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APPLICABILITY OF LEAN MAINTENANCE PRACTICES TO MITIGATE MAINTENANCE MANAGEMENT ISSUES IN SRI LANKAN HIGH-RISE RESIDENTIAL BUILDINGS

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ABSTRACT

Maintenance management (MM) is considered a critical function in residential buildings, ensuring longevity, safety, operational efficiency and cost-effectiveness. Compared to low-rise or mid-rise residential structures, high-rise residential buildings often face more complex and frequent maintenance-related issues due to their scale, building systems, and occupancy density. According to previous studies, implementing lean in maintenance is an effective strategy to improve maintenance efficiency. Thus, this study investigates the applicability of lean maintenance practices to mitigate such issues in Sri Lankan high-rise residential buildings and proposes suitable strategies for improvement. A qualitative case study approach was adopted, involving semi-structured interviews with maintenance personnel from four high-rise residential buildings in Colombo district. Additionally, the findings revealed that seven out of eight lean maintenance wastes prevailed in the selected cases. Further, three expert interviews were carried out to propose strategies to overcome the identified challenges in lean implementation. The findings of expert interviews revealed that the lack of lean knowledge and resistance to change in top management are the main challenges to implement lean maintenance in high-rise residential buildings in Sri Lanka. Further, experts proposed several key strategies for high-rise residential buildings, including encouraging lean certificates for maintenance supervisors, integrating feedback systems using QR codes or CMMS, visual dashboards, conducting lean awareness workshops, etc. The findings of this study are useful to address the existing MM issues and implement lean maintenance practices in high-rise residential buildings in Sri Lanka.

Keywords: *High-Rise Residential Buildings; Lean; Lean Maintenance; Maintenance Management; Strategies.*

1. INTRODUCTION

Maintenance management (MM) is a systematic process of planning, organizing, and evaluating maintenance activities and the associated costs (Khider & Hamza, 2022). Organizations consider maintenance as a critical requirement for providing a better built

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environment to occupants by ensuring assets and equipment are optimally functional (Mong et al., 2019).

MM is crucial in the housing industry to support human daily routines and improve the productivity of the activities in and around the residences (Au-Yong et el., 2019). In prior studies, it is mentioned that the maintenance issues faced by residents of high-rise residential buildings are mainly caused by inefficient maintenance management systems, insufficient regulations in maintenance management, and resident dissatisfaction with the service quality of building management because of the increasing demand (Amani et al., 2018). Through the implementation of lean concepts and procedures, lean thinking can be integrated into maintenance works and it can be applied to address challenges in MM while aligning maintenance with business objectives, thus maximizing revenues (Ghayebloo & Shahanaghi, 2010). According to Jasiulewicz-Kaczmarek and Saniuk (2018), Lean Maintenance (LM) aims to achieve the optimal level of equipment reliability while using a minimum of resources. In addition, maintenance performance can be enhanced by implementing LM tools (Mostafa et al., 2015).

However, there is a lack of empirical research on its application within the context of high-rise residential buildings in developing countries such as Sri Lanka. This gap is particularly critical given the increasing demand for high-rise housing and the complex challenges associated with managing such facilities. Therefore, this paper aims to investigate the potential for applying Lean Maintenance principles in high-rise residential buildings in Sri Lanka. Specifically, the study explores existing MM practices, identifies barriers to LM adoption, and recommends strategies for effective implementation. The paper begins with a literature review, followed by the research methodology, data analysis, key findings, and concludes with practical implications and future research directions.

2. LITERATURE REVIEW

2.1 COMMON MAINTENANCE MANAGEMENT ISSUES IN HIGH-RISE RESIDENTIAL BUILDINGS

MM is critical in high-rise residential buildings as it directly impacts the safety, functionality, and longevity of the building's systems and structures (Horner et al., 1997). Au-Yong et al. (2018) reported that poor MM performance in high-rise residences often arises from systematic inefficiencies, including the absence of maintenance standards, irregular preventive maintenance and poor service quality. According to Au-Yong et al. (2023), common MM issues include lack of awareness or cooperation of the residents, lack of preventive maintenance, unavailability of spare parts, etc. More recent findings by Au-Yong et al. (2023) highlighted specific challenges such as unqualified contractors, inadequate staff training, limited use of maintenance software, unclear job roles, and non-cooperative residents. According to De Silva et al. (2012), the lack of defined maintenance policies and reliance on reactive approaches increases such challenges. Although MM issues are prevalent in high-rise residential buildings in Sri Lanka, they have not been extensively explored; therefore, it is essential to address these issues through structured and proactive strategies (De Silva et al., 2012).

2.2 LEAN MAINTENANCE IN HIGH-RISE RESIDENTIAL BUILDINGS

The LM concept is based on lean manufacturing, which emphasizes reducing waste and increasing production efficiency (Bruun & Mefford, 2004). LM aims to increase overall equipment efficiency (OEE), decrease unnecessary downtimes and streamline operations by eliminating non-value-added activities (Womack & Jones, 1997). There are eight types of lean waste identified during maintenance which can negatively impact operational efficiency (Bhamu & Sangwan, 2016). While lean principles have been widely adopted in the manufacturing and industrial sectors to improve process efficiency and eliminate non-value-added activities, their application in residential building maintenance, especially in high-rise environments, is still underexplored (Womack & Jones, 1997).

Residential buildings show unique challenges that are not present in industrial operations, such as unpredictable tenant behaviour, varied building system usage patterns, shared responsibilities, and lack of centralized operational management (Au-Yong et al., 2018). These variations in context limit the direct transferability of traditional lean tools, which were initially intended for structured, repetitive industrial processes (Ghayebloo & Shahanaghi, 2010). Furthermore, the research indicates a lack of prior studies focusing on the integration of lean practices within the high-rise residential maintenance context in developing countries like Sri Lanka (De Silva et al., 2012). The majority of research focuses on Lean applications in manufacturing or on general maintenance strategies in commercial and public facilities, with little emphasis on adapting lean thinking to address the unique maintenance inefficiencies in high-rise residences (Au-Yong et al., 2023). However, Mostafa et al. (2015), stated that, in high-rise residential buildings with high complexity and maintenance demands, lean tools like as 5S, visual management, standardised work, and root cause analysis can assist in simplifying operations and decreasing delays caused by poor planning, unqualified employees, or a lack of preventive maintenance. Further, lean can be considered as the most flexible, easiest and low-cost solution for any buildings (Ahiakwo et al., 2012).

2.3 CHALLENGES IN IMPLEMENTING LEAN MAINTENANCE IN HIGH-RISE RESIDENTIAL BUILDINGS

De Silva et al. (2012), have established eight challenges of lean maintenance out of fifty-one maintainability causes associated with building maintenance in a study conducted in thirty high rise buildings in the Colombo district namely, 1) Architecture and design, 2) Service integration, 3) Materials and spare parts, 4) Construction quality, 5) Accessibility, 6) Structural and detailing, 7) Maintenance requirements, and 8) Maintenance management. Except for maintenance management, every other issue starts during a building's design and construction phases, making it difficult to deal with them during the operational stage (De Silva et al., 2012). According to Wood (2005), long-term and cost-effective strategies are not used in building maintenance, which makes it more challenging to apply lean principles and effective use resources. People are resistant to change because they feel more comfortable and safer being in the immediate environment and fear the consequences of change, which makes it challenging to implement lean maintenance in high-rise buildings (Asnan et al., 2015).

3. RESEARCH METHODOLOGY

This study aims to investigate the applicability of lean maintenance practices as a solution to mitigate the maintenance management issues in Sri Lankan high-rise residential buildings. As proven in the background and literature review, it is evident that MM in high-rise residential buildings has not been paid enough attention and can be improved by applying lean maintenance principles and tools. Therefore, MM practices in high-rise residential buildings in Sri Lanka were selected as the unit of analysis for this study. A comprehensive literature review was conducted to perceive theory-based knowledge regarding the concept of lean maintenance and identify the applications of lean maintenance in building maintenance.

Data collection for this study was carried out in two phases. Phase I involved a case study analysis, focusing on four high-rise residential buildings located in the Colombo District. These buildings, each exceeding 50 meters in height, were purposefully selected to generate comparable results relevant to the study. Further selection was narrowed down to four cases with a time limitation. From these buildings, eight participants were chosen for semi-structured interviews, representing a range of roles from managerial to technician level. All respondents had over five years of direct experience in maintenance operations.

The selection of four high-rise residential buildings was based on purposeful sampling to ensure relevance and data richness. These buildings were chosen as they represent typical residential high-rises in Sri Lanka facing common maintenance issues. Criteria included building height, residential function, being operational for over five years, and accessibility to maintenance data. In qualitative case study research, depth of insight is prioritized over quantity. A multiple-case design with as few as four well-documented cases can offer robust analytical generalization when each case is carefully selected based on theoretical and practical relevance. The four selected buildings provided a comprehensive dataset through interviews, observations, and document analysis, which allowed for meaningful cross-case comparisons.

The primary aim of the case studies was to identify common maintenance management (MM) issues, examine existing lean maintenance waste, and explore challenges in implementing lean maintenance practices in high-rise residential buildings. Given the exploratory nature of the study, a qualitative approach was deemed appropriate. Data collected from the interviews were analyzed using manual content analysis and cross-case analysis techniques to uncover key themes.

The profile of the selected high-rise residential buildings and the case study participants in this research are provided in Table 1 and Table 2 respectively.

Table 1: Profile of the selected cases

Case name	Description
Case A	A residential building which is 182 meters in height in Colombo
Case B	A residential building which is 240 meters in height in Colombo
Case C	A residential building which is 50 meters in height in Colombo
Case D	A residential building which is 126 meters in height in Colombo

Table 2:Profile of the respondents with experiences

Building	Code of respondents	Description	Years of experience
A	A1	Property Manager	10 years
	A2	Technician	More than 5 years
B	B1	Property Manager	10 years
	B2	Technician	5 years
C	C1	Property Manager	More than 5 years
	C2	Technician	More than 5 years
D	D1	Property Manager	10 years
	D2	Technician	More than 5 years

Expert interviews were conducted under Phase II of the data collection to suggest strategies to eliminate identified lean maintenance waste which then contributes to mitigating maintenance issues. Another purpose of the expert interviews is to suggest strategies to overcome challenges in implementing lean maintenance in high-rise residential buildings in Sri Lanka. Three specialists with experience in both lean and maintenance fields were chosen for the expert interviews. The experts were questioned through semi-structured interviews and revealing the gathered data from case studies securing confidentiality. The data gathered from expert interviews were analysed using a qualitative data analysis technique called template analysis. Table 3 presents a summary of the experts selected.

Table 3: Profile of the selected experts

Expert Respondents	Year of Experiences	Description
E1	10+ years	Senior Lecturer, Lean Consultant
E2	15 years	Certified Total Production System & Total Management System Practitioner (Grade IV) by a leading automobile manufacturer in Japan
E3	27+ years	Systems Consultant (KAIZEN, TQM, Japanese 5S, TPM, Japanese Management Practice)

4. FINDINGS AND DATA ANALYSIS

4.1 FINDINGS OF THE CASE STUDY

Data collection from case studies was executed based on a semi-structured interview guideline which mainly covered areas such as existence of MM issues, existence of lean maintenance wastes and challenges to implement lean maintenance. Existence of the following common MM issues were identified through the case studies.

Table 4:Responses on existing maintenance issues in selected cases

Common MM Issues	Case A		Case B		Case C		Case D		Total
	A1	A2	B1	B2	C1	C2	D1	D2	
Lack of Awareness or Cooperation of the residents	✓	✓	✓	✓	✓	✓	✓	✓	8/8
Unqualified Maintenance Contractors	✓		✓		✓		✓	✓	5/8
Lack of Maintenance Personnel Training and Motivation	✓				✓		✓		3/8
Budget Constraints					✓	✓	✓	✓	4/8
Lack of knowledge and Skills	✓		✓		✓		✓		4/8
Lack of staff and Specialists	✓		✓		✓	✓	✓		5/8
Lack of Maintenance Software Tools	✓		✓		✓		✓		4/8
Unclear Job Description or Department Structure	✓		✓		✓		✓		4/8
Failure of preventive maintenance	✓	✓	✓		✓		✓		5/8
Unavailability of Spare parts	✓		✓		✓		✓		4/8

Table 4 presents the summary of the respondents in selected cases regarding the existence of common maintenance issues in high-rise residential buildings. According to responses, each case has more than five maintenance issues.

4.1.1 Lack of Awareness or Cooperation of the Residents

As noticed in the interviews, residents' cooperation plays a crucial role in maintenance efficiency. All the respondents highlighted that lack of awareness or cooperation of residents is an issue in all four cases. Respondents C1 and D1 highlighted that delays often occur due to residents failing to report issues promptly. A1 further noted that ineffective communication between residents and maintenance staff leads to repeated visits for the same issue. Similarly, B1 explained that when residents are unaware of their responsibilities, such as reporting minor leaks or faults, small issues escalate into major repairs. Moreover, D2 stated that, by the time they get to a reported issue, it has already worsened because residents waited too long to inform them.

4.1.2 Unqualified Maintenance Contractors

In all four cases, respondents A1, B1, C1 and D1 mentioned that maintenance contractors are often hired based on cost rather than expertise. Respondent C1 observed that some contractors perform unnecessary repairs due to a lack of specialized training, which

increases operational costs. Respondent B1 highlighted that sometimes unqualified contractors often fail to diagnose the root causes of issues, leading to repetitive repairs.

4.1.3 Lack of Maintenance Personnel Training and Motivation

Training and motivation gaps were commonly mentioned by most of the respondents. Respondent D1 emphasized that some junior technicians lack formal training, making them inefficient in troubleshooting complex building systems. Respondent C1 added that due to poor career development opportunities, maintenance staff often feel demotivated, leading to suboptimal performance.

4.1.4 Budget Constraints

Financial limitations are commonly in all four cases. Respondent C1 mentioned that maintenance budgets are frequently cut due to financial constraints from building management committees, which delays crucial repairs. In addition, respondents C2 and D1 both agreed that budgetary restrictions also hinder the adoption of advanced maintenance technologies, reducing efficiency in the long run.

4.1.5 Lack of Knowledge and Skills

Respondents D1 and B1 both pointed out that maintenance personnel often lack updated technical knowledge, particularly in specialized systems such as HVAC, elevator maintenance, and fire safety. Further, respondent A1 also agreed with the above statements and suggested that regular technical training sessions could solve more problems in-house instead of relying on expensive external contractors.

4.1.6 Lack of Staff and Specialists

Both respondents A1 and B1 noted that many high-rise residential buildings face a shortage of skilled maintenance personnel, leading to increased workload for existing staff. Moreover, respondent C1 highlighted that specialist services, such as major electrical and plumbing repairs, frequently require outsourcing due to the unavailability of in-house experts, increasing overall maintenance costs and response times.

4.1.7 Lack of Maintenance Software Tools

Respondents A1, B1, and C1 noted that their buildings still rely on paper documents for tracking and recording maintenance tasks and information, which is leading to inefficiencies and data loss. Furthermore, A1 pointed out that they planned to include maintenance record process into a software in near future which needs high investment and staff training.

4.1.8 Unclear Job Description or Department Structure

All four respondents in four cases, A1, B1, C1 and D1, agreed that unclear job responsibilities cause inefficiencies in maintenance operations. However, all respondents stated that in their buildings, the occurrence of unclear job descriptions and department structure is limited.

4.1.9 Failure of Preventive Maintenance

As observed in the case studies, preventive maintenance strategies are implemented in all four buildings but often result in inefficiencies. Respondents A1 and B1 stated that excessive preventive maintenance is sometimes unproductive, as certain tasks are

performed without evaluating necessity. Further, respondent A2 argued that even preventive maintenance takes time it is essential to perform which cannot be skipped.

4.1.10 Unavailability of Spare parts

The unavailability of spare parts is a common issue identified among all four cases. Respondent A1 explained that they only keep spare parts which needed in their daily minor maintenance activities and all other major activities are outsourced, and the required spare parts will be provided by them.

4.2 The Relationship between Common Maintenance Issues and Existing Lean Maintenance Wastes

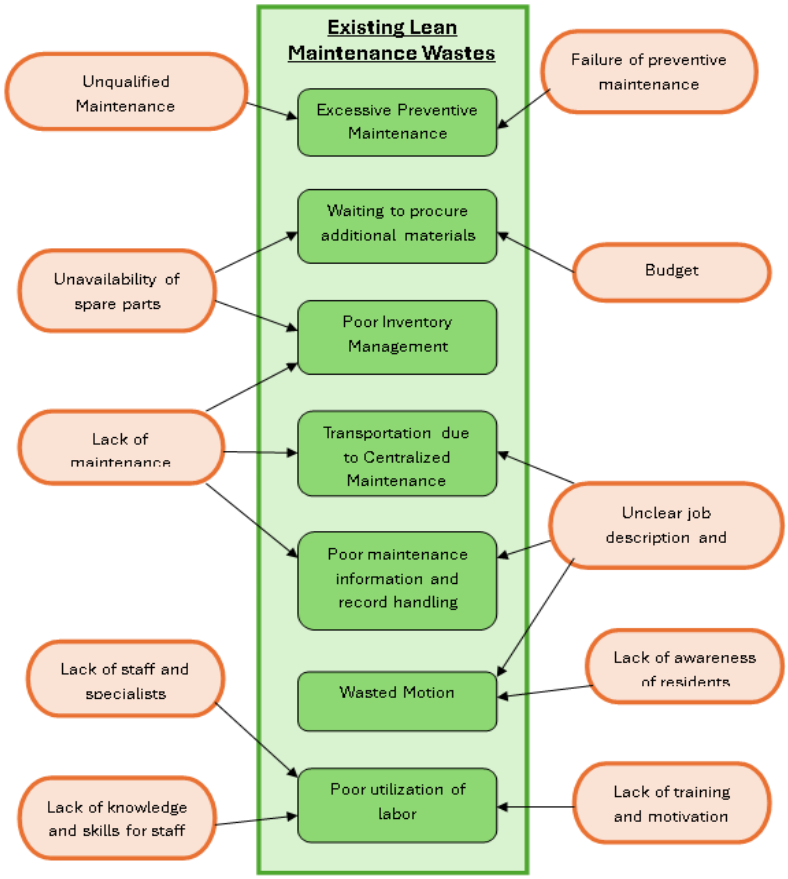

Figure1: Relationship between common maintenance issues and existing lean maintenance wastes

Figure 1 presents the relationship between the identified maintenance issues in the selected cases which are caused for the occurrence of identified existing lean maintenance waste. The indicated LM wastes in Figure 1 identified and confirmed through the conducted four case studies. Further, the relationship between these MM issues and LM wastes were identified with the discussion of experts who were involved in expert interviews.

4.3 Identification of Challenges in Implementing Lean Maintenance in High-Rise Residential Buildings in Sri Lanka

Challenges identified in the literature in implementing lean maintenance in high-rise buildings were discussed with the interviewees in four case studies to verify their

availability in the selected cases. The presented challenges were modified based on the interview findings and the list of challenges are shown in Table 5.

Table 5:Responses on challenges in implementing lean maintenance

Challenges	Case A		Case B		Case C		Case D		Total
	A1	A2	B1	B2	C1	C2	D1	D2	
Ineffective maintenance strategies	✓	✓	✓	✓	✓	✓	✓	✓	8/8
Lack of standards and regulations	✓	✓	✓	✓	✓	✓	✓	✓	8/8
Lack of policies	✓	✓	✓	✓	✓	✓	✓	✓	8/8
Lack of lean knowledge	✓	✓	✓	✓	✓	✓	✓	✓	8/8
Poor involvement of top management and resistant to change	✓		✓		✓	✓	✓	✓	6/8
Lack of technology usage	✓	✓	✓		✓		✓		5/8
Infirm feedback collecting mechanisms	✓		✓		✓		✓	✓	5/8

As Table 5 shows, all the respondents agreed that they face ineffective strategies, lack of standards, regulations, policies and knowledge of lean. Furthermore, poor involvement of top management, infirm feedback collecting mechanisms and lack of technology usage also prevail in all the selected cases. The following subsections present the explanation of the challenges shown in Table 5.

4.3.1 Ineffective Maintenance Strategies

All the respondents agreed that they follow preventive maintenance as their main maintenance strategy in their buildings. It was shown that only cases A, B and C have adopted to condition based maintenance up to a certain extend which is a preventive maintenance strategy that relies on the monitoring of assets or equipment to determine when maintenance work is necessary. But in case D they mentioned that, sometimes they follow corrective maintenance strategies with the preventive maintenance as well. It is evident that currently none of the cases has been fully adopted for any cost-effective maintenance strategy like condition-based maintenance. Therefore, it will be challenging to adopt lean with the traditional maintenance methods.

4.3.2 Lack of Standards and Regulations

All the respondents confirmed that currently, they do not follow any specific standard or regulation relating to maintenance. However, some of the respondents mentioned that in the Apartment Ownership Law there are certain rules regarding the maintenance. Further, respondent B1 stated that for the condominiums the governed law is Apartment Ownership Law, and, in that law, there are certain requirements regarding apartment maintenance like management council is only responsible for managing common areas and residents should manage and maintain the inside of their apartment units, etc. In addition to that, respondents in cases C and D also stated that they are not following any

standard or regulations related to maintenance. Therefore, it is evident that none of the cases are following or complying with standards or regulations relating to maintenance except the Apartment Ownership Law.

4.3.3 Lack of Lean Knowledge

All the respondents in four cases stated that they do not have knowledge regarding the lean concept and its applications. However, respondent A1 mentioned that even though she has learnt about lean in higher studies, she has not specifically come across lean maintenance before. Therefore, it is revealed that all the respondents do not know about lean. Thus, for the successful implementation of lean, it will be required to educate maintenance staff about lean concept, its principles and tools.

4.3.4 Lack of Policies

It was discovered that none of the cases has an explicit maintenance policy. All the respondents affirmed this. Respondent A1 stated that their plan is to shift from preventive maintenance to conditioned based maintenance. Respondent B1 also confirmed that they always aim to reduce maintenance costs and reduce breakdowns as much as possible, even though they do not have a policy. Respondents from cases C & D also stated that there is no maintenance policy. Therefore, it can be concluded that none of the cases have identified need for a maintenance policy.

4.3.5 Poor Involvement of Top Management and Resistant to Change

Six out of eight respondents identified top management's involvement in maintenance as a key obstacle to implementing lean maintenance strategies. Respondents from cases A, B and C mentioned that it is difficult to get the approval from top management for the new maintenance systems since they are resistant to change from the traditional maintenance methods due to high costs and unclear returns. For getting approval from top management, they require the estimated cost savings, but the maintenance staff does not track the cost of replacements or improvements, making it hard to prove financial benefits. Similarly, respondents D2 mentioned that top management does not fully understand the need for maintenance upgrades and remains hesitant due to uncertainty about potential benefits. Therefore, it is identified that resistant to change among the top management is the main challenge of lean implementation.

4.3.6 Lack of Technology Usage

The respondents from all cases confirmed that no advanced technology is currently used for maintenance, only use MS Excel and no dedicated software. Respondent A1 stated that they plan to incorporate maintenance activities into resident complaint management software and respondent B1 emphasized that they plan to implement a helpdesk system to track maintenance activities. Moreover, all the respondents mentioned that having a centralized system for tracking maintenance tasks and spare parts availability would be much easier to reduce delays and ensure preventive maintenance.

4.3.7 Infirm Feedback Collecting Mechanism

Five out of eight respondents mentioned that there is no formal mechanism for collecting and recording feedback on attended maintenance complaints. Respondent B1 also stated that they do not have proper feedback collection process, but they plan to include that feedback mechanism also in the proposed helpdesk system. The responses from respondents A1, B1, C1, D1, and D2 indicate that the feedback collection process in these

buildings is entirely informal and lacks consistency, which makes it difficult to assess customer value and service quality. Therefore, it is important to implement such a computerized mechanism to collect and review feedback from end-users for improving maintenance operations and enhancing customer satisfaction.

4.4 STRATEGIES TO OVERCOME CHALLENGES IN IMPLEMENTING LEAN MAINTENANCE IN HIGH-RISE RESIDENTIAL BUILDINGS IN SRI LANKA

4.4.1 Strategies to Overcome Poor Involvement of Top Management and Resistance to Change

All the experts suggested conducting awareness programmes for the management regarding lean as the main strategy to overcome poor involvement of top management as most of the organizations do not practices lean tools and have no proper knowledge about lean. Further, they emphasized the importance of providing financial information such as, implementing costs and expected ROI, to help top management make informed decisions. Additionally, they suggested introducing low-cost or no-cost lean suggestions as pilot projects to encourage top management's involvement in capital intensive maintenance projects.

4.4.2 Strategies to Overcome Ineffective Strategies

According to respondent E1, it is important to have brainstorming sessions in between the maintenance staff and stakeholders which help to fine-tune the existing strategies and practices. Moreover, conducting brainstorming sessions with people in the work floor give effective results because they have the best experience in every perspective. In addition to that, setting KPIs are essential to make strategies effective.

4.4.3 Strategies to Overcome Infirm Feedback Collecting Mechanism

All the respondents agreed that it is essential to implement computerized feedback collecting software to collect feedback from residents. Further, respondent E2 added that feedback is very important to improve the current state of the maintenance works. Therefore, it would be easy for them to have a computerized system to collect feedback. Similarly, respondent E3 also stated that the best option is to streamline feedback collection system, in that way it is easy to trace the jobs requested, actions taken and to give feedback on the job performed. Therefore, it is confirmed that implementing computerized feedback collection system is essential.

4.4.4 Strategies to Overcome Lack of Lean Knowledge

All the experts unanimously agreed that to increase awareness of lean among maintenance staff is important and for that conducting awareness programs are crucial. Furthermore, Respondent E3 added that practical knowledge in implementing lean can be gained by engaging in lean professional qualifications for instance lean six sigma professional qualifications. Similarly, E1 also mentioned that it would be beneficial to engage with lean experts.

4.4.5 Strategies to Overcome Lack of Policies

Lack of proper policies will impact the proper implementation of lean maintenance. To overcome this challenge, both E2 and E3 experts mentioned that it is essential to establish proper maintenance policies, and those policies need to be drafted integrating SMART such as, specific, measurable, achievable, relevant, and timely objectives. Furthermore,

link the established policies with incentives, which means rewarding teams for reducing downtime or energy waste in the building systems

4.4.6 Strategies to Overcome Lack of Standards and Regulations

Lack of proper standards and regulations also will impact negatively when implementing lean maintenance in any organization. When addressing this challenge experts suggested that align with industry benchmarks such as, adopt ISO 41001 standard for facility management or NFPA codes for fire safety compliance are important. Similarly, E3 added that if there are no local standards and regulations relating to maintenance it is essential to comply with other global standards available with appropriate modification. Furthermore, developing customized SOPs can also be identified as a strategy.

4.4.7 Strategies to Overcome Lack of Technology Usage

In present, technology is a key aspect in any organization, which improves the operational efficiency and saves time. To overcome this challenge, experts suggested that application of Industry 4.0 and the adaptation of information technology advancements in maintenance sector is essential.

5. DISCUSSION

This study investigates the suitability of LM approaches for addressing MM challenges in Sri Lankan high-rise residential buildings. The findings demonstrated a clear relationship between LM wastes and common MM issues in the local residential context, confirming the importance of applying lean strategies to this sector. Across all four case studies, recurring issues such as excessive preventative maintenance, high wait times, poor inventory management, and personnel underutilisation were directly associated with recognised Lean maintenance wastes. These inefficiencies restrict building performance and highlight the necessity for structured, proactive approaches. For example, excessive PM was prevalent within all four cases, typically due to rigid OEM schedules and unprepared application of standard checklists. This supports Mostafa et al. (2015), who emphasized that over-maintenance could result in waste if not tailored to actual asset conditions. Similarly, transportation waste due to centralised maintenance hubs and waiting for spare parts was evident in the cases investigated, echoing Lean theory which emphasis on reducing unnecessary movements and delays (Womack & Jones, 1997). These issues were worsened by a limited use of digital tools, poor inventory control, and fragmented job responsibilities, which decrease system reliability and increase costs.

All cases indicated a lack of Lean awareness, the absence of maintenance policies, and limited involvement from top management, demonstrating structural barriers to implementing Lean. The consistency of these findings across multiple buildings suggested systemic weaknesses rather than isolated operational failures. The lack of computerised systems or digital tracking methods limited real-time monitoring, resulting in inadequately documented procedures and reactive maintenance behaviour. This finding supports Jasiulewicz-Kaczmarek and Saniuk (2018), who identified digitalization as critical to Lean integration. Notably, unqualified contractors and lack of skilled labour resulted in more rework, longer downtimes, and high costs, which is consistent with prior findings by Au-Yong et al. (2023), on MM inefficiencies in high-rise residential contexts. The reported absence of formal standards, such as ISO 41001, emphasises the need for regulatory support to enable Lean adoption in residential settings.

Expert interviews validated these findings and suggested practical Lean strategies. For example, to address excessive PM, experts proposed switching to condition-based maintenance and autonomous maintenance. These approaches, while frequently used in industry, are novel in the residential sector and show potential for increasing system uptime and decreasing resource waste. Similarly, the idea of using mobile carts and decentralised hubs to reduce technician travel time aligns with Lean's philosophy of minimising motion waste. Additionally, experts emphasised the importance of computerised feedback systems, visual dashboards, and Industry 4.0 technologies to enhance decision-making and transparency. These solutions could help minimise feedback gaps and increase maintenance teams' responsiveness, which were previously restricted by paper-based processes.

Overall, the study shows that Lean Maintenance can be successfully applied to the residential high-rise context when supported by simple technologies, adequate training, and leadership commitment. These findings contribute to developing both theory and practice by providing a context-specific approach for improving maintenance performance in the built environment.

6. CONCLUSION

This study examined the applicability of LM practices in mitigating MM issues in Sri Lankan high-rise residential buildings. Through case studies, the research identified seven out of eight lean wastes prevalent in the selected buildings. Common MM issues were found to correspond with known lean inefficiencies. Further, key challenges are lack of lean knowledge and limited support from top management factors that hinder the lean adoption. Expert interviews validated these findings and proposed suitable strategies including, lean awareness programs, feedback systems using digital tools and aligning maintenance policies with SMART objectives. This study provides practical insights for facility managers and decision makers, highlighting feasible strategies to improve building maintenance efficiency. Thus, this study emphasizes the applicability of lean maintenance practices in mitigating maintenance issues in Sri Lankan high-rise residential buildings.

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