A REVIEW OF MAINTENANCE PRIORITY SETTING METHODS

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Abstract

Maintenance priority setting enables maintenance works to be planned under constraint during insufficiency of resources. The purpose of this paper is to review the literature on maintenance prioritization methods for assets including buildings and infrastructures. A brief introduction and literature review on maintenance priority methods were discussed. This paper uses a systematic search on literatures over the period of 1990 to 2015 on several database. A total of 184 literature were obtained from various literature database using the keywords "maintenance priority", "maintenance prioritization", "asset maintenance" and "building maintenance". The literature review outlines the maintenance priority-setting methods used in various case studies. The most used methods in the literature are Analytical Hierarchy Process, Priority Criterion, Matrix based Priority and Failure Mode and Effect Analysis. A discussion on the pros and cons of the maintenance priority-setting methods was carried out. The trend of maintenance priority setting methods and organizational factors related to priority setting were also discussed. Recommendations for future research includes the incorporation of organizational factors into the maintenance priority-setting methods. This paper has provided references and case studies on maintenance prioritization methods for parties involved in maintenance management.

Keywords: *Maintenance Priority, Maintenance Planning, Priority-setting Method*

1.0 INTRODUCTION

Maintenance is required in ensuring the assets of an organization such as building, infrastructure and equipment remains in the best form for use (Akasah *et al*., 2009). Instead, it is consider as a necessary evil as it is unavoidable cost required to keep the assets operational (Moua and Russell, 2001). This leads to most organizations prioritizing on their core business rather than maintenance of their assets (Kumar *et al*., 2013). Traditionally, organizations view maintenance as a cost burden and display unwillingness to spend in order to preserve the condition of their assets (Albert, 2002; Chew *et al*., 2004). However, there has been a shift in how the different facets of maintenance should be managed due to changing technologies and organizational roles of maintenance. Maintenance are seen to be moving from the operational perspective towards an organizational strategic perspective (Simões *et al*., 2011)

Adequate budget and sufficient resources are required is required to maintain the quality of the maintenance activities (Lee and Scott, 2009). Maintenance managers ponders on multiple considerations in deciding which maintenance works to be prioritized and deferred (Shen, 1997). This is to ensure proper decisions and priorities in maintenance allocation to prevent the deterioration of maintenance performance (Shah, 2009). In order to decide which maintenance work to prioritize and the consequences of each prioritization, it requires the consideration of multiple factors and thorough understanding of the business (Moore and Starr, 2006). In another study by Labib *et al*. (1998), it was stated that decision makers in maintenance tends to be efficient before being effective. Maintenance managers might prioritize based on the number of maintenance calls received while neglecting other important factors such as downtime, capacity, bottleneck constraints and spare part cost (Labib *et al*., 1998). In order to justify the investment for maintenance, effectiveness and quality of maintenance has to be measured (Aditya and Gopi, 2007).

2.0 BACKGROUND

Maintenance priority tools provides the required justification for the allocation of budget decided by maintenance manager (Shen, 1997). The intention of using such methods is to allow trade-offs between options. However, in the beginning especially the post-second world war, these tools and systems delivered little impacts and results (Smith *et al*., 2012). Various methods can be used to prioritise maintenance works. In the beginning, there are no set of rules or systems that determine the priorities of maintenance works. Priorities are determined through subjective judgement of stakeholders and are changed depending on the situation (Shen *et al.*, 1998). As maintenance planning becomes more popular, priorities are determined based on a set of criteria determined by stakeholders such as the upper management or maintenance managers (Shen *et al.*, 1998; Hakim *et al.*, 2012). Managers would categorize maintenance works and carry them out based on the order of priorities through simple ranking or priority criterions. Examples can be seen in UK schools during 1985 where priorities are categorized into 3 categories of different work urgencies. However, some of these methods are considered to be too subjective and sometimes do not accurate represents the work priorities (Shen, 1997) Thus began the development of priority setting with the proposal of formal priority setting frameworks such as the program budgeting and marginal analysis (PBMA) (Mitton and Donaldson, 2009). Priority index such as Roue's formula were proposed as early as 1986 but it was lacking in flexibility and subsequently abandoned (Shen, 1997). Priorities settings that are based on weightage of criteria such as Failure Mode and Effect Analysis (FMEA), Analytical Hierarchy Process (AHP), matrix table, Genetic Algorithm (GA) were proposed. The usage of these methods becomes popular as it provides additional justification especially from the quantitative perspective. FMEA is frequently used in industry to prioritize equipments and improving the process of the business. It is usually applied in processes and equipments that cannot afford to have critical breakdowns or downtimes such as equipments for manufacturing semi-conductors (Kai and Chee, 2006) and claddings (Layzell and Ledbetter, 1998). AHP has been gaining popularity in setting priorities since it was introduced by Saaty (1990) and it is still relevant until today. AHP has been applied in maintenance planning for school, hospital, commercial buildings and assets such as critical equipments. (Das *et al*., 2010; Shen *et al.*, 1998; Flores-Colen *et al.*, 2010; Arunaj *et al.*, 2010). Henceforth, myriads of priority setting methods have been suggested by various authors.

This study attempts to explore the available methods used to prioritize maintenance. The organization of the paper is as follows; introduction, existing literature and case studies on maintenance prioritization, discussion on these methods and lastly conclusion.

3.0 METHODOLOGY

A systematic search on literatures related to maintenance prioritization models was carried out. The database reviewed are as followed: Emerald, JSTOR, ScienceDirect, Scopus, Taylor and Francis. A total of 184 literature were reviewed. The reviewed literature focused on maintenance prioritization methods which included various models, frameworks and techniques. The period ranges from 1990 to 2015. The main keywords used are maintenance priority, maintenance prioritization, asset maintenance and building maintenance. The review is further refined and literatures that were unsuitable for this paper were excluded. Figure 1 shows the publication in relation to maintenance priority distributed over the period of 1990-2015.

There were 70 journals related to maintenance priority were reviewed. A total of 26 journals which contains more than 2 publications are shown in Figure 2. The top 5 journals are Journal of Quality in Maintenance Engineering, Facilities, Journal of Facilities Management, Structural Survey, and Construction Management and Economics. Journal of Quality in Maintenance Engineering has the most published articles related to maintenance priority.

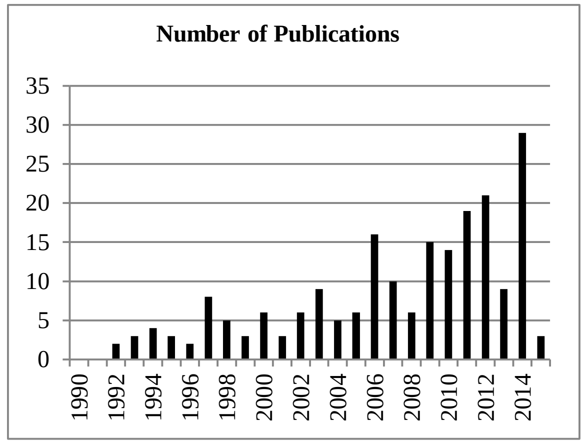

Figure 1: Publication over period of 1990-2015

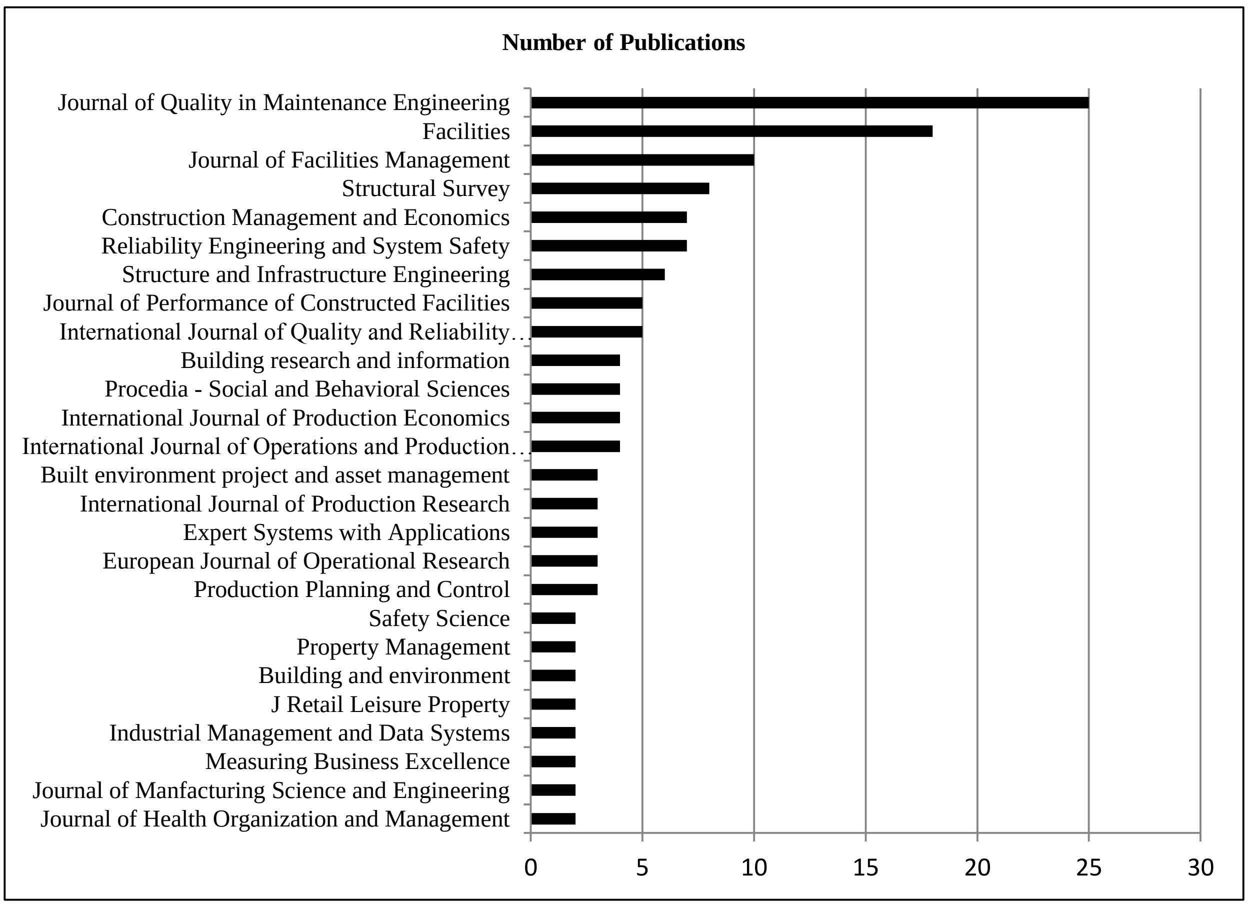

Figure 2: Publication in journals

4.0 RESULTS

From the literature, a total of 57 case studies were reviewed. The case studies ranges from assets such as plants, educational building, manufacturing, general building, equipment, residential building, automotive, bridge, road, hospital, heritage building, government facilities, railway, facades and airplanes as shown in Figure 3. Plants records the highest number of case studies followed by educational buildings, manufacturing building and general building. The least mentioned case studies are railway, facades, and airplane.

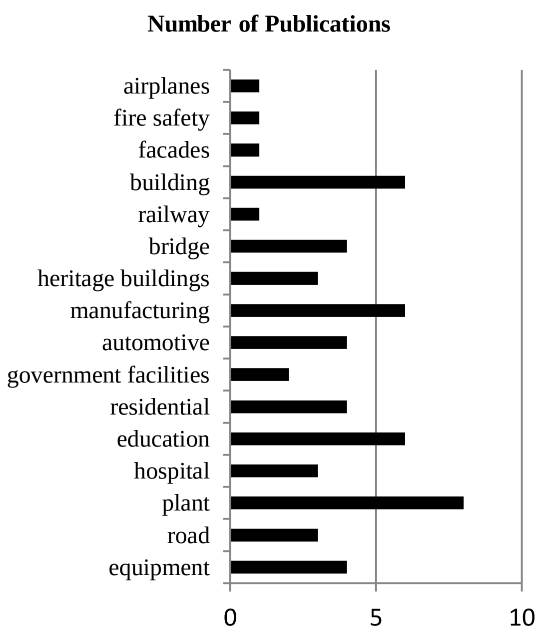

Figure 3: Types of case studies

Through detailed and systematic content analysis of the publications, a total of 62 presented framework/models and measurements were reviewed as shown in Figure 4. Analytical Hierarchy Process (AHP) based measurement recorded the highest followed by priority criterion, matrix based measurement, framework and Failure Mode and Effect Analysis (FMEA) based measurement. Some of the least used methods are; simple comparison, criticality index, additive ration assessment (ARAS), fuzzy group Analytic Network Process (ANP), cost-based criticality, Roue's formula, benchmarking, Artificial Neural Network (ANN), probabilistic risk assessment, comparative risk analysis, critical failure analysis, and priority cost FMECA. The AHP group has a few variations which include Goal Programming (GP), Bayesian Tools and decision rules. FMEA based measurement includes Risk Probability Number and Fuzzy sets. The variation of matrix contains importance and performance matrix, priority matrix, priority category matrix, hybrid structural interaction matrix and risk priority matrix. A more detailed description of the methods are described in the following section.

4.1 Analytical Hierarchy Process

Analytical Hierarchy Process (AHP) is developed by Thomas L. Saaty to incorporate both subjective and objective data into a logical hierarchical framework (Shen, 1997).

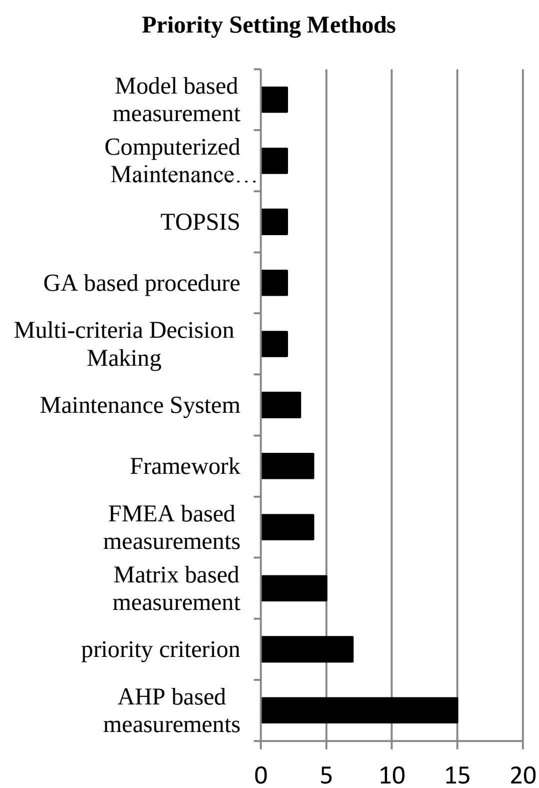

Figure 4: Priority-Setting Methods

AHP is used to assess the alternatives in relation to the criteria and sub-criteria in order to achieve a goal (Das *et al*., 2010). Pair-wise comparisons between the criteria and goal are calculated in a reciprocal matrix form in a nine point scale with 1 being equal and 9 being extreme preference. The next step is repeated for the subsequent sub-criteria until the process reaches to the lowest strata of alternatives (Saaty, 1990). The basic steps for AHP is the construction of hierarchy, followed by data collection and finally data analysis to calculate global weights. From the results, AHP is the most employed method in priority settings. In Shen and Spedding (1998), government schools was prioritized using AHP with the criteria of building status, physical condition, importance of usage, effects of users, cost implication and effects on service provision. In another study by Labib (2004), a manufacturing company uses AHP to prioritize the machines based on downtime, frequency, spare parts, and bottlenecks. The result is then used to decide on the maintenance policy. In a bridge case study by Sasmal *et al*. (2007), the condition assessment of existing bridge was conducted using AHP based on 3 criteria namely visual assessment, general assessment and detailed assessment.

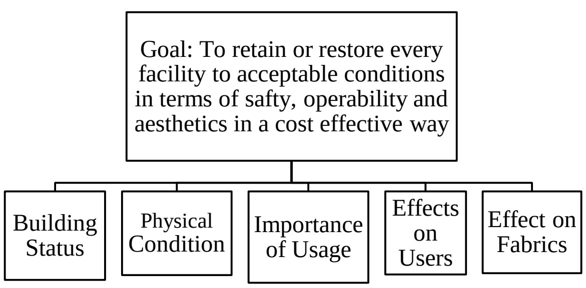

Figure 5: Hierarchy for prioritization of public buildings.
Source: Shen *et al*., 1998

4.2 Priority Criterion

For priority criterion, it is usually based on a pre-determined ranking of priorities for the maintenance items. It could be based on historical data or expert judgment (Dekker and Scarf, 1998). This method collects the feedbacks of the maintenance personnel and items are prioritized based on the pre-determined priorities. More than often, priority criterion only highlights the ranking of the maintenance work or items without describing the required actions to rectify the issue (Banae and Oliveira, 2002; Dekker and Scarf, 1998). A study of maintenance prioritization on municipal housing stocks by Banae and Oliveira (2002) employed the priority index to sort the maintenance actions based on their urgency level. The factors used were based on technical concerns, political concerns, and social concerns which were then evaluated and prioritized according to four urgency categories which are absolute urgency, urgent, medium priority and low priority. In Dekker and Scarf (1998), priority criterion was used in the maintenance of an airplane. The criterion shows a list of maintenance work with its priorities that has been determined by engineers earlier on. The list merely indicates the importance and due time of each activity without the prescription of actions. Another study by Yusof *et al*. (2012) involves the assessment of maintenance priority preferences in public housings. Residents were asked to prioritize the maintenance for 13 building elements using a four-point scale with 1 = strongly agree and 4 = strongly disagree.

4.3 Matrix based priority

A matrix is a rectangular array of numbers, symbols, or expression arranged in rows and columns (Anton, 2010). In priority setting, it visually represents the factor or criteria used against a rating of priorities as described in the following case studies. The management system information (PROMIS) is based on a priority category matrix used for property maintenance with the function of facilitating maintenance priority (Shen, 1997). The factors used are physical condition, property status, user effect, and fabric effect. Score ranges from 1 to 3 are assigned to these factors and multiplied to obtain the priority for that specific maintenance items (Shen, 1997).

In Ad (2009), the author made a reference to the Dutch Government Building Agency's risk-priority matrix (Table 1) which functions to adjustment of annual maintenance stock in relation to available budget. The "risk" category contains safety and health, cultural and historical value, utility and business, consequence damage, increase of response maintenance, and aesthetics. They are then rated against a 9-point priority scale with 1 being most important and 9 least important.

Table 1: Risk Priority Matrix

Risk	Priority								
	9	8	7	6	5	4	3	2	1
Safety and health									
Cultural and historical value									
Utility and business									
Increase of response maintenance									
Aesthetics									

Source: Ad (2009)

4.4 Failure mode and effect analysis

The failure mode and effect analysis is a planning tool designed to identify and prevent potential problems (Layzell and Ledbetter, 1998). The steps to conducting FMEA are as follow;

1) Identify potential and unknown failure modes and corresponding failure mode causes and effects

2) Ranking of causes of failure based on probability of occurrence and of non-detection and severity of effect (Kay and Chee, 2006; Vijay and Chaturvedi, 2011). The ranking of these three parameters form the Risk Priority Number (RPN). The formula is;

$$\boldsymbol{RPN = O \times S \times D}$$

Where,

RPN	= Risk Priority Number;
O	= Occurrence;
S	= Severity;
D	= Non-detection

3) Follow up and identify course of actions.

In the case study of cladding for automotives, FMEA is used as a form of risk analysis. Real data is required to determine the level of risk. A risk priority number (RPN) is created using the form of ranking of failure modes and causes based on probability of occurrence, severity of effects and probability of non-detection.. Similarly, RPN can be used to identify and prioritize maintenance task as seen in gearbox equipment for steel rolling plant (Vijay and Chaturvedi, 2011) and semiconductor manufacturing process (Kai and Chee, 2006).

5.0 DISCUSSION

With the various methods available, the main question falls on the selection of the best method to implement priority setting for maintenance. Simple methods such as priority ranking or reference to a preset priority table is preferred in some cases while mathematical models and frameworks such as AHP and FMEA show both quantitative and qualitative advantages over the simpler methods. In general, the effort of maintenance priority-setting using specific methods is lacking due to various reasons such as the complexity of the process, the need for vigorous data and the cost of implementing the method (Dekker and Scarf, 1998; Keith and Mark, 2007). One of the major issue in maintenance is the reliability of the data. It can be costly and mistakes will surface if the data recording was not carried out correctly (Dekker and Scarf, 1998). Methods such as simple ranking and priority category matrix are often plagued with subjectivity and the absence of justification for the priority allocation (Shen, 1997). FMEA requires an extensive amount of real data and this poses a problem for maintenance personnel (Kai and Chee, 2006). AHP itself has issue with rank reversal, consistency and interdependency between factors (Bevilacqua and Braglia, 2000; Keith and Mark, 2007). Thus, each methods have their pros and cons.

The current trend of maintenance priority is more focused on being cost-effective, and hassle free. As maintenance works are still considered as a "necessary evil" instead of adding value, upper managements are not willing to invest into priority setting methods that are costly (Layzell and Ledbetter, 1998; Kumar *et al.*, 2013).

Methods that are more advance such as AHP, FMEA and GA models require huge amount of data which can be time consuming and expensive. Unless the benefit outweighs the cost, organizations would stick to the previous options that are cheaper and more familiar to them (Shen, 1997).

Another apparent gap in these methods is the lack of organizational directions. From the findings, organizational goals and objectives are rarely taken into consideration in the priority setting process. The considerations for priority setting in these case studies are usually centered on the economical, social, financial, technical, political and legal factors (Spedding *et al*., 1995). In the ideal situation, the decision on maintenance priorities is dependent towards the needs and circumstances of the organization. Organizational goal and objectives are created to ensure the alignment of department efforts with the needs of the organization (Kumar *et al*., 2013). By defining goal and objectives, maintenance managers can provide the rationale for evaluation of infrastructure condition and performance, and the prioritization of maintenance repair and renovation works (Schraven *et al*., 2011).

The circumstances of maintenance priority-setting should be based on nature and direction of the organization. For example, production focused assets would focus on the prioritizing the effectiveness and efficiency of production (Fangxing and Brown, 2004; Labib *et al*., 1998; Layzell and Ledbetter, 1998) while building based maintenance would focus on building condition, safety, and user satisfactions. (Flores-Colen and de Brito, 2010; Shah, 2009; Shen and Spedding, 1998). Factors prioritized would differ based on case studies. Thus the method employed has to complement with these factors. The future trend of maintenance priority should move towards priority setting method that is user-friendly and easy to implement. At the same time, it should include consideration for the nature and strategic directions of the organization. Finally, it is recommended that further a investigation is carried out in regards to the incorporation of organizational factors and critical factors into the methods of maintenance priority setting.

6.0 CONCLUSION

The literature review has examined the issues relevant to the different aspects of maintenance priority methods in various case studies. Articles published from 1990 to 2015 were classified and analyzed. Based on the findings of this study, methods such as AHP, FMEA, matrix based priority and priority criterion were reviewed. Discussion on the pros and cons of using such methods are discussed. It is recommended that strategic factors such as organizational goals and objectives are included into the consideration of maintenance priority-setting together with other critical factors. Priority setting process that aligns with the need of the organization can assist in the justification of resource allocation and the management of maintenance works. The findings in this study contributes towards the understanding of maintenance priority setting especially in the methods used.

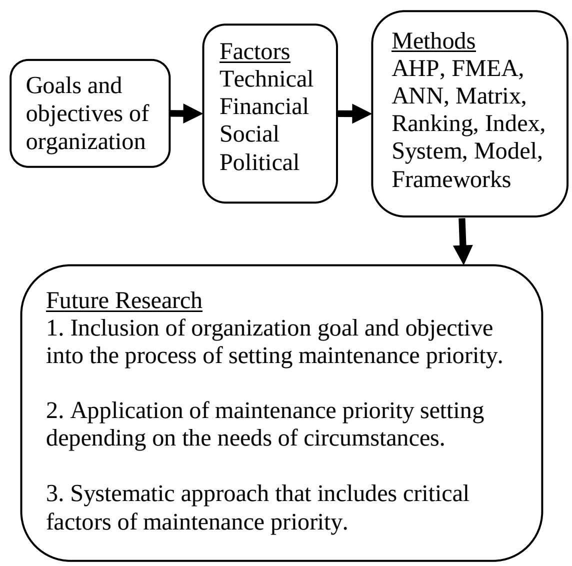

Figure 6: Conceptual framework for priority-setting methods in building maintenance

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