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# Optimal inspection frequency to mitigate the risk of building system failure

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**Abstract.** The poor maintenance practice increases the possibility of system failure. Subsequently, the consequences of failure fall on the aspects of output, safety and healthy, environmental integrity, system quality, and customer satisfaction. Condition-based maintenance is seen as a potential strategy to improve performance. Whereby, the key success factor of this maintenance strategy is identified as the system inspection. This study aims to investigate the association between system breakdown rate and frequency of inspection. A mixed method approach is implemented by distributing questionnaire and interviewing for data collection. Subsequently, descriptive analysis, correlation analysis and regression are adopted to analyse the collected data from 100 respondents and the results are validated with interview data of 10 interviewees. The research result establishes significant relationship between the system breakdown rate and the frequency of inspection. Additionally, the result of regression analysis confirms that the frequency of inspection is the significant predictor of system breakdown rate. Planning of accurate inspection frequency is crucial to secure the system performance. Hence, the research signifies the importance to carry out regular inspection towards the building systems and components. As a recommendation, the maintenance personnel should assess the risk criticality of the building systems. Then, continuously monitor the condition of critical building systems; regularly inspect the condition of non-critical building systems and randomly inspect all of them.

**Keywords:** inspection; preventive maintenance; condition-based maintenance; system failure; maintenance performance

## 1. Introduction

In Malaysia, practice of maintenance strategies is inefficient and this leads to the low service quality (Kamaruzzaman and Zawawi, 2010, Ruslan 2007). Public is not aware of the consequences of poor building maintenance, such as the massive costs required for solving the maintenance backlog, repairing or replacing the damaged systems (Lateef 2008). Indeed, all building components subject to failure as a result of continuous deterioration (Zhang *et al*. 2016). However, most of the buildings adopt corrective maintenance strategy, which carries out repair works only after failure occurs. At best, they only implement scheduled maintenance strategy that performs maintenance tasks at fixed interval without understanding the condition of systems (Edward *et al*. 1998, Moubray 2007). The possibility of the system failure occurrence still exists.

In fact, system failure leads negative impacts to the stakeholders of building, such as organisations, users and customers in commercial building (Eti *et al*. 2006). The impacts could be in terms of productivity, user satisfaction, safety and healthy, environmental integrity, system quality, and additional maintenance cost incurred. Therefore, the enhancement to the current maintenance strategies is required to improve the maintenance outcomes. Condition-based maintenance is seen as the advancement of scheduled maintenance, where maintenance works are performed upon the knowledge of system condition from continuous monitoring and regular inspection (Au-Yong *et al*. 2014a, Veldman *et al*. 2011).

However, continuous monitoring of systems is often expensive and raw signals with noise may produce inaccurate diagnostic information (Golmakani and Pouresmaeeli 2014). Furthermore, it is not applicable for all system components due to the limitation or availability of alarm and detection systems and hence, the systems often do not show the symptoms of degradation state or the imminence of failure (Maaroufi *et al*. 2015). Therefore, inspection is critical in identifying their condition state or in evaluating the level of deterioration to make appropriate maintenance decision. (Chen and Nepal 2015) stated that effective inspection of deterioration ensures the accuracy of condition assessment. Additionally, the increase in complexity and size of building systems urges the maintenance personnel to stress on system inspection that helps to reduce unwanted failure, overall cost and risk exposure (Hameed *et al*. 2016).

Whereby, the key success factor of the maintenance strategy is identified as the system inspection. This paper seeks to investigate whether frequency of inspection is able to optimise the maintenance performance, which is

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minimising the rate of building system failure.

## 2. Maintenance inspection

Deterioration is an unavoidable process of building components and systems due to the aging or wear-and-tear effect. In order to ensure the building systems operate in a reliable state, effective inspection and maintenance is one of the essential elements to focus on. The main aim of inspection and maintenance is to ensure that the building systems are enhanced in which does not only improve the quality and availability of the systems, but also mitigate the overall operational risk (Hameed *et al*. 2016).

According to Zhang *et al*. (2016), the components, especially mechanical components, may operate in two stages, a normal stage and a wear-out stage. Wear-out stage is a transition stage between normal stage and breakdown stage. The components experience increased deterioration rate at this stage and prone to the failure occurrence. Abnormal condition can only be observed or detected at this stage if inspection is executed. Then, the inspection data become the source of information for maintenance decision-making (Lam and Banjevic 2015). An appropriate inspection policy produces accurate condition data that reflect the operational life of parts and components. In this circumstance, postponed replacement based on the maximum operational life of parts and components is feasible to avoid excessive maintenance and extend the system lifetime, and hence optimise the maintenance cost (Yang *et al*. 2016).

Proper practice of system inspection guarantees the efficiency of condition-based maintenance. The statement is proven by Sherwin (2000), stating that increased maintenance attention in system inspection helps to reduce the downtime of a system. Hameed *et al*. (2010) supported that the ability to monitor and inspect the condition of building services and facilities greatly influences the planning of proper maintenance activities prior to failure and maintenance expense. Additionally, inspection ensures the safety of system and helps to identify necessary maintenance, repair, or strengthening works (Naser and Zonglin 2011). The preventive replacement is performed only if the risk of failure reaches critical level or exceeds the threshold (Golmakani and Pouresmaeeli 2014). In addition, Lam and Banjevic (2015) emphasised that inspection is a must to understand the condition of systems. In order to meet the reliability requirements and mitigate the occurrence of system breakdowns, inspection is of vital to provide information about the system condition for execution of maintenance activities, such as repair and replacement (Yang *et al*. 2016).

Taking into cognisance the significance of inspection, the frequency of inspection should be reviewed, either carry out inspections with predetermined interval or at random interval, so that remedy can be performed to prevent the breakdowns or failures that might occur (Tsang 1995). The maintenance personnel need to sort out an ideal frequency or interval of inspection to avoid over-inspection or under-inspection. Then, the resources will not be wasted and the changes of system condition will not be neglected and jeopardised too (Au-Yong *et al*. 2014b). In order to achieve optimum monitoring of building and its system conditions, inspections should preferably be carried out at organised intervals. This would provide adequate condition data for selecting the most cost-effective means for maintenance execution and hence minimising the risk and hazards to the building occupants (Jardine *et al*. 2006, Lo and Choi 2004). Meanwhile, Maaroufi *et al*. (2015) noted that it is vital to determine the interval of inspections because each inspection implies a certain cost and a certain duration.

Although system inspection is carried out in regular interval basis, it may not enhance the profitability of the maintenance strategy, especially when the inspection task is costly (Grall *et al*. 2002). System inspection may be scheduled, on request or in a continuous basis, depending on the criticality of the systems or components. Kwak *et al*. (2004) had proven that the inspection frequency affects the profit of condition-based maintenance. In addition, Jardine *et al*. (2006) argued that periodic inspection is more economical and provides more precise analysis using filtered and processed information and evidence. Thus, it is necessary to identify the optimal frequency of inspection, so that condition-based maintenance can improve the performance in terms of system quality and economical factor. Eventually, the building owner gains profits because of the effective maintenance expenditure and minimal system maintenance downtime in management.

Indeed, Lam and Banjevic (2015) suggested the less execution of inspections in the early stage of operation, and more frequent inspections as the system ages. The idea seems logical because the building systems usually work in good condition at the early stage. This will significantly improve the saving of inspection cost. However, the capability to reduce or even avoid the risk of failure by presenting optimal inspection frequency is still unknown. As such, this paper focuses on measuring the maintenance performance in terms of system breakdown rate.

## 3. Maintenance performance

According to Halim *et al*. (2011), measuring the maintenance performance involves technical evaluation of mechanical and electrical systems provided in a building. They proposed a systematic approach in measuring maintenance performance, named as “SPRINT”. In the approach, one of the aspects they focused on was the performance history of systems. For instance, the total number of system breakdowns and the duration of breakdowns were recorded and documented. In fact, the breakdown data could reflect the maintenance performance directly.

Moreover, Chan *et al*. (2001) suggested that system failure frequency could be identified by recording the sum of urgent and general repairs. The researchers further explained that if the maintenance personnel are capable to execute the maintenance jobs effectively, the failure rate of the building systems would be minimised or reduced from time to time. The example has proven that the measurement

1. Please rate the frequency of inspection on air-conditioning system with the following scale.

   1 2 3 4 5

   *Very rare* [ ][ ][ ][ ][ ] *Very often*

2. Please indicate the average rate of AC system breakdown (that requires 1 day or more to repair it) per year.

   [ ] 0 [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 and above

Fig. 1 Example of questions

of system failure frequency could determine the maintenance performance in relation to labour skill and knowledge. In this study, the inspection frequency is examined along with the system breakdown rate, where the former is the independent variable and the latter is the dependant variable.

Therefore, the maintenance performance measurement adopted in this study is system breakdown rate for the building services and components.

## 4. Research method

The study focused on the buildings with at least seven floors, which is categorised as high-rise building under Uniform Building By-Laws 1984, Malaysia. Whereby, the high-rise buildings are necessarily installed with more sophisticated systems such as lift system, air-conditioning system, and firefighting system. Nevertheless, this paper limited to study on air-conditioning system only since Wu *et al*. (2006) convinced that air-conditioning maintenance programme is the reference and basis in formulating most maintenance programmes of building systems. In addition, the study limited to those buildings with minimum age of two years because the needs of maintenance of new buildings are varied from the older buildings. Generally, the maintenance works to be executed for a new building are fewer compared to old building (Nik Mat 2009).

This study engaged mixed method approach with reference to the work done by Ali (2009), including questionnaire survey and semi-structured interview. This approach allows the researcher to validate the results among the different methods and enhance the reliability of research outputs (Yin 2009). With the intention of acquiring an acceptable response rate for questionnaire survey, the design of questionnaire needs to be clear and easily understood. It should not be spending too much of time for the respondents to complete the questionnaire too. Hence, close-ended questions were set up in the forms of 5-point Likert scale and multiple choices as shown in Fig. 1. Simple random sampling was implemented for distribution of questionnaire. For this study, the relevant respondents were those who have been or are currently responsible in the field of building maintenance management. They were requested to response the questions based on their experience and knowledge in maintenance management for high-rise office buildings. Questionnaire survey obliges a minimal response rate of 30 percent to demonstrate reliable and substantial results (Hoxley 2008). In this study, 300 questionnaires were disseminated to the maintenance experts, namely building manager, building executive and supervisor,

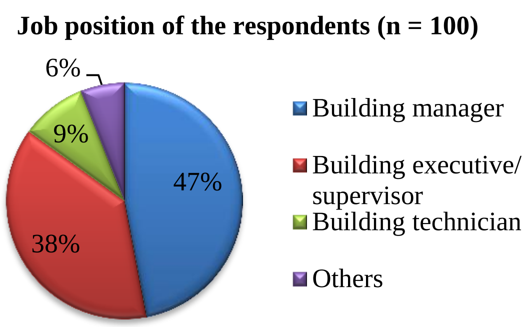


Fig. 2 Job position of the respondents

Table 1 Working experience of the respondents

| Working Experience | Percentage ($n$ =100) |
|---|---|
| <5 years | 27 |
| 6-10 years | 43 |
| 11-15 years | 16 |
| >15 years | 14 |

technician and other maintenance personnel. As a result, 106 responses were gathered, but only 100 were completely answered and valid for the investigation. Another 6 questionnaires were unfinished and thus unacceptable for analysis purpose. Therefore, the survey attained a 33 percent response rate. The job position of respondents is illustrated in Fig. 2. 85 percent of the respondents were the managerial and executive staffs. They are the expertise in the planning and execution of the maintenance activities. Basically, they are knowledgeable on the significance of the maintenance criteria through planning, managing, controlling, and monitoring the maintenance activities. Furthermore, 73 percent of the respondents work at least six years in the field of maintenance management (refer Table 1). Consequently, the gathered data were reckoned reliable and trustworthy.

In order to confirm the questionnaire results, interview sessions were conducted. The selection criteria of the interviewees were building managers who have working experience of not less than 5 years. The participants were shortlisted from the survey respondents who fulfil the criteria. Detailed explanations about the relationship between the frequency of inspection and system breakdown rate were acquired during the semi-structured interview sessions. For instance, the interview questions sounded "*Does the frequency of inspection influence the breakdown rate of air-conditioning system?*" and "*How it influences the system breakdown rate?*" In fact, the interview sessions allow obtaining the participants' opinion thoroughly

Table 2 Correlation coefficient between the system breakdown rate and frequency of inspection

| | | System Breakdown Rate |
|---|---|---|
| Frequency of inspection | Correlation Coefficient | -0.459* |
| | Sig. (2-tailed) | 0.000 |

*. Correlation is significant at the 0.01 level (2-tailed)

Table 3 Coefficient of model (Enter Method)

| Model | | Unstandardised Coefficients | | Standardised Coefficients | *t* | Sig. | 95.0% Confidence Interval for B | | Collinearity Statistics | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *B* | Std. Error | Beta | | | Lower Bound | Upper Bound | Tolerance | VIF |
| 1 | (Constant) | 4.667 | .398 | | 11.731 | .000 | 3.877 | 5.456 | | |
| | FI | -.609 | .119 | -.459 | -5.120 | .000 | -.845 | -.373 | 1.000 | 1.000 |

Dependent Variable: System Breakdown Rate

Table 4 Measurement units of the research variables

| Variable | Attribute | Measurement Unit |
|---|---|---|
| Frequency of inspection | Very rare | 1 |
| | Rare | 2 |
| | Moderate | 3 |
| | Often | 4 |
| | Very often | 5 |
| System breakdown rate | No breakdown/year | 1 |
| | 1 breakdown/year | 2 |
| | 2 breakdown/year | 3 |
| | 3 breakdown/year | 4 |
| | 4 breakdown/year | 5 |
| | ≥5 breakdown/year | 6 |

(Marshall and Rossman 2006). 42 survey respondents fulfilled the criteria of being the interview participants. Nonetheless, only 10 of them were willing to be interviewed.

## 5. Findings and discussion

In this research, a correlation test using Pearson product-moment coefficient analysis investigated the association between the system breakdown rate and frequency of inspection as tabulated in Table 2. This study expected significant relationship between the frequency of inspection and system breakdown rate in the analysis outcome.

In the correlation test, null hypothesis is rejected at significance level of 0.05. In other words, the probability of error in rejecting the null hypothesis is 5 percent. The null ($H_0$) and alternative ($H_1$) hypothesis are stated as follow:

$H_0$–There is no significant association between the system breakdown rate and frequency of inspection.

$H_1$ – There is significant association between the system breakdown rate and frequency of inspection.

The result as shown in Table 2 reveals that the frequency of inspection is significantly correlated with system breakdown rate at correlation coefficient of -0.459 ($p < 0.05$). Basically, the frequency of inspection towards the building systems ensures the accuracy of awareness on the changes of systems' condition. The result supported the statement of Hameed *et al*. (2010), that the ability to monitor and inspect the condition of systems at the right time influences the planning of maintenance activities prior to failure. In other words, the more frequent the conditions of building systems are monitored and inspected, the earlier the defects of building systems can be identified. Then, maintenance tasks can be planned and performed to prevent the occurrence of part damage or system failure. Consequently, the system breakdown rate can be minimised.

Chore and Shelke (2013) demonstrated that regression model helps to improve the accuracy of predictions between independent and dependent variables. Thus, a regression analysis develops a prediction model of the strength of the relationship between the dependent variable, system breakdown rate (SBR) and the independent variable, frequency of inspection (FI). The regression model for this research is formulated as follow (refer Table 3)

$$\text{SBR} = 4.667 - 0.609\ \text{FI} \qquad \text{Coefficient of regression, } R^2 = 0.211 \tag{1}$$

This result indicates that the frequency of inspection is the significant predictor in the model, namely, FI ($\beta$=-0.459, $p$<0.05). Whereby this research only focuses on a single independent variable, the $R^2$ is expected to be less. 21.1% of the system breakdown rate can be predicted by the frequency of inspection. Thus, the frequency of inspection is an influential contributor in system breakdown rate. Since the regression model was identified fit to estimate the system breakdown rate, the model was applied to determine the appropriate frequency of inspection to secure the acceptable system breakdown rate. Given the measurement units of the two variables in Table 4, the prediction of system breakdown rate is calculated and tabulated in Table 5. Nevertheless, there might be other significant factors that affecting the system breakdown rate and this create further research opportunity.

Based on Table 5, the frequency of inspection categorised as "very rare" implies three major breakdowns per year, which is unacceptable. Then "rare" and "moderate" inspection frequencies cause two major breakdowns per year. "Often" and "very often" inspection frequencies contribute to only one breakdown per year. The prediction shows that often and even more execution of inspection than what is recommended by the manufacturer ensure the lowest occurrence of system breakdown. However, Golmakani and Pouresmaeeli (2014) viewed that it is uneconomical to inspect the building system too frequently. Considering the prediction result and literature statements, it is ideal to carry out maintenance inspection slightly frequent than what is recommended by the manufacturer. The prediction model assists to obtain the balance and equality between controlling the performance (reducing system breakdown) and economics (optimising inspection and maintenance cost) (Chore and Shelke 2013). Meanwhile, the interval of inspection should be reviewed from time to time based on the degradation rate of system in order to achieve balance between the inspection cost and failure cost (Lam and Banjevic 2015, Maaroufi *et al*. 2015, Zhang *et al*. 2016).

Table 5 Prediction of system breakdown rate

| Frequency of Inspection | Calculation | System Breakdown Rate |
|---|---|---|
| Very rare | SBR=4.667–0.609 (1)<br>= 4.058<br>≈ 4 | 3 breakdown/year |
| Rare | SBR=4.667–0.609 (2)<br>= 3.449<br>≈ 3 | 2 breakdown/year |
| Moderate | SBR=4.667–0.609 (3)<br>= 2.84<br>≈ 3 | 2 breakdown/year |
| Often | SBR=4.667–0.609 (4)<br>= 2.231<br>≈ 2 | 1 breakdown/year |
| Very often | SBR=4.667–0.609 (5)<br>= 1.622<br>≈ 2 | 1 breakdown/year |

After that, the interview participants were asked for detailed explanation about the relationship between frequency of inspection and system breakdown rate during the interview. The interview data were analysed using data reduction and display method, which is able to produce the interview summaries, categorising the data, and constructing narrative (Sekaran & Bougie, 2009). All the participants confirmed that the frequency of inspection has significant impact towards the system breakdown rate and other performance aspects. The summary of interview about the relationship between the frequency of inspection and system breakdown rate is tabulated in Table 6. The interview result validates the survey result, stating that there is significant relationship between the frequency of inspection and system breakdown rate.

In summary, the result rejects the null hypothesis and accepts the alternative hypothesis. The frequency of inspection is a vital aspect to be considered in condition-based maintenance. Planning of accurate inspection frequency ensures the parts of building systems to be restored to their functional standard on time, so that the conditions of building systems stay above the satisfactory standard and operate effectively to support the building purpose.

## 6. Recommendations

Yang (2004) claimed that the fixed-interval maintenance programs might not be able to mitigate the risk of failure from taking place in system components before the routine replacement time, advanced preventive action needs to be taken. Continuous or regular inspection is a proactive strategy to identify the condition of building systems and components timely (Au-Yong *et al*. 2014a). It ensures the planning of accurate maintenance interval prior to failure (Hameed *et al*. 2010). Nevertheless, the result indicates that the system failure cannot be avoided though routine inspections are performed. It is recommended to review the building systems using risk analysis, as suggested by Hameed *et al.* (2016), to determine the criticality in the aspects of operation of system, functional loss and impact on system failure. Then, the maintenance personnel can prioritise the frequency of inspection for critical and risky systems. In addition, Yang *et al*. (2016) recommended to execute random inspection on top of the regular inspection, which is able to detect defect occurs between the period of regular inspections. The inspection data allows the maintenance personnel to decide on postponement of replacement when system components are in good condition; while perform preventive replacement when system components are defective. Consequently, it improves the effectiveness of the maintenance strategy.

Table 6 The importance of the frequency of inspection towards system breakdown rate: interviewees' feedback

| | Importance |
|---|---|
| Frequency of inspection | • Ensure maintenance work is performed immediately once defect is detected to prevent system failure.<br>• Allow maximum usage of parts and components instead of replace them regularly without knowing their condition.<br>• Avoid failure (corrective repair and replacement) cost that is usually more expensive than preventive repair cost.<br>Minimise failure downtime that might be jeopardising the building functions. |

Despite the objective of this study is attained, it is believed that the research outcome might be differed when similar research are carried out to a specific building system, such as lift system, power supply system, building automation system, and others. Meanwhile, there are other considerations to optimise the maintenance outcome such as the availability of inspection tools, knowledge and skill of maintenance personnel, accuracy of inspection data, and others. Therefore, further explorative study is recommended to determine the essential elements that influencing the performance. Then, research on specific building systems can be implemented.

## 7. Conclusions

In conclusion, the literature review identifies the frequency of inspection as an importance characteristic of condition-based maintenance strategy. The result of correlation test reveals significant association between the system breakdown rate and frequency of inspection. Inadequate frequency of inspection implies negative impact in maintenance management; while over-inspection is costly. Hence, the maintenance organisation must take into account the importance of inspection frequency. Accurate inspection frequency is likely to enhance the maintenance outcome by decreasing the system breakdown rate without burdening the maintenance expenditure. The research signifies the importance to carry out regular and random inspections towards the building systems and components. For example, the maintenance personnel should continuously monitor the condition of critical building systems; regularly inspect the condition of non-critical building systems and randomly inspect the building systems between periods of regular inspections.


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