An assessment of maintainability of elevator system to improve facilities management knowledge-base

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Abstract. Elevator system is a highly specialized machinery that requires technicians that have a wider array of knowledge in maintaining the system to be safe and reliable. While attaining reliable data of elevator malfunction become challenges, this study has filled the gap by gathering the management-maintenance issues and operational defects of elevator system. Forty-three types of operation defects were found and the consequence defects and their possible causes of occurrences were discussed. To respond to the prime challenges of maintaining elevator system provided by the industry players’ perspective, a theoretical framework is established as a recommendation to improve knowledge base of defects in elevator system which comprises good practices, and solutions to rectify each defects found. Hence, this research paper has theoretically improved the knowledge base of maintainability of elevator system and provide meaningful guidelines in practical senses to the industry professionals.

1. Introduction

Building maintainability has significantly affect building’s cost, risk, and performance. A review of building performance of construction industry was undertaken and it expressed building maintainability is substantially affecting building performance [1]. Mechanical and Electrical (M&E) services which include elevator system is one of the elements which contribute to a major percentage of the total construction cost of a building from initial to its operation and maintenance costs. If M&E services are facing with malfunction or breakdown, it will contribute to the entire building performance substantially influence the building’s life cycle cost [2]. This system must operate in an efficient and effective manner as its operation not only affected the system’s life cycle cost but also ensure safety consideration to the users.

Inappropriate maintenance of elevator system can cause rusted and cracked steel wire rope and it is one of the examples of defective in an elevator system, which can trigger accidents to happen. The most common practice of elevator inspection is depending on human visual inspection, and such practice fails to detect the faults occurred in the system [3]. Over the past few years, there have been some reported cases of injuries caused by elevator defects or malfunction. Hence, it is very important for the building owners, particularly for the facility management team to perceive it as a dominant part of building maintenance element, while not merely putting all the duty of care to the mechanical and electrical team. Meanwhile, one of the strategies to minimize the failures is by recognizing the defects and its causes. By doing so, a proper maintenance of building systems can be achieved which may delay the process of degradation of the systems [4].

This study aimed to investigate the maintainability issue of elevator system by recognizing the type of operational defects or malfunction that could be found in the elevator system and the possible causes of each defect detected. By understanding the common defects found and the possible causes, it helps the maintenance management team to make a prediction of possible more damages resulted from independent defects of each elevator’s components. In addition, the maintenance-management issues were discussed to identify the prime challenges of maintaining elevator system. Finally, a recommendation framework was then tabulated with the objective to improve the knowledge base of which includes the testing and diagnostic, good practices and solutions to rectify the elevator defects.
2. Literature Review

2.1 Regulatory controls of elevator system in Singapore

As according to Singapore Standard for Lift, Escalator and Building Maintenance (SS550:2009), the maintenance for elevators system in Singapore is done in periodic regime which include daily, monthly, biannually, annually, and every five (5) years’ examinations. Meanwhile, The Building Maintenance & Strata Management (BMSMA) [5], has clearly stated the duty of care for both elevators owner and elevator service in relation to the health and safety of passengers or property which may be affected by their actions, or failure to act. This include the requirement for the elevator owners need to keep all the maintenance records for a period of at least five (5) years from the date the documents are recorded or issued. Likewise, the elevators service contractors are required to submit full report involving elevator system’s malfunction, and notify the Commissioner if the elevators are found to be unsafe to be operated. There is a legal requirement to report any incidents associated with malfunctions of elevator system, which include:

i. Incidents that involved injury or death where the cause of such injury or death is associated with equipment or machinery of the elevator;

ii. Failure of main drive system, except in the case of failure of the main power system;

iii. Breakage of suspension ropes;

iv. Failure of brakes, overload device, safety component and safety equipment;

v. Failure of an interlocking device for any door of the elevator way or door of the elevator car, except for the reason of safety contact does not make electrical contact.

2.2 Maintainability issues of elevator system

Elevator malfunctions create inconvenience to the public especially for those with disabilities and diminishes public confidence to utilize this facility [6]. Some of residents’ concerns on elevator maintenance practices for the residential apartments include [7]:

i. Alternative for building residents to report where there are repeated elevator malfunctions

ii. Delayed rectifications due to shortage of elevator parts

iii. Insufficient qualified manpower to conduct repair works

iv. Servicing works done by penalized contractor and still fails to do an effective service

v. Organize an authority lift expert team in or working with the industry to improve insufficient qualified manpower to service the elevator system

To acquire a reliable accident statistics become challenges as the users generally would not make a report when they encountered minor accidents, reports involving major accidents being decentralized, and most of the elevator companies do not always consent to involve in reporting any breakdown or malfunctions. Meanwhile, it is vital to have an accurate and reliable statistics and records of accidents as it can help to prevent the accidents from occurring in future by assisting the relevant parties to identify the causes of the accidents. In conjunction, proposals to improve guidelines and regulations shall be improved, by identifying common malfunctions that caused accidents in order to improve safety features [8]. The recent years of media-released accident reports involving elevator malfunction in Singapore varies from causing injuries to the users and even fatal accident and make it even more unfortunate, some cases still under investigations and the causes remained unknown [9]. Figure 1 is some examples of elevator accidents in Singapore.
User’s hand was severely injured as the elevator sensor unable to detect dog leash attached to the victim’s hand [10].

Poor levelling of elevator and landing doors causing fatal accident to the impaired user [11].

Elevator door remained open while travelling while outer and inner panels were closed [12].

Figure 1. Examples of elevator-accident cases in Singapore

3. Research Methodology

3.1 Research design

This research uses a sequential explanatory mixed-method design where qualitative method was used in the initial phase followed by quantitative method on the later phase which presented in a flowchart below.

Figure 2. Flowchart of Research Methodology

The data collection phase starts by conducting secondary research. A preliminary review of the background of this topic was conducted to identify research gap, aim, and objectives. A more comprehensive literature review was then done to identify essential knowledge of elevator system and maintenance issues with regards to elevator system in Singapore.
Secondly, the primary data of this research was retrieved in two phases where the first phase was done by conducting interviews and the second phase was by distributing questionnaires survey with industry personnel. In order to achieve valuable insights from the industry professionals, the interviewees were carefully selected. Five interviews were conducted, where three of the interviewees are Senior Facility Managers, a representative from Singapore’s Town Council, and a lecturer form Building Department National University of Singapore (NUS). During the interview, maintenance-management issues were raised, and common type of defects in elevator system was collected by reviewing maintenance checklist records. Defect library was then tabulated comprised from both primary and secondary data, stating type of defects, possible causes of defects and description of defects. Thereafter, the findings from the interviews conducted were used to structure the content of the questionnaires in order to validate the finding.

The questionnaires were structured in two sections where the first section was to identify the prime challenges in maintaining elevator system, the second section was to identify prime recommendations to address the challenges. Survey questionnaires were sent out electronically to the industry players in Singapore and out of sixty-six (66) responses, only thirty (30) surveys were usable as the remaining were partially completed hence the data were not used to evaluate the survey. From a total number of respondents who able to complete the survey, sixteen (16) of them are the Facility Managers, six (6) from developer companies, five (5) from elevator contractors’ companies and the remaining three (3) are building owners. The data was then compared, ranked and discussed from both primary and secondary research sources to enable to determine the severity of each challenges in maintaining elevator system and the effectiveness of suggested solutions to address the challenges. Finally, survey findings are discussed and a recommendation framework is tabulated to improve knowledge base of elevator systems. The framework consists of testing and diagnostic method, good practices, and correction for each defect type found in the earlier section.

4. Data analysis
4.1 Discussion of industry professional interviews and survey questionnaires
Based on the interview conducted, there are similarities responses given by the industry expert interviewees pertaining management challenges in maintaining elevator system. According to the experts’ judgment, the knowledge gap among the technicians sent to do servicing work restricting them to be able to detect premature wearing signs of elevator components. In addition, there is a limitation on the availability of skilled technicians and engineers in Singapore, due to low interest of people to participate in the elevator industry and finally, maintenance record of faults and defects of elevator system provided by the elevator contractors is insufficient and unreliable to be referred. From the interview, maintenance records were reviewed, and some common operational defects were identified. Literature study was used to find the further description of the defects and possible causes of each operational defect found, partially shown in Figure 4 and a summary of common operational defects of elevator system are tabulated in Figure 3.

The questionnaire survey was then sent out to the industry players in Singapore to validate the findings from the interview with the objective of identifying the prime challenges in elevator system maintenance. Three prime challenges in maintaining elevator system were found, which include:

a) Insufficient maintenance records by the technicians sent to do servicing works
In the usual practices of periodic maintenance records, a detail description of system’s faults will not be recorded, nor photos will be attached. In contrast, reporting in detail the condition of components faults is very important as a record to assist both building managers and contractors to achieve agreement in the case of a period of replacement of components.

b) Limited availability of skilled manpower
As elevator system is being a very specialized system, the qualified technicians and engineers are limited hence the price competitiveness are remaining low. Consequently, this scenario promotes the industry players to keep the consultation charge to be high.

c) Lack of knowledge among the technicians sent to do servicing works

The technicians sent to do servicing works are lack of knowledge to be able to detect the early signs of wearing of components in elevator system. As the elevator system is to be modernized nowadays, the software used to control the performance of the system is even more complex and the technicians sent to do servicing works may not be fully quipped with knowledge to manage these advanced technologies implemented in the system.

In conjunction, the respondents agreed that the three most perceived to be effective solution to address the challenges are by providing maintainability grading system, raising awareness to the public on how to use the elevator appropriately, and providing the elevator system faults library. In order to respond to challenges mentioned above which include deficiency on the records of operational defects of elevator system, a framework which comprised of diagnostic and testing methods, good practices, and method of rectifications are provided with the objective to improve the knowledge base of the industry players, specifically among the Facility Managers. An example of tabulated framework is shown in Figure 5. A comprehensive explanation on each of the elevator defect which include possible causes of defects and the framework can be retrieved in the Maintainability of Buildings website (http://www.hpbc.bdg.nus.edu.sg/).

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**Figure 3.** Common operational defects found in the elevator system
Worn traction sheave [13]

Breakage of suspension ropes [14]

Stretch marks on safety gears [14]

Missing ropes’ fibre core [15]

Severely corroded suspension ropes [16]

Elevator and landing door misaligned [16]

Figure 4. Some of the operational defects of elevator system

| Element | Diagnostic/testing method and good practices | Good practices | Corrections | Diagram |
|---------|----------------------------------------------|---------------|------------|---------|
| 1. General elevator travelling performance | Elevator vibration analysis is a method to measure ride quality for elevators. The hardware test system combined with a software will allow the technicians to measure vibration and sound and the measured value shall be referred to the ride quality standards, such as ISO 18738:2012 (PMT, 2016). | The unit for vibration is [μm/√(m/s²)], and one mg equals ca. 0.01 m/s². | Elevator and landing door misaligned [16] | Physical Measurement Technologies EVA-625 Elevator Vibration Analysis system (PMT, 2016) |

To avoid discomfort motion of rides, in the case where displacement of air pressure in the doorway creates lateral vibrations, the doorway shall have a clear area at least 15% of the car platform area for elevators speeds up to 5 m/s and this figure shall be increased by 5% for each additional 0.5 m/s increase in car speed.

To reduce lateral vibration produced from the roller guide, it is recommended to use Electric Active Roller Guide that reduces vibration produced by 50%. It comprised with an accelerometer that detects car vibration during operation, and the actuators will cancel the vibration through a controlled electromagnetic force (Carlolaft, 2016).

Figure 5. An example of tabulated framework to improve knowledge base of elevator defects available in the website
5. Conclusion
In brief, this research has provided the information from the perspectives of industry professionals with regards to maintainability issues of elevator system both management and operational defects. Aided with the secondary data, the possible causes and consequence defects were discussed to enable to understand the impact of defects on each component on the overall performance of elevator system. Responding to the issues of insufficient information on elevator faults from the service records, these gathered information could be used by the industry players to be referred. In addition, the possible solutions to address the challenges in maintaining elevator system were also evaluated to recognize effectiveness of each solution from the industry players point of views. Finally, with this study, maintainability of elevator system can be better understood by gathering the information pertaining elevator’s good practices as according to standard, diagnostic and correction methods and hence improving the knowledge base of elevator maintenance, to be used both academic and practical use and value to this research.

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