (refer to Table VII).

The measurement unit score of the predictor was inserted into the regression model for calculation as follows:

$$\begin{aligned} MCV &= 5.949 - 0.580\ QSP \\ &= 5.949 - 0.580\,(4) \\ &= 3.629 \approx 4 \end{aligned}$$

The results showed that the prediction of MCV calculated through the regression model exactly matches the scenario in the case study. Therefore, the applicability of this regression model in practical life is validated and confirmed. This result also indicates that a very high degree of concern towards the QSP is essential in eliminating the issue of over-budgeting.

6. Conclusion

The significance of spare parts management in improving maintenance cost performance was the focus of this paper. The literature review revealed three important contributors of spare parts management in building maintenance, namely, QSP, budget allocations for the acquisition of spare parts, and level of stocks. However, the ranking analysis showed a lack of concern towards level of stocks by building practitioners. The result of the associative test demonstrated a significant correlation of the three contributors with cost variance. Meanwhile, the regression analysis result emphasised the significance of the QSP. These results highlight the fact that improper management of spare parts must be avoided to achieve better maintenance performance. In order to avoid unavailability of spare parts, this study recommends that maintenance management set up a spare parts management department for updating stocks frequently. Additionally, management should avoid ad-hoc acquisition of spare parts - as this is always more expensive- and focus on the QSP instead of selecting spare parts based on lowest cost. In conclusion, the findings and discussion of this research emphasise that selection of good quality spare parts is the most important principle to be practised by practitioners of building maintenance. As mentioned before, in order to ensure the acquisition of good quality spare parts, selection of reliable suppliers is of utmost concern. Finally, this paper proves that effective management of spare parts tends to improve maintenance cost performance. Furthermore, the effective management of spare parts does not only enhance maintenance performance, but also aids organisations in achieving their organisational objectives. This is because positive maintenance performance ensures that buildings and systems operate effectively to support the organisations' activities.

Maintenance cost variance (ratio)	Measurement unit
0-0.80	1
0.81-0.90	2
0.91-1.00	3
1.01-1.10	4
1.11-1.20	5
1.21 and above	6

Table VII. Measurement units of the prediction

References

Ali, A.S. (2009), "Cost decision making in building maintenance practice in Malaysia", *Journal of Facilities Management*, Vol. 7 No. 4, pp. 298-306.

Ali, A.S., Kamaruzzaman, S.N., Sulaiman, R. and Au Yong, C.P. (2010), "Factors affecting housing maintenance cost in Malaysia", *Journal of Facilities Management*, Vol. 8 No. 4, pp. 285-298.

Amaratunga, D. and Baldry, D. (2002), "Moving from performance measurement to performance management", *Facilities*, Vol. 20 Nos 5/6, pp. 217-223.

Assaf, S., Hassanain, M.A., Al-Hammad, A.M. and Al-Nehmi, A. (2011), "Factors affecting outsourcing decisions of maintenance services in Saudi Arabian universities", *Property Management*, Vol. 29 No. 2, pp. 195-212.

Au-Yong, C.P., Ali, A.S. and Ahmad, F. (2013), "Office building maintenance: cost prediction model", *Gradevinar*, Vol. 65 No. 9, pp. 803-809.

Au-Yong, C.P., Ali, A.S. and Ahmad, F. (2014), "Improving occupants' satisfaction with effective maintenance management of HVAC system in office buildings", *Automation in Construction*, Vol. 43, July, pp. 31-37.

Bevilacqua, M. and Braglia, M. (2000), "The analytic hierarchy process applied to maintenance strategy selection", *Reliability Engineering and System Safety*, Vol. 70 No. 1, pp. 71-83.

Costantino, F., Gravio, G.D. and Tronci, M. (2013), "Multi-echelon, multi-indenture spare parts inventory control subject to system availability and budget constraints", *Reliability Engineering and System Safety*, Vol. 119, November, pp. 95-101.

De Silva, N. and Ranasinghe, M. (2010), "Maintainability risks of condominiums in Sri Lanka", *Journal of Financial Management of Property and Construction*, Vol. 15 No. 1, pp. 41-60.

El-Haram, M.A. and Horner, M.W. (2002), "Factors affecting housing maintenance cost", *Journal of Quality in Maintenance Engineering*, Vol. 8 No. 2, pp. 115-123.

Eti, M.C., Ogaji, S.O.T. and Probert, S.D. (2006), "Development and implementation of preventive-maintenance practices in Nigerian industries", *Applied Energy*, Vol. 83 No. 10, pp. 1163-1179.

Flores-Colen, I. and De Brito, J. (2010), "A systematic approach for maintenance budgeting of buildings facades based on predictive and preventive strategies", *Construction and Building Materials*, Vol. 24 No. 9, pp. 1718-1729.

Forster, A.M. and Kayan, B. (2009), "Maintenance for historic buildings: a current perspective", *Structural Survey*, Vol. 27 No. 3, pp. 210-229.

Groote, P.D. (1995), "Maintenance performance analysis: a practical approach", *Journal of Quality in Maintenance Engineering*, Vol. 1 No. 2, pp. 4-24.

Hameed, Z., Ahn, S.H. and 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*, Vol. 35 No. 5, pp. 879-894.

Hassan, J., Khan, F. and Hasan, M. (2014), "A risk-based approach to manage non-repairable spare parts inventory", *Journal of Quality in Maintenance Engineering*, Vol. 18 No. 3, pp. 344-362.

Horner, R.M., El-Haram, M.A. and Munns, A. (1997), "Building maintenance strategy: a new management approach", *International Journal of Quality in Maintenance*, Vol. 3 No. 4, pp. 273-280.

Hoxley, M. (2008), "Questionnaire design and factor analysis. Advanced research methods in the built environment", in Knight, A. and Ruddock, L. (Eds), *Advanced Research Methods in the Built Environment*, Wiley-Blackwell, Chichester, pp. 122-134.

Idrus, A., Khamidi, M.F. and Lateef, O.A. (2009), "Value-based maintenance management model for university buildings in Malaysia – a critical review", *Journal of Sustainable Development*, Vol. 2 No. 3, pp. 127-133.

Kamaruzzaman, S.N. and Zawawi, E.M.A. (2010), "Development of facilities management in Malaysia", *Journal of Facilities Management*, Vol. 8 No. 1, pp. 75-81.

Kranenburg, A.A. and van Houtum, G.J. (2008), "Service differentiation in spare parts inventory management", *Journal of the Operational Research Society*, Vol. 59 No. 7, pp. 946-955.

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

Nilsson, J. (2007), "Reliability and cost centered maintenance methods: nuclear power and reliability centered maintenance (RCM)", *Maintenance Management in Power Systems*, KTH School of Electrical Engineering, Stockholm, pp. 1-17.

Parida, A. and Kumar, U. (2006), "Maintenance performance measurement (MPM): issues and challenges", *Journal of Quality in Maintenance Engineering*, Vol. 12 No. 3, pp. 239-251.

Roda, I., Macchi, M., Fumagalli, L. and Viveros, P. (2014), "A review of multi-criteria classification of spare parts", *Journal of Manufacturing Technology Management*, Vol. 25 No. 4, pp. 528-549.

Ruslan, N. (2007), "Campus facilities management experience", paper presented at the National Asset and Facilities Management (NAFAM) Convention, National Asset and Facility Management Development, Kuala Lumpur, 13 August.

Salonen, A. and Deleryd, M. (2011), "Cost of poor maintenance: a concept for maintenance performance improvement", *Journal of Quality in Maintenance Engineering*, Vol. 17 No. 1, pp. 63-73.

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

Swanson, L. (2001), "Linking maintenance strategies to performance", *International Journal of Production Economics*, Vol. 70 No. 3, pp. 237-244.

Tsang, A.H.C. (1995), "Condition-based maintenance: tools and decision making", *Journal of Quality in Maintenance Engineering*, Vol. 1 No. 3, pp. 3-17.

Wang, W. (2012), "A stochastic model for joint spare parts inventory and planned maintenance optimisation", *European Journal of Operational Research*, Vol. 316 No. 1, pp. 127-139.

Yik, F.W.H. and Lai, J.H.K. (2005), "The trend of outsourcing for building services operation and maintenance in Hong Kong", *Facilities*, Vol. 23 Nos 1/2, pp. 63-72.

Zuashkiani, A., Rahmandad, H. and Jardine, A.K.S. (2011), "Mapping the dynamics of overall equipment effectiveness to enhance asset management practices", *Journal of Quality in Maintenance Engineering*, Vol. 17 No. 1, pp. 74-92.

Corresponding author
Cheong Peng Au-Yong can be contacted at: auyongcp@um.edu.my