Identification of E-Maintenance Elements and Indicators that Affect Maintenance Performance of High Rise Building: A Literature Review

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Abstract. There are still many high-rise building managements that carried out in a conventional method and do not involve the latest ICT. So that the maintenance implementation is not running effective and efficient which causes the maintenance performance of the building is not optimal. Therefore, it is necessary to identify elements and indicators that can be used to evaluate the implementation of e-maintenance in high-rise buildings in terms of both effectiveness and efficiency. This study aims to identify the elements and indicators in the implementation of e-maintenance that affect the performance of maintaining high-rise buildings using the literature study and Delphi methods. First, the elements and indicators were obtained by the literature study and then were validated by the experts. As for the research produced five elements that affect the performance of high-rise building maintenance, those are maintenance policies (planning and development, implementation, systems, and improvement): 15 indicators; WBS (scope and value): 7 indicators; guidelines (procedures and methods, program, tools and equipment): 11 indicators; information systems (organization, management, information technology): 15 indicators; and BIM (utilities, information, functional, technical, and organizational/legal criteria): 9 indicators. The building maintenance performance obtained (failure rate, downtime, cost, and service quality) consists of 14 indicators.

1. Introduction

High rise building is a solution to urban problems regarding increased land use [1]. Like the other kind of buildings, high rise building has a life cycle that similar to them, that is planning phase, design phase, construction phase, operations and maintenance phase. During O&M phase, building and facilities performance will degrade as the structural components and elements are aging [2]. The current condition of the industry faces many challenges in optimizing operations and maintenance due to the development of technology, global competitiveness, environmental and safety requirements. Maintenance is not just ensuring the healthiness of equipment in a facility but it also plays a crucial role in achieving organizational goals and objectives with optimum maintenance cost and maximum production [3]. Information and communication technology (ICT) development could bring significant advantages in promoting and strengthening their competitiveness in facilities management by providing powerful strategic and tactical tools for organizations [4]. Integrating ICT with maintenance strategies is a concept of e-maintenance [5]. E-maintenance implementation could offer the opportunities for the development...
of new maintenance types and strategies by remote maintenance operations and decision making, business processes integration and collaborative maintenance, fast ‘on line’ maintenance, and predictive maintenance. E-maintenance could also improve maintenance support and tools by failure analysis using ICT and other technologies, and maintenance documentation for instance. Besides that, e-maintenance capable to improve the maintenance activities by fault diagnosis/localization and repair/rebuilding for instance which downtimes could conceivably be reduced [6]. All of these advantages that e-maintenance offers are related to indicators of maintenance performance. So, this research aims to identify the elements and leading indicators of e-maintenance that affect the maintenance performance of high rise buildings to improve its maintenance performance.

2. Literature Review

2.1. Maintenance Performance
According to [7] performance measurement is a very basic and important thing to do in management principles so that the gap between actual performance and planned performance can be identified. And the maintenance performance based on their research consists of three dimensions including failure rate, maintenance cost, and downtime. Based on [8] research, maintenance performance includes asset development — failure age, organization and management, performance management, and cost maintenance efficiency. Then according to [9] maintenance performance consists of three dimensions those are functional — management service delivery, technical — maintenance service, and image — building image. Then based on [10] maintenance performance includes equipment effectiveness — downtime, maintenance cost-effectiveness, and the number of safety, health, and environmental incidents. In [11] maintenance performance includes reliability of equipment, quality and speed of execution/response, maintenance costs, and prediction of failure. Regarding to maintenance performance of the building, according to Minister of Public Works and Housing Regulation No. 24 of 2008 the building must fulfill several aspects, including safety, health, convenience, and easy access.

2.2. E-Maintenance Systems
E-maintenance is integration between maintenance strategy/plan with information and communication technology (ICT) [5]. According to [12] maintenance strategies are based on the objectives of the maintenance policies. The maintenance policy is a sequence of tasks that must be considered to support future maintenance and estimates used from a subsystem and its components. Based on [13], optimizing maintenance policies can be described as a balance between maintenance solutions that fit the objectives under certain criteria by using predetermined approaches. Optimal maintenance policy generally covers four main aspects, including a description of the system being maintained, a model on how the system deteriorates and the consequences, a description of the available response options, an objective function and an analytical framework (or tools) according to which the optimal maintenance policy is to be derived [14]. Whereas according to [15], the dimensions of maintenance policy are maintenance planning and development, maintenance policy implementation, and maintenance systems.

Based on [16] dan [17] developing a maintenance strategy can be supported by work breakdown structure (WBS) and the guideline as input. WBS is used as a plan by making a sequence of activities that need to be carried out in maintenance and the resources needed, so that it can be a guideline for the perpetrators of maintenance in carrying out their duties. WBS (Work Breakdown Structure) is a hierarchical structure that defines and arranges the entire scope of a deliverable-oriented project with each level in the hierarchical structure displaying more detailed definitions of a work project [18]. Based on the theory that was already developed by Moine in [19], WBS consists of two aspects that have 8 dimensions in the form of questions, namely scope: what, how, for what, and where; and value: why, who, when and how much. Further according to [20] [21], key elements of WBS include: describing the process or activity content, assign responsible persons, work package life cycle, and pursuant to a work package to develop plans or allocation of necessary resources.
Then building maintenance guidelines according to Minister of Public Works and Housing Regulation No. 24 of 2008 there must consist of building maintenance procedures and methods, building maintenance work programs, tools and equipment of building maintenance work, and maintenance performance standard indicators. In accordance with [22] that business processes and standard operating procedure of maintenance can be used as a basis for guidelines making. Besides that according to [23], there are four levels of the system used in maintenance guidelines, namely the identification of building component systems, identification of the type of equipment used, identification of the number of equipment used, and identification of the frequency of maintenance implementation. 

Then in the use of information and communication technology to maintenance strategies can provide effectiveness and efficiency through information systems management [24]. The role of the information system (IS) in the maintenance system, namely the collection of data from relevant events while the technical and maintenance system is operating, processing data to obtain information diagnostics, forecasting, planning, decision making, and the realization and control of preventive and corrective maintenance. According to [25], the dimensions of the IS consist of organization, management, and information technology. Whereas based on [26], IS consists of IS role, management level, IT portfolio, value chain, and products-utility.

In addition, information management in the maintenance process according to [27], can be integrated with building information modeling (BIM) as a form of ICT utilization. By implementing BIM in maintenance can improve efficiency so that it can reduce maintenance costs and save work time. The advantage of using BIM is to be able to make parameters that have been connected from each building element that has been created and all data that has been inputted into the program, such as resources needed, costs, and schedules, include the engineer’s evaluations become a 3D model. Based on [28], BIM has six indicators, there are data property, utility, information criteria, functional criteria, technical criteria, and organizational/legal criteria. And according to [29] things that affect the BIM implementation include, the adoption of the process of technology usage, operating environment, and organizational culture.

### 3. Research Method

The detailed research has stages of the process to achieve the research objectives described through the flow diagram as follows.

![Research Flow Chart](image)

**Figure 1.** Research Flow Chart

Based on Figure 1. The elements and its indicators of e-maintenance were conducted by literature review, then the results of the literature review were processed into a questionnaire and used as research instruments for expert validation. The validation results are the output of the research question.

### 4. Research Results

Identification of elements and indicators of e-maintenance is carried out through literature studies then discussions and interviews with experts are conducted for validation. The results of the acquisition of literature studies, elements and indicators of e-maintenance that affect the maintenance performance of high-rise buildings are as follows.

| Elements – Variable X | Indicators |
|-----------------------|------------|
| Maintenance Policies - Queensland | **Maintenance Planning and Development**: Internal maintenance policies, Standard index condition, Department strategy, Maintenance strategy plan |
Table 1. Elements of Maintenance System and Indicators

| Elements – Variable X | Indicators |
|----------------------|------------|
| **Government, 2017; Bhuyan, Jorgensen, dan Sharma, 2010; Ding & Kamaruddin, 2015; Marquez, 2009** | Maintenance Implementation: Asset condition assessment, Maintenance needs assessment, Maintenance budget cost, Maintenance program development, Maintenance supervision, Maintenance performance evaluation |
| **Work Breakdown Structure (WBS) - AlFadha, 2014; Devi & Reddy, 2012; Tonder & Bekker, 2002** | Maintenance Systems: Maintenance information, Data collection, Maintenance computer-based systems, Maintenance report systems |
| **Guidance - U-HAB and HPD of the City of New York, 1984; UU No. 28 Tahun 2002; PerMen PU No. 24 Tahun 2008** | Maintenance Improvement: Maintenance sustainability and technical renewal |
| **Information Systems - Laudon & Laudon, 2014; Alaraifi et. al, 2011; Alter, 2008** | **Scope**: Maintenance complexity identification, Maintenance needs identification, Maintenance scope simplicity, Maintenance scope flexibility |
| **Information Systems** | **Value**: Duration and cost estimation, Maintenance project control, Resources identification |
| **Building Information Modeling (BIM) - Jung & Joo, 2011; Rahim & Zakaria, 2017** | **Organizational**: Standard operational and procedures of the organization, Structures of the organization, Organizational environment, Organizational politics, Organizational culture |
| **Building Information Modeling (BIM)** | **Management**: Senior management (long-term goals and budget decision), Middle management (budget planning), Operational management (maintenance execution) |
| **Information Systems** | **Information Technology**: Hardware, Software, Data management technology, Telecommunication and networking technology, World wide web, IT infrastructure platform |
| **Building Information Modeling** | **Utilities**: Maturity level, Data morphology, BIM utilization |
| **Information Systems** | **Information Criteria**: Identification the needs of information data, Interoperability |
| **Building Information Modeling** | **Functional Criteria**: Identification the goals of BIM utilization, Life cycle determination of BIM utilization |
| **Information Systems** | **Technical Criteria**: Level of detail, Data collection methods, Information modeling, Objects recognition |
| **Organizational/Legal Criteria** | **BIM interoperability utilization strategy, Stakeholder collaboration, BIM training, Contractual relationship, Law that supports the BIM implementation process** |

Table 2. Indicators of High Rise Building Maintenance Performance

| Variable Y | Indicators |
|------------|------------|
| **High Rise Building Maintenance - Weber & Thomas, 2005; Kumar, Galar, Parida, & Stenstrom, 2013; Baharum et al, 2006; Myeda, Kamaruzzaman, & Pitt, 2011** | **Failure Rate**: Hidden consequence, Safety consequence, Environmental consequence, Operational consequence, Non-operational consequence |
| **Maintenance Cost**: Percentage of equipment replacement costs, Percentage of sales revenue, Percentage of maintenance cost per unit |
| **Downtime**: Unscheduled downtime (hours), Scheduled downtime (hours), Shutdown overrun (hours) |
| **Functional-Service Quality**: Reability of maintenance process, Responsive to the needs of building users, Warranty |

Based on Table 1, the results of the literature, there are 5 elements of e-maintenance system, namely maintenance policy, work breakdown structure (WBS), guidelines, information systems (IS), and building information modeling (BIM). The total of leading indicators of all the elements is 63 indicators of e-maintenance and based on Table 2. There are 14 indicators of the maintenance performance of high rise buildings. The results of the literature study were carried out a validation process through interviews...
and discussions with experts and it was found that all elements and indicators obtained were relevant to the maintenance performance of high-rise buildings with e-maintenance systems. Based on the result of discussion with one of the experts also obtained an additional indicator of information system (IS) elements related to the company's portfolio on the organizational dimension.

5. Conclusions
Based on the results of the study it can be concluded that the development of e-maintenance systems can be carried out through 5 elements, namely maintenance policies, work breakdown structure (WBS), guidelines, information systems (IS), and building information modeling (BIM). Where the maintenance policy consists of 15 indicators, WBS consists of 7 indicators, guidelines consist of 11 indicators, IS consists of 15 indicators (14 indicators based on literature and 1 indicator based on expert validation), and BIM consists of 16 indicators. And then, maintenance performance of high-rise buildings obtained 4 dimensions of assessment, include failure rate dimension consists of 5 indicators, maintenance cost dimension consists of 3 indicators, downtime dimension consists 3 indicators, and functional-service quality dimension consists of 3 indicators. These elements and leading indicators can be formulated to be a framework to improve e-maintenance on high rise buildings.

6. Future Study
The main elements and leading indicators of e-maintenance identified is the first phase of the research to develop a relationship model between elements and its indicator on maintenance performance of high rise building. The second phase is an analysis of the relationship model using SEM-PLS software and experts validation regarding to the relationship model and the improvement that should be done.

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