MAINTAINABILITY APPROACH FOR LEAN MAINTENANCE

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ABSTRACT

The concept of lean maintenance is promoted to eliminate maintenance waste and to maximise efficiency of the manufacturing process for overall cost reduction. The optimum usage of labour, material and technology is thus, proposed to eliminate waste during the maintenance process. This paper proposes a maintainability approach to minimise maintenance waste in order to promote lean maintenance concept to the construction industry. The approach has widened the focus of existing lean maintenance concept by moving it boundaries from the maintenance phase to early phases of the development process.

Eight challenges of lean maintenance have been established from fifty one maintainability causes of high-rise buildings. Their impact to maintenance cost was evaluated using a case study and found 40% reduction in the maintenance cost as wastage.

Keywords: *Lean Maintenance, Building Maintainability, Maintenance Cost, High-Rise Buildings.*

1. INTRODUCTION

The concept of lean maintenance which originated in the manufacturing industry is known as a systematic approach to identify, analyse and eliminate waste through proper management and continuous improvement (Bagadia, 2009). In the construction industry, the concept of maintainability of buildings focus on achieving efficient maintenance by eliminating waste in maintenance cost for rectifying maintenance deficiencies (De Silva, 2012). Thus, in turn this concept of maintainability promotes lean maintenance due to its similar focus on minimising waste.

The causes for deficiencies in maintenance can be considered as maintainability risks (Low and Chong, 2004; Wong and Hui, 2005; Flores-Colen *et al.*, 2008; De Silva and Ranasinghe, 2010). These risks are not occurred only during the maintenance phase of a building (De Silva and Ranasinghe, 2010; De Silva, 2012). They can moreover be originated from poor design and construction practices. Poor accessibility for maintenance, inadequate design detailing, poor quality and incompatibility of materials, poor specifications, non availability of spare parts, lack of standard tools and instruments for regular maintenance were some of the highlighted design and construction related risks which incur many wastes in terms of financial losses in maintenance (Shabha, 2003; Chew and De Silva, 2003; Chew *et al.*, 2004; Low and Chong, 2004; Wong and Hui, 2005; Flores-Colen *et al.*, 2008; De Silva and Ranasinghe, 2010). In addition, lack of maintenance policies and strategies, budgets, skills, technology are identified as some such risks faced during the maintenance phase of buildings (Shabha, 2003). These risks can also be defined as contributing factors for waste in maintenance and thus, are referred as "challenges of lean maintenance."

Costly, difficult and unsafe maintenance are recorded in the literature as a result of above deficiencies, increasing waste in maintenance (De Silva, 2012). For instance, Ramly *et al.* (2006) reviewed 4,389 records from 36 public housing areas in Kuala Lumpur, and found that 47% were caused due to design faults. There were 11,625 maintenance records which identified inferior quality of construction as the cause for houses built between 1982 to 1999 in Victoria, Australia (Mills *et al.*, 2009). Chong and Low (2006) found that nearly 60% of latent defects can be preventable with better design, 33% with better

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workmanship, 24% with better materials, and only 4% with better maintenance. Devoicing users from the design process has highlighted as a critical challenge by Sudjiman-Spinks (2002).

Therefore, minimising the causes of these defects can save a considerable amount of waste in maintenance budgets, by eliminating the unnecessary repairs and replacements. However, detailed studies are required to analyse these challenges of lean maintenance and their impact.

2. AIM AND OBJECTIVES

The aim of the paper is to analyse these challenges of lean maintenance to evaluate its impact to lean maintenance. Thus, the objectives of the study are as follows;

- identify the challenges of lean maintenance,
- analyse their impact in terms of monetary values.

3. METHODOLOGY

A survey based methodology was used in this paper to establish challenges of lean maintenance through identifying risk causes of maintainability. These risks that occur throughout the life cycle of buildings were compiled through an extensive literature survey and using a pilot survey of substantive experts. A total number of fifty one maintainability risks were established and grouped them into eight such challenging factors, considering their similarities. Views of two experts were obtained regarding the appropriateness of the assigned names for these challenging factors.

Field surveys were conducted to evaluate these risks related to thirty high-rise buildings. The building managers/engineers were interviewed to elicit their knowledge to estimate the significance of these risks in relation to their buildings. The building managers who are employed in these high-rise buildings were assumed to be substantive experts, as they have vast experience and knowledge by managing these buildings. The managers/engineers of these 30 buildings designated as “maintenance managers or engineers” (43%), “facilities managers or overall managers” (40%), and “building managers” (17%) were selected for the survey.

Interviews were conducted in an organised way with several steps: motivation, structuring and description and discussion, judgment and reporting as follows (Renooij, 2001; Dawes and Riebe, 2002; Chang *et al.*, 2008);

1. Motivation: Briefed the research objectives and information to be elicited.
2. Structuring and Description: Walkthrough survey was carried out with the building manager to explore the existing maintainability issues and challenges, maintenance-free features/situations and the condition of the building component. Elements covered during this survey were roof, façade, basement and internal areas. Pre-identified challenges of lean maintenance were then introduced to understand the question and mapped them with existing condition of the building to remember the relevant information.
3. Discussion and Conditioning: Pre-set interview guidance was used to start the discussions by focusing the minds of experts to a common set of measuring rules to maintain the consistency of the experts’ judgments. The identified 51 maintainability risks were discussed under 8 challenges.
4. Making Judgment: Experts were asked to make subjective judgments of the significance on each challenge.
5. Response Mode or Reporting: Direct estimates were taken using a numerical scale of 1 to 7 Likert scale.

A high-rise building located in Colombo region was randomly selected and analysed to explore implications of these eight challenges to its maintenance budget. The data for the case study were obtained by field inspections of the building and subsequent interview sessions as discussed. The interview sessions were carried out with the maintenance manager to elicit subjective judgments on eight established factors.

4. CHALLENGES OF LEAN MAINTENANCE

The challenges were derived from eight significant maintainability risk factors, extracted from 51 maintainability risk causes. The significance these eight factors on lean maintenance were evaluated using data collected from thirty high-rise buildings which are of 10 or more storeyed high in Colombo metropolis and discussed in the next section.

4.1. ARCHITECTURE AND DESIGN OF THE BUILDING

Architecture and the design of the building elements have a greater role in facilitating the proper function of the building. Similarly, the flexibility of the design is important in further developments and expansions to meet the future demands (Ikpo, 2009). For instance, changes of the user demands and requirements at the later phases have increased maintenance waste when increasing the facility due to lack of provisions for such changes.

When the design of a building is suited for the exposure conditions such as loading conditions for future requirements, climatic and usage level of its stakeholders, the maintenance of such buildings are easier, thus waste in the maintenance cost is lesser (Ramly *et al.*, 2006; De Silva and Ranasinghe, 2010). Opposing to this, cracking, water seepages through window frames of flushed windows with lack of drainage provisions, water-ponding along open corridors under heavy rains, fungus growth and paint failures under moist conditions, and damp patches of ceiling boards caused due to the condensation of the air-conditioned buildings are some common issues found during survey, due to the lack of climatic considerations in the designs. Among them, some of these issues are not able to correct in the designs and thus, these failures are continued to be occurred.

4.2. STRUCTURAL AND DETAILING

It is presumed that all buildings should be structurally stable to retain them for their desired service life (Chew *et al.*, 2004; Adejimi, 2005). Thus, suitability of the building to its exposure conditions such as external forces and impacts created by loading conditions, rain, moisture, heat, UV rays, corrosion, pests, fire, etc., were identified as important to maintain the structural stability. This can in turn avoid early deterioration by saving money for rectifying them.

The preliminary findings of the survey showed that most of the buildings in Sri Lanka are provided with necessities for maintaining the structural stability and the reliability throughout their expected service life. However, the structural cracks including settlement and shear were observed in few buildings. The maintenance engineer of one such buildings mentioned "*I have to spend huge amounts of money as costs for rectifying the corroded re-bars, cracks and the spalled areas of the slab and some columns due to lack of sufficient cover provided to these structural elements under the coastal conditions*". The building age is approximately 28 years.

Secondly, the detailing to the structure and inter-connections are similarly important to the reliability of the structure throughout its service life (Chew and De Silva, 2003; Low and Chong, 2004). There were many failures such as cracks, water leakages, and deterioration of the finishes were observed due to lack of detailing to movements, moisture, ground water, condensation, chemical attacks, corrosion and pests attacks like termites.

4.3. INTEGRATION

The integration of building services is important to maintain the integrity of the building and also to serve at the maximum efficiency of these services in the operation of the building (Chan *et al.*, 2001). Further, the provisions made within the building elements to accommodate these building services have a great impact on their maintenance costs. Among them, accessibility plays a greater role in saving costs (Ikpo, 2009; De Silva and Ranasinghe, 2010). For instance, in one of the hotels, the minimum opportunity cost for repairing a pipe leakage in the bathroom of a guest room was approximately US$ 135-180 (SL Rs. 15,000 - 20,000) (US$ 1 = SL Rs. 110), as it is required to break the riser wall to gain access to the pipe line which runs in an enclosed vertical riser. Similarly, no space or provisions for accessibility for maintenance are provided in the suspended ceilings, service ducts, and embedded service runs in many buildings. Many "patchworks" were observed due to hacking of the building elements, mainly in walls, and slabs to accommodate the service runs during the construction process due to lack of coordination between the main contractor and the specialist contractors. These construction joints created by the "patchworks" could cause latent defects such as seepage problems, commonly in wet areas and on the external walls.

4.4. ACCESSIBILITY FOR MAINTENANCE

The safe and economic means of access for maintenance has been ignored in most of the buildings, as similar to cases found in the literature (Ikpo, 2009; De Silva and Ranasinghe, 2010). One of the maintenance managers of a high-rise building highlighted that "*no gondola can be installed for the external access due to the restrictions in movements at the roof top and also due to insufficient strength of the parapet wall. Therefore, the repairs to leakages of its curtain wall are costlier with erection of the temporary scaffolding and thus the remedial action is postponed*". Similarly, the painting cost of the external wall has been increased with the erection of temporary scaffolding for many instances when no other means of access systems are available in the high-rise buildings. The efficiency of the access systems has become lesser when the entire surface cannot be accessed by a single system. Under these circumstances, more than one system were utilised, due to odd shapes created by many discontinuities of the surface, sharp corners, and permanent architectural fixtures of the façade surface. Thus, the cost to provide additional support for accessibility can be considered as waste in the maintenance budget.

4.5. MAINTENANCE REQUIREMENTS

The future maintenance requirements were ignored in most of the buildings that were surveyed and thus, it has led to increase the maintenance cost. These findings are similar to established evidences given in the literature (Ikpo, 2009; De Silva and Ranasinghe, 2010).

In one of the Foreign Direct Investment (FDI) projects through the Board of Investment (BOI) of Sri Lanka, scaffoldings were imported as it was duty free to the foreign company. Unfortunately there are no local agents in the country for that type of scaffoldings. As a result, they are out of order today, and the management is facing difficulties in repairing the scaffoldings, as neither the technology nor the knowledge is available locally. The maintenance manager in another organisation said "*though we have a good access system, the availability of skilled workers who can operate the scaffolding to carry out regular maintenance and cleaning of the external wall is the biggest problem, to get the maximum use of it*". In some instances, the provided systems are not safe enough to operate under the prevailing wind conditions. Subsequently, the staining of the curtain walls has become permanent increasing the maintenance cost for such unnecessary cleaning.

Applicability and practicality of maintenance should be a primary consideration during the design phase. For instance, even when access to maintenance of services such as plumbing is provided, obtaining permission to carry out repairs is not possible if the access doors are located inside the residential units. Under these circumstances, rectification the defect has created huge non-value added cost component to the maintenance budget.

Therefore, a certification from a qualified facilities manager on the future maintenance requirements and their feasibility should be made a legal requirement, before approving the plans of high-rise buildings. This can be proposed as an important requirement in future developments.

4.6. MATERIALS AND SPARE PARTS

The performance of materials for local exposure conditions and for long service life is important to improve the reliability of systems (Ishak *et al.*, 2007; Yong, 2007). For instance, some sealants were noted cracked, giving early signs of deterioration under tropical conditions. One maintenance manager expressed "*most of the glass panels used in this building are faded due to direct exposure to the sunlight"* and he further added *"the building is just seven years old*". Not only fading of the glass panels, most of the aluminium panels were discoloured with stains and eroded due to rain water run-off along the surface.

The availability of similar materials and spare parts for future maintenance is an important fact to be considered during the material selection process to minimise waste in the maintenance budget for replacing. Many buildings developed as BOI projects in Sri Lanka have used foreign materials as they were free of duty. These may face difficulties when they require repairs and replacements. One maintenance engineer highlighted "*we are facing a problem in replacing the door locks which were imported from a foreign company which does not have local agents, nor is there a similar type of locks available in the local market*" and he further added "*the organisation is not in a position to open a letter of credit for direct purchasing of the locks from the foreign country, and thus we have to consider changing them into a locally available type*".

Similarly, the use of compatible and suitable materials for repairs is another risk for their durability. In many cases, cracks, hollowness and de-laminations were observed in the repair works increasing the frequency of maintenance cycles. However, with the advancement of new technology and material sciences, many new products which are more durable for unfavourable exposure conditions are available in the market.

4.7. CONSTRUCTABILITY AND CONSTRUCTION/INSTALLATION QUALITY

Constructability plays a bigger role in minimising the latent defects in buildings. Good project management, coordination, communication, commitment and performance of all parties involved in the construction process, clarity of the information such as drawings, bill of quantities, specifications and work orders, inspection, supervision and changes are the main factors and events that control the constructability and quality of the construction process (Andi and Minato, 2004). Constructability Appraisal System (CAS) (BCA, 2008) and Buildable Design Score of buildings in Singapore are typical examples to improve constructability (BCA, 2011). Further, many quality assurance systems including, international standards, in-house systems, checklists, manuals, and inspections and tests can be used to enhance the quality (Low and Wee, 2001).

Moreover, the construction process needs an integrated approach to minimise these latent defects due to the disintegration of different trades, professionals and phases. A considerable improvement can be expected with more integrated procurement types, such as design and built, BOO, and BOT, in which a single team handles different phases of the project, compared with traditional procurement approaches.

4.8. MAINTENANCE MANAGEMENT

The maintenance process is the "tail-end" actions to be performed to prevent the buildings from early deterioration. It is however known that these actions have little control over the maintainability of a building compared with other actions that can be executed during the design phase and the construction phase. When considering these "tail-end" actions, the maintenance strategies, performance of the staff and leadership, availability of the resources, mode and method of maintenance, materials and spare parts, planning and scheduling, availability of the documents and the performance policies and regulations are considered to be important to minimise waste in the maintenance budgets (Cholasuke *et al.*, 2004; Hui, 2005; Pintelon *et al.*, 2006; Marquez *et al.*, 2009; Flores-Colen and De Brito, 2010).

Based on our survey findings, the management has less interest in using the cost effective strategies such as condition-based maintenance, innovative techniques like risk analysis; feedback systems; recording systems, and IT related tools. Mostly, corrective maintenance strategies and few preventive actions were used. Lack of knowledge, qualified staff, existing regulations, and the attitudes are the main barriers, where high-rise buildings are concerned. This may cause lack of consideration of organisational goals and objectives by the maintenance personnel and thus maintenance is challenged as wastage by the top management (Chan *et al.*, 2001; Lee and Scott, 2009).

Lack of understanding the importance of maintaining the building as well as its services has created an attitude that maintenance of services is more important and critical than attending to the maintenance of civil works in the buildings. This may be due to the fact that they are not critical at the early stages (e.g.: *non structural cracks are not critical until it causes carbonation or chloride attacks and water seepages in the concrete elements*), results of the remedies are not immediate (e.g.: *extent of the services life of the building by doing preventive/corrective maintenance is not immediate nor visible*), and the high cost (e.g.: cost of *waterproofing paint over a wall will be around US \$ 9 per* m^2). Most of the building managers are M&E qualified or promoted through experiences and thus have no proper background knowledge on building surveying or civil engineering. These factors compel the management to obtain short-term benefits. The long-term strategies like preventive methods or further cost effective strategies like condition-based methods and proactive strategies are still at infancy at the industry level. However, more efficient maintenance approaches such as predictive maintenance strategies should be introduced and practised (Wood, 2005; Baek, 2007; Hegazy *et al.*, 2010). In this strategy, it attempts to detect the onset of a degradation mechanism with the goal of correcting it, prior to significant deterioration in the component or equipment (Sullivan *et al.*, 2004). The proactive maintenance strategy in which the sources of the maintenance problems (i.e. root causes) are treated, is the most efficient approach to eliminate the waste, even though its application in the construction industry is very limited.

Lack of knowledge, manpower and IT tools are the main barriers to making the use of IT in developing very efficient and sustainable systems, feedback mechanisms, maintenance schedules and plans. However, a few organisations use IT tools such as facilities management software to programme the whole maintenance programme which reminds the facilities managers, engineers and supervisors of their daily duties, information on asset stocks and users' complaints and feedback. Further, in some large commercial buildings, technologies like "building management systems" (BMS) and "enterprise resource planning" (ERP) systems are used to maximise the efficiency of the facilities management process.

Proper leadership and the skills/ competencies of the maintenance staff are useful to take efficient decisions. Many large organisations have qualified building managers to take the leadership to run the maintenance and further some of them have been involved in the development phase of the building to increase maintainability right from the beginning to avoid wastage in maintenance.

The availability of resources such as financial, technical and human and their management are important to run an efficient maintenance programme (Cholasuke *et al.*, 2004; Ikpo, 2009). One of the best examples to view the consequences of lack of such resources is the condominiums developed for low income families in the past. The users lacked capabilities in terms of finance, technology and sometimes manpower to manage the building or rectify the problem when they arose. Their social background exaggerated the situation due to lack of knowledge to form a proper Management Corporation (MC) which is a legal requirement in buildings that are registered as condominiums.

5. IMPACT OF THE MAINTAINABILITY

A high-rise building owned by a private local bank in Colombo, Sri Lanka was selected to evaluate the impact caused by these challenges to the maintenance cost. It is a 15 years old building developed for a bank and customer activities. It has a basement floor which is used as the car park and machine rooms. The building was developed and constructed by a local engineering firm. It has a good architectural view created by the steps of the vertical façade. The flushed windows are provided at the façade to benefit from the surrounding view shaped by a lake. The building is located near a lake and the ground water table is high in this area. Two sides of the building border busy roads. Modern materials such as glazed windows, partitioning materials are used. The roof-top has been constructed with a garden to make it an entertainment area. The building is managed by a private company appointed by the management of the bank. This company has a maintenance manager and the technical staff to carry out the maintenance work.

The challenges were evaluated based on the findings of the field observations and interview sessions with the maintenance manager are summarised in Table 1.

Table 1: Challenges of Lean Maintenance

No	Challenge	Status
1	Architecture and design	• The shape of the building is complex. Accessibility to the external façade for maintenance has been limited by its shape from all sides. Temporary scaffolding has to be erected for each painting cycle.
2	Structural and detailing	• Several settlement cracks were observed at two sides of walls. However, it was identified that they have not created threats to the structure, according to the investigation report given by a structural engineer. • A severe ground water seepage was observed in the basement due to the high Ground Water Table (GWT). High GWT was not considered and detailing was not provided to the structure. Therefore the seepage problem has become a big issue during the rainy season. • Water seepage from the roof top' garden water was observed and it has damaged the internal wall paper, paint coating and ceiling boards at several locations. This seepage was due to lack of design of the water proofing system.
3	Services integration	• Services cores, duct lines and maintenance access for their maintenance are not properly designed. • According to the building manager, services were not installed according to the standard norms.
4	Accessibility	• A permanent access system was not provided for external cleaning and painting. • Provisions for temporary access system were not available due to the building's odd shape. • Accessibility for services was not considered as new service lines have been installed without repairing the existing lines due to lack of accessibility.
5	Materials and spare parts	• Most of the materials used in the building were available locally. • Poorly-performing materials under tropical conditions were not observed.
6	Maintenance requirements	• Future maintenance requirements are not well thought of in terms of accessibility, frequencies, method and technology. Examples: (1) Poor accessibility has created additional painting cost of external façade for erecting temporary scaffoldings. Regular painting cycles are important to maintain the prestigious look of the building being a private bank. Thus reduction of the extra high painting cost or cut down the painting frequencies is not possible. (2) Methods of maintenance of services such as plumbing, electrical, AC have not been thought as some have been already replaced with many lines due to lack flexibility and provision for maintenance work.
7	Construction quality	• Quality of construction of elements such as basement floor, walls were poor. Cracking and spalling caused by poor workmanship were evident for such quality of elements.

No	Challenge	Status
8	Maintenance management	• Only corrective maintenance strategies are being practised due to lack of knowledge. Sometimes improper maintenance works were carried out to patch-up the defect due to constraint in budgetary requirements. Therefore it was observed that some maintenance issues have happened repeatedly over the past several years. • Proper policies and maintenance documents were not developed or used. • Proper maintenance schedules, plans, budgets were not maintained to perform maintenance work systematically due to lack of professional staff, strategies and commitment.

The whole life maintenance cost of this building was estimated from the records of the client as US$ 5,127,000 (SL Rs. 563,970,567). The cost items considered in this case are small repairs such as replacing of ceiling boards; tiles; repairing of window fittings; skirting etc., and major repairs that include waterproofing, painting, etc., building materials and construction work, testing and consultancies, insurances, administration and other overheads (see Table 2 for a brief calculation process).

Table 2: Calculation Process

Existing Scenario

1	Whole life maintenance cost (US $)	*end of 15th year*:	5,127,000
2	Equivalent maintenance cost (US $)	*over 15 years*:	183,270
3	Equivalent initial construction cost (US $)	*for 40 years of service life*:	27,300
4	*MEI* – using cost data	*equation* (3.7):	6.7 (class 5)

Improved Scenario

1	Whole life maintenance cost, after removing the waste (US $)	*end of 15th year*:	3,096,740
2	Equivalent maintenance cost (US $)	*over 15 years*:	110,690
3	Equivalent initial construction cost (US $)	*for 40 years of service life*:	27,300
4	*MEI* – using cost data	*equation* (3.7): (class 3)	4.1

Existing maintenance issues for increased cost

1	Additional painting cost due to lack of access to the external wall (25%)	(a)*in year 2000* : (b)*in year 2010*:	8,180 10,900
2	Tile cracks due to settlements at internal areas	*to be repaired* :	450
3	Re-waterproofing of the roof top due to incomplete repair of waterproofing in the previous years	*to be repaired* :	1,360
4	Alternative work to the basement leakage	*suggested* :	725,450
	Cost Saving (US $)	2,030,260	
	% Reduction	40%	

As shown in the above calculation in Table 2, the whole life maintenance cost can be reduced to US$ 3,096,740 (SL Rs. 340,641,569), if waste could be eliminated by addressing the deficiencies identified by the eight challenges of lean maintenance. Then 40% reduction in the maintenance cost was shown.

6. CONCLUSIONS

The study highlighted that improving maintainability of buildings can promote lean maintenance. Fifty one maintainability causes were considered to establish eight challenges of lean maintenance. Many of these causes are initiated during the design phase and therefore, management and control of such challenges should start at the early stages of the life cycle of the building, and continue throughout the whole cycle.

The impact caused by maintainability of building to its reduction in the whole life maintenance cost was assessed using a case study. This reduction was obtained by reducing waste when managing and controlling the challenges of lean maintenance. The waste was calculated as US$ 2,030,260 which was 40% reduction in the whole life maintenance cost. Therefore, concept of lean maintenance can be promoted with the approach of improving maintainability of buildings.

Thus, achieving maintainable buildings will in turn create a momentum to promote lean maintenance by minimising waste in the maintenance cost. The waste minimisation should not focus only on the maintenance phase of a building, as the early phases such as design has a bigger role in this regard. At the cutting edge of the lean maintenance, its focus should be widen to capture the maximum benefits.

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