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A Perception Survey of Lean Management Practices for Safer Off-Site Construction

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Abstract: Lean practice is recognised for having a great potential in promoting safety risk management in offsite construction (OSC). This paper presents results of a study conducted to assess the impact of lean practice in safety risk management in OSC in a developing country. A quantitative approach using survey-based questionnaire was adopted. Lean management practices (LMPs) identified from literature review were empirically tested using a sample survey of 103 OSC contractors. The survey responses were subjected to descriptive and inferential statistics. The top ranked LMPs for safety risk management in OSC included two mistake proofing practices, i.e., use of personal protective equipment (PPE) and use of hazard warning equipment; two last planner system (LPS) practices, i.e., involvement of workers in safety planning and providing necessary working equipment and one first run studies (FRS) practice, i.e., critical analysis of work methods. These LMPs are useful in controlling high consequence safety risks in OSC. Based on evidence found in this study, the paper argues that lean practice can bring great value in the safety risk management in OSC in countries where OSC is transitioning.

Keywords: lean management practices; lean practice; off-site construction; safety hazards; safety risk management

1. Introduction

Off-site construction (OSC) refers to a process where modules are manufactured and partly assembled in a specialised off-site factory, then transported and assembled on-site into a complete building structure [1,2]. The term OSC is espoused in international literature under various terminologies such as modularised, prefabricated, standardised, volumetric [3], modular integrated construction (MiC) [4] and design for manufacture and assembly (DfMA) ([5]. The terminologies are used inter-changeably in extant literature to describe prefabricated construction [2,6].

OSC gained momentum as a result of its sustainability benefits. Compared to traditional construction, OSC is believed to promote robust safety risk management, causing its acceptability and wider adoption in the recent years [7]. Across the spectrum of off-site production systems, the products of modular building (MB) are the most complete components made in-factory that are delivered partially or fully finished, with minimal finishing and installation operations performed on site [2,8]. Actually, MB products are engineered and manufactured to 95% completeness in an off-site workshop [9]. Higher degree of off-site prefabrication and assembly entail significant safety benefits. Transferring of hazardous and risky on-site building operations from site to factory forestalls the occurrences of accidents. By its nature, MB entails a higher degree of prefabrication with minimal finishing work performed on site and the number of on-site workers is significantly reduced. The proportion of off-site to on-site workers for OSC operations in MB oscillates between 30% and 70%, respectively [10]. Obviation of the need for a large on-site workforce in the equation of the construction process is a major safety benefit of the MB production system., especially due to the fact that human behaviours are in the vogue of accident causality in the construction industry.

However, OSC processes present unique safety risks that are a cause of concern [11,12]. OSC operations involve material imports and loading, cutting, welding, lifting, unit assembly, interior and exterior finishing, and packing, i.e., in the manufacturing phase, and unit transport, site preparation, unit lifting/hoisting, unit/s assembly and installation, screwing, roof, interior and exterior finishing, i.e., in the construction phase [13,14]. The nature of these operations increases' workers safety risks. Most of the OSC operations involve working at high altitude or under heavy load to assemble and install modules [3]. Use of elevated work platforms (EWPs) such as ladders and mobile scaffolding and cranes were cited as causes of accidents in OSC [13]. During manufacture of modular units, workers are required to produce units of varying sizes due to uniqueness of each project. This complicates the work processes and increases frequency of irregular work positions, manual work and extra steps [13]. Due to its meticulous operations, OSC processes require well trained workers which are available in limited numbers [13]. Use of untrained workers results into improper operations which expose workers to safety hazards [13 Oftentimes, accidents are also caused by conflicts between personnel activities and machinery during construction process. Falling and struck-by are the commonest types of accidents experienced in OSC [3]. They are believed to be caused by complex production and construction processes of OSC, lack of experience, competencies and conflicts between machinery mobility and personnel activities [13].

Lean practice is recognised for having a great potential in promoting safety risk management in OSC. Lean practice is characterised as a set of management practices for eliminating wastes and non-value adding activities in the production process. It is aimed at minimising construction wastes, such as accidents, to achieve efficiency in OSC [15]. The philosophy is argued to eliminate most of the causative agents of accidents in the construction industry [15,16–18]. LC is an approach that advocates for identification of operational conflicts or root causes of waste/accidents, removing the waste/accidents using related LC tools and practices, and promoting prevention of waste/accidents and its negative effects. While lean management tools (LMTs) are higher-level methodologies adopted to realise reliable construction activities, LMPs are specific qualitative practices that define a how certain activities should be executed safely.

The safety impact of LMPs has been documented in literature. Han et al. [19] highlighted the use of visualisation tools to abate accidents caused by cranage operations. Li et al. [20] approved the use of visualisation tools to plan arrangements of construction assets on site to improve workplace design. The motion-based applications were recommended for identification of unsafe human behaviours to proactively prevent occurrence of accidents [20]. Safety training and communication were recommended for safety management in construction processes [21]. Liu et al. [22] emphasised on the importance of safety meetings and involvement of workers in training and communication events in improving safety climate. Goh et al. [23] proposed a simulation-based training which allow workers to experience the real-life activity in augmented reality. Worker's safety skills and knowledge imparted through organised safety trainings are an important element for maintaining higher safety standards in OSC [24,25]). For this reason, training programmes designed to impart knowledge based on the needs of the workers is considered pivotal for creating a safe workplace environment. Continuous safety training and education can enrich workers safety behaviour and eliminate unsafe human behaviours caused by inappropriate working procedures and mistakes [20,22]. Furthermore, lean techniques are used in the planning and management of OSC workplace design to improve safety [24,26,27]. Employee task allocation [28], planning and proper management of OSC tasks [29] were recommended as measures for safety improvement in OSC. Formulation of safety plan based on anticipated safety risks was promoted as a technique for fulfilling OSC tasks safely [30]. Mao et al. [31] suggested creation of a workplace environment that supports safer movement of people and machineries. This is critical in OSC where most of the operations are executed by machines. Additionally, OSC involve multiple stakeholders with varying and sometimes conflicting responsibilities working at different locations to design, manufacture, transport and install the components [24]. Extensive collaboration among stakeholders and workers can improve coordination and communication in determining and overcoming safety issues in OSC [24]. The

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foregoing discussion shows that a plausible link exists between lean practice and safety risk management in OSC.

This paper presents results of a study conducted to assess the impact of lean practice in safety risk management in OSC. The paper departs from prior studies which characterize construction as the most hazardous industry and lean practice as a philosophy for addressing safety issues in construction. Additionally, the compelling vantage point from which to examine the connections between lean practice and safety risk management in OSC is from the perspective of the urgent need for OSC as an alternative construction method to the hazardous conventional stick-built construction method. The shift to OSC provides a platform for deriving optimal lean manufacturing and construction interventions for OSC projects. This apparent potential relationship is significant to imbue an exploration of lean practice optimal contribution to safety in OSC. This could in turn demonstrate its full breadth of potential to safety in OSC processes and increase its global employment. Besides, an increasing number of scholars have begun exploring the safety considerations in OSC projects using modern advanced construction technologies. Chattzimmichailidou and Ma [3] reviewed how BIM could be used in safety risk management of modular construction. Banks et al. [32] and Chen et al. [33] examined the safety benefits of DfMA in OSC. This trajectory makes safety risk management a key area of research in OSC and application of lean for safety improvement in OSC an urgent mission. Besides, in countries where advanced construction technologies such as BIM have not been assimilated, mature production systems such as lean practice become essential to establish reliable manufacturing and construction activities to minimize process and production wastes.

Additionally, very little research exist that provides generic overview of how various LMPs control safety hazards in OSC. Soltaninejad et al. [34] explored the safety climate improvement of construction workplace using 5S + safety system. James et al. [26] and Nahmens and Ikuma [35] focused on the safety impact of Kaizen in modular home manufacturing. Bashir et al. [35] reviewed the safety impact of three lean principles of last lanner system (LPS) 5S housekeeping and poka yoke while Bajjou et al. [15] explored the potential safety effectiveness of LPS, visualization management, 5S housekeeping and poka yoke. Thus, studies that offer a thorough analysis of the impact of lean practice in safety risk management in OSC are limited. Similar studies in the context of countries where OSC is transitioning are practically non-existent. The dearth of literature on this topical issue could lead to pseudo implementation of LMPs with consequential negative impact on the overall safety risk management in OSC. Consequently, this paper investigates the impact of various lean practices safety risk management in OSC. Based on results presented in this paper, lean practice can bring great value in the safety management of OSC. Integrating lean concepts in safety risk management in OSC will result in a more comprehensive conclusion on ways to enhance safety in OSC. LMPs could be taken as a first intervention for proactively preventing high consequence safety risks where adoption of OSC is still in the transition phase. Th findings contribute to the body of knowledge in lean practice and safety risk management in OSC.

2. Materials and Methods

The study adopted a quantitative research design within the confines of positivism epistemology where statistical analysis formed the basis for evaluating the impact of LMPs in safety risk management in OSC. The study implemented a multi-stage methodological framework comprising prior literature, survey design and administration, sampling, pre-testing of dataset and data analysis. A similar methodological approach is widely used in construction engineering and management (CEM) research i.e., [1,36–38].

2.1 Prior Literature

An intensive review of literature was undertaken to identify LMPs that control safety hazards in OSC. In developing items to be included in the survey, consideration of whether to develop new scale items around LMPs (option 1) or use existing ones (option 2) as available in the literature was made. The study relied on option 2 for two reasons. First, due to time limitations, it was impossible

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to develop new constructs. As observed by the seminal work of Prajogo and Sohal [39], the development of new constructs is a complex task. Second, as argued by Ta et al. [40], use of pre tested survey constructs from previous empirical studies ensures their validity and reliability. Consequently, available relevant literature on lean tools and practices was reviewed. There are several lean tools and practices being applied in the construction industry [41]. However, only those that were considered relevant in safety risk management in OSC were considered. This was based on the empirical evidence in the reviewed literature. A similar approach is common in CEM research, i.e., Chileshe et al. [36], Hwang et al. [42] and Ameyaw [43]. Some of the selected studies with relevant lean tools and practices for safety risk management in OSC include [15,41,44–48]. Consequently, a total of 6 LMTs comprising 30 LMPs were identified as having impact on safety in OSC. These included daily huddle meetings (DHM) comprising 5 LMPs, first run studies (FRS) with 2 LMPs, mistake proofing (i.e., 6 LMPs), 5S housekeeping (i.e., 4 LMPs), improved visualisation (i.e., 5 LMPs) and LPS (i.e., 8 LMPs) (See Table 1). The LMPs formed the basis for designing the survey instrument to collect respondents' perception on how the LMPs control safety hazards in OSC. A methodological approach that uses comprehensive literature review for identification of variables for questionnaire design is common in lean practice research, i.e., [49,50].

Table 1. Lean management practices for safety improvement in OSC.

Lean management technique	Lean management practice	Source
Daily huddle meetings	Two-way communication	[15,44–48,51]
	Hazard identification and elimination	
	Information sharing	
	Review previous work	
	Identify good and bad practice	
	Two-way communication	
First run studies	Critical analysis of work methods	
	Use video files, photographs and illustrations to review work	
Mistaking proofing	Use of personal protective equipment	
	Use of hazard warning equipment	
	Use of safeguards	
	Visual inspection	
	Use of audible devices	
	Use of visual tools	
5S housekeeping	Organising	
	Cleanliness and orderliness	
	Improved circulation around the workplace	
	Eliminate emplacements	
Improved visualization	Use of graphical dashboards and digital billboards	
	Use of safety borders and demarcations	
	Standardise work procedure	
	Use of safety signs and labels	
	Use of lights for activities performed at night	
Last planner system	Providing necessary work equipment	
	Involvement of workers in safety planning	
	Eliminate all potential work constraints	
	Correlate work methods with workers' abilities and skills	
	Schedule site activities and simultaneous supervision plan	

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Empower safety workers in schedule planning
Undertake pre-task hazard analysis
Select the most appropriate and safest method

2.2. Survey Design and Administration

A questionnaire is an instrument used most frequently for data collection in quantitative studies. It contains standardised and comparable questions [52] to which participants provide responses. The choice of questionnaire for solicitation of data in this study was mainly influenced by two reasons. First, the study draws on the cumulative experiences and knowledge of OSC contractors regarding LMPs [1]. Questionnaires are more appropriate for measuring lived experiences [53]. Second, the statistical analysis of the data required quantitative data that was consistent and specific. Such data could only be collected through a questionnaire. The questionnaire design focused on answering specific research questions and had two sections. Section 1 comprised relevant respondents' and company characteristics including respondents' role, experience and size of organization. Section 2 was designed to solicit respondents' views on what LMPs control safety hazards in OSC. The survey instrument contained 30 LMPs under five categories, i.e., DHM, FRS, mistake proofing, 5S housekeeping, improved visualization and LPS. The respondents were asked to rate the likelihood with which LMPs could control safety hazards in OSC. A 5-point rating scale was used where 1 = extremely unlikely, 2 = unlikely, 3 = neutral, 4 = likely and 5 = extremely likely. A 5-point rating scale was chosen for various reasons. First, it generates unbiased data that is valid and reliable. Second, it maximizes communication within its rating scale gradations, thereby allowing respondents to concisely convey their thoughts [54]. Third, it captures data in a quantitative manner for robust statistical analysis [55] and has remained a preferred data collection tool in CEM discourse ([44,46]. It has been used in investigating management and implementation issues in OSC [42], occupational health and safety (OHS) and lean practice [44]. The survey was administered using two respondents' preferred methods, including a completion of an online "Survey Monkey" and physical administration of the questionnaire at the respondents' offices. Data was collected in Malawi between May and August 2023.

2.3. Sampling

The study targeted technical management personnel working with OSC contractors. Due to unavailability of a central database for OSC contractors, purposive sampling was used to select the respondents. The list of potential OSC contractors was downloaded from the national construction industry council (NCIC) website, and initial telephone inquiries were made to ascertain the companies' involvement in OSC. Since OSC is still in its infancy in Malawi, the potential respondents were asked to state if they have ever been involved in projects where two or three-dimensional building components such as beams, columns, shower rooms, toilet pods etcetera, or modular construction was used. This approach was augmented by site visits to ascertain the potential respondent's organization involvement in OSC. The study targeted a medium sample size for a purposive sampling of 100-999 respondents [56]. After a considerable period of searching and tracing, a total of 360 contractors were identified and invited to complete the questionnaire.

2.4. Data Analysis Procedures

The collected data was analyzed using IBM Statistical Package for the Social Sciences (IBM SPSS v.26). The internal consistency of the survey instrument containing 30 LMPs was measured using Cronbach's alpha statistic. It is popular reliability statistic which determines the average correlation of items in a survey instrument [57]. The Cronbach's alpha reliability coefficient values range from 0 to 1, with $0.7 \leq \alpha < 0.9$ deemed within acceptable range [58].

Shapiro Wilk test was conducted to examine the normality of the dataset. This comes on the backdrop of many statistical tests assuming normally distribution in the dataset thereby employing parametric testing [59]. Shapiro Wilk test is the most popular omnibus test for normality distribution and has been employed in many previous CEM research studies, i.e., Hwang et al. [42] and Wuni and Shen [1]. Furthermore, Kruskal –Wallis test was conducted to determine whether there were statistically significant differences in the responses of the raters in the rating the safety impact of LMPs in OSC. The Kruskal-Walli's test is widely used to conduct inter-group comparison for checking significant differences among respondents ([42,60]. The approach forms the basis for treating collected data as a unified whole for analysis [1].

Descriptive statistical methods of mean score (MS) and standard deviation (SD) were used as a basis for ranking LMPs. The MS formed the basis for ranking the techniques, while the SD was used to rank techniques with the same MS values. Techniques with lower SD were ranked higher than techniques with higher SD. MS analysis is widely adopted statistical tool in CEM studies for determining the impact of a set of constructs [37). Furthermore, the statistical MS values for LMPs were used to calculate overall average MS value for ranking the relative impact of LMTs. The traditional cut-off point for a rating scale depends on the fuzzy linguistic variables assigned to each number on the scale [1]. The 5-point Likert scale used in this study implied that the values 4.0 and 5.0 represent likely and extremely likely, respectively. Thus, the value 4.0 is seen here as the level at which LMP is useful in safety risk management in OSC. As such, 4.0 was considered the minimum threshold average MS value for determining safety impact of LMPs and associated LMTs. Though other studies, i.e., Wuni and Shen [1] and Mao et al. [31] have used 3.5 as a minimum threshold on a 5-point Likert scale, 3.5 was considered closer to neutral.

3. Results

3.1. Survey Response

Out of 360 questionnaires distributed, a total of 103 valid responses were returned. This is considered adequate considering that it exceeds the 30 minimum valid responses required for central limit theorem to make valid conclusions [55]. Furthermore, a response rate of 28.6% size compares favourably against construction safety studies targeting similar geospatial respondents, i.e., 15.7% [61] and 28% [62]. Regardless, the relatively smaller response rate necessitates cautious application of the study results.

3.2. Respondents Profile

The results of respondents' profile are given in Table 2. The results of the professional roles show that more than half of the respondents (51.9%) were either project managers (26.4%) or quantity surveyors (25.5%). Most of the respondents had over 15 years of general experience in construction with 31.8% having over 11 years of experience in OSC. Regarding company size, most of the respondents' companies were medium-sized organizations (42.7%). The majority of the companies, i.e., 65%, undertake both building and civil engineering works. Taken together, the respondents' profile could depict a true reflection of their perception regarding safety impact of LMPs in OSC.

Table 2. Respondents profile.

Attribute	Sub-attribute	Responses	% Responses
Professional roles	Company director	28	25.5
	Safety officer/manager	9	8.2
	Project manager	29	26.4
	Quantity surveyor	27	25.5
	Sit engineer/agent	7	6.4
	Site manager	1	0.9
General experience in construction	1-5 years	20	18.2
	6-10 years	30	27.3
	11-15 years	21	19.1
	Over 15 years	32	29.1

Experience in OSC	1-5 years	33	30
	6-10 years	35	31.8
	11-15 years	16	14.5
	Over 15 years	19	17.3
Size of company	Small	29	26.4
	Medium	47	42.7
	Large	27	24.5
Work undertaken by company	Building	22	21.4
	Civil	14	13.6
	Building and Civil	67	65

3.3. Pre-Testing Survey Response

The Cronbach's alpha reliability coefficient value of 0.833 was obtained which is higher than the standard value of 0.7 espoused by Nunnally [62]. It is also within the acceptable range of $0.7 \leq \alpha < 0.9$ proposed by Surucu and Maslacki [58]. This indicates that the responses had internal consistency, and as such, the 5-point scale measurement instrument used for data collection was significantly reliable. The assessment of normality using Shapiro Wilk Test shows that there was a statistically significant difference between collected data and normal distribution (See Table 3). The observed p value of 0.01 was less than the common alpha value of 0.05 thereby confirming that the data was not normally distributed at 95% confidence level. This implied that only non-parametric statistical methods could be used for data analysis. The results of a rank-based non-parametric test; Kruskal - Wallis test undertaken at a significance level of 5% are shown in Table 3. The observed p values are greater than alpha value of 0.05. Thus, the responses of the respondents were unanimous to the effect that none of the LMPs were perceived statistically different by various respondents which rendered the data credible for further analysis.

Table 3. Ranking of lean management practices.

Code	LMPs	MS	SD	Rank	Shapiro-Wilk test (p- value)	Kruskal-Walli's test (p- value)
LMP_1	Use of personal protective equipment	4.41	0.619	1	0.001	0.311
LMP_2	Involvement of workers in safety planning	4.35	0.652	2	0.001	0.897
LMP_3	Providing necessary work equipment	4.30	0.639	3	0.001	0.305
LMP_4	Use of hazard warning equipment	4.30	0.725	4	0.001	0.321
LMP_5	Critical analysis of work methods	4.28	0.569	5	0.001	0.726
LMP_6	Two-way communication	4.28	0.569	6	0.001	0.975
LMP_7	Use of safeguards	4.28	0.736	7	0.001	0.403
LMP_8	Visual inspection	4.25	0.606	8	0.001	0.780
LMP_9	Illumination	4.25	0.637	9	0.001	0.603
LMP_{10}	Use video files, photographs and illustrations to review work	4.25	0.670	10	0.001	0.833
LMP_{11}	Organising	4.25	0.532	11	0.001	0.427

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LMP_{12}	Use of graphical dashboards and digital billboards	4.24	0.633	12	0.001	0.318
LMP_{13}	Use of audible devices	4.23	0.675	13	0.001	0.128
LMP_{14}	Improved circulation around the workplace	4.23	0.689	14	0.001	0.559
LMP_{15}	Cleanliness and orderliness	4.23	0.703	15	0.001	0.920
LMP_{16}	Hazard identification and elimination	4.23	0.716	16	0.001	0.511
LMP_{17}	Use of safety borders and demarcations	4.23	0.770	17	0.001	0.027
LMP_{18}	Information sharing	4.22	0.576	18	0.001	0.866
LMP_{19}	Eliminate all potential work constraints	4.22	0.625	19	0.001	0.452
LMP_{20}	Correlate work methods with workers' abilities and skills	4.22	0.685	20	0.001	0.104
LMP_{21}	Review previous work	4.21	0.618	21	0.001	0.511
LMP_{22}	Identify good and bad practice	4.21	0.635	22	0.001	0.378
LMP_{23}	Select the most appropriate and safest method	4.20	0.632	23	0.001	0.331
LMP_{24}	Eliminate emplacements	4.20	0.705	24	0.001	0.422
LMP_{25}	Standardise work procedure	4.19	0.482	25	0.001	0.713
LMP_{26}	Use of visual tools	4.19	0.728	26	0.001	0.542
LMP_{27}	Use of safety signs and labels	4.18	0.751	27	0.001	0.159
LMP_{28}	Schedule site activities and simultaneous supervision plan	4.17	0.596	28	0.001	0.606
LMP_{29}	Empower and involve safety workers in schedule planning	4.17	0.663	29	0.001	0.783
LMP_{30}	Undertake pre-task hazard analysis	4.14	0.715	30	0.001	0.852

3.4. Mean Score Analayis and Ranking of LMPs

Table 3 provides results of the perception of the respondents on the impact of lean practice in safety risk management in OSC. The five top most ranked LMPs with high likelihood of controlling safety hazards in OSC include LMP1, i.e., use of PPE with MS 4.41 and SD 0.619; LMP2. i.e., involvement of workers in safety planning with MS 4.35 and SD 0.652; LMP3, i.e., providing necessary working equipment with MS 4.30 and SD 0.639; LMP4, i.e., use of hazard warning equipment with MS 4.30 and SD 0.725; and LMP5, i.e., critical analysis of work methods with MS 4.28 and SD 0.569. As pointed out, SD was used to measure how far the overall rating of LMPs deviated from the associated MS. It was also used to rank LMPs with the same MS, in which LMPs with lower SD were ranked higher, i.e., LMP3 & LMP 4; LMP5, LMP6 & LMP7; LMP8, LMP9, etcetera. The SD also helped to measure the consensus in the ratings of the respondents of the safety impact of LMPs in OSC. Though there are no minimum and maximum threshold for SD, smaller values suggest higher consensus among the respondents. As can be seen from Table 3, all LMPs had SD less than 1.0, indicating higher consensus in the rating of LMPs among the respondents. The least ranked LMPs include LMP26, i.e., use of visual tools with MS 4.19 and SD 0.728; LMP27, i.e., use of safety signs and labels with MS 4.18 and SD 0.751; LMP28, i.e., schedule site activities and simultaneous supervision plan with MS 4.17 and SD 0.596; LMP29, i.e., empower and involve safety workers in schedule planning with MS 4.17; and SD 0.663; and LMP30, i.e., undertake pre-task hazard analysis with MS 4.14 and SD 0.715. Though the ranking of the LMPs indicate different levels of their safety impact,

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they all exceeded the minimum threshold of 4.0, signifying that they were perceived likely to control safety hazards in OSC.

3.5. Average Mean Score for LMTs

LMTs were ranked based on average MS values calculated from individual MS values of LMPs within a particular LMT. As shown in Table 4, mistake proofing had a highest average MS of 4.33 and SD of 0.682. Second ranked LMT was FRS with average MS of 4.27 and SD of 0.620. The third ranked LMT was DHM with average MS of 4.23 and SD of 0.623 while fourth ranked was 5S housekeeping with average MS and SD of 4.23 and 0.657, respectively. LPS was ranked fifth with average MS of 4.22 and SD of 0.651 while improved visualisation was least ranked with average MS and SD of 4.22 and 0.655, respectively.

Table 4. Average mean scores for ranking LMTs.

Code	LMTs/LMPs	Mean	SD	LMP rank	Av. MS	Av. SD	LMT rank
	Mistaking proofing						
LMP_{1}	Use of personal protective equipment	4.41	0.619	1	4.33	0.682	1
LMP_{4}	Use of hazard warning equipment	4.30	0.725	4			
LMP_{7}	Use of safeguards	4.28	0.736	7			
LMP_{8}	Visual inspection	4.25	0.606	8			
LMP_{13}	Use of audible devices	4.23	0.675	13			
LMP_{26}	Use of visual tools	4.19	0.728	26			
	First run studies						
LMP_{5}	Critical analysis of work methods	4.28	0.569	5	4.27	0.620	2
LMP_{10}	Use video files, photographs and illustrations to review work	4.25	0.670	10			
	Daily huddle meeting						
LMP_{6}	Two-way communication	4.28	0.569	6	4.23	0.623	3
LMP_{16}	Hazard identification and elimination	4.23	0.716	16			
LMP_{18}	Information sharing	4.22	0.576	18			
LMP_{21}	Review previous work	4.21	0.618	21			
LMP_{22}	Identify good and bad practice	4.21	0.635	22			
	5S housekeeping						
LMP_{11}	Organising	4.25	0.532	11	4.23	0.657	4
LMP_{14}	Improved circulation around the workplace	4.23	0.689	14			
LMP_{15}	Cleanliness and orderliness	4.23	0.703	15			
LMP_{24}	Eliminate emplacements	4.20	0.705	24			
	Last planner system						
LMP_{2}	Involvement of workers in safety planning	4.35	0.652	2	4.22	0.651	5
LMP_{3}	Providing necessary work equipment	4.30	0.639	3			
LMP_{19}	Eliminate all potential work constraints	4.22	0.625	19			
LMP_{20}	Correlate work methods with workers' abilities and skills	4.22	0.685	20			

LMP_{23}	Select the most appropriate and safest method	4.20	0.632	23			
LMP_{28}	Schedule site activities and simultaneous supervision plan	4.17	0.596	28			
LMP_{29}	Empower safety workers in schedule planning	4.17	0.663	29			
LMP_{30}	Undertake pre-task hazard analysis	4.14	0.715	30			
	Improved visualisation						
LMP_{9}	Use of lights for activities performed at night	4.25	0.637	9			
LMP_{12}	Use of graphical dashboards and digital billboards	4.24	0.633	12			
LMP_{17}	Use of safety borders and demarcations	4.23	0.770	17	4.22	0.655	6
LMP_{25}	Standardise work procedure	4.19	0.482	25			
LMP_{27}	Use of safety signs and labels	4.18	0.751	27			

5. Discussion

Results of the MS analysis shows that all 30 LMPs are useful in safety risk management in OSC, having scored an MS exceeding 4.0 on the 5-point rating scale. Additionally, the minimal differences in the MS values among the LMPs suggest that respondents unanimously evaluated the LMPs as almost equally likely, i.e., significant, in safety risk management in OSC. However, construction companies would usually prioritize selection and implementation of LMPs that focus on aiding elements of practicality and efficiency to the construction processes [64], as well as those that provide immediate initial successes, i.e., in terms of safety, beside those that improve project success factors such as time, cost and productivity [65]. Furthermore, construction companies would prioritize LMPs in which they have organizational expertise and those which have spillover benefits [65]. It is understood that only LMPs that are affordable, compatible and efficient contribute significantly to the overall outcome of the project [65]. This could be the basis for results of the ranking of LMPs shown in Table 3. Thus, for example, LMP1, i.e., use of PPE is deemed efficient and affordable; a significant factor in project success; an LMP which can easily be implemented; and thus, effective in safety risk management in OSC. Unlike top ranked LMPs such as LMP1, low ranked LMPs such as LMP30 could be is viewed as lacking in helping orgaisations to realise immediate initial gains in safety. They could also be difficult to actualize due in part to lack of organizational expertise to implement them. The following section discusses the perceived impact of LMPs in safety risk management in OSC in chronological order of their significance. Accordingly, LMPs are discussed under their respective LMTs.

5.1. Lean Management Practices for Safer Offsite Construction

5.1.1. Mistake Proofing

The first overall ranked LMT was mistake proofing with average MS and SD values of 4.33 and 0.682, respectively. Mistaking proofing involves implementation of LMPs that prevent free flow of inadvertent errors in the construction process. It is widely useful in prevention of accidents caused by human errors and equipment failure [15,66]. In view of this finding, human errors and equipment failure could be seen as prevalent safety hazards in countries where OSC in transitioning. Even in countries where OSC is in maturity stage, the aforementioned safety hazards were reported to be among the frontline accident causal factors [13]. The emergent implication from the above finding is that, for any OSC project, in order to effectively minimise safety hazards caused by human errors and equipment failure, contracting organisations should consider implementing mistake proofing LMPs. It was therefore not surprising to note that mistake proofing related LMPs were ranked higher as

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more likely to control safety hazards in OSC. Such practices included LMP1, i.e., use of PPE, LMP4, i.e., use of hazard warning systems, LMP7, i.e., use of safeguards and LMP8, i.e., visual inspections.

The use PPEs was the overall top ranked LMP with MS = 4.41, implying that it is perceived likely to control safety hazards in OSC. PPEs are a form of body insulation consisting of hard hats, overall or work suits, gloves, boots or gumboots, googles, as well as masks. PPEs protect the workers from a wide variety of hazards including burns, laceration potential from impaling and striking objects, struck against objects, struck-by moving equipment or flying objects, trip and slip hazards and falling hazards, [67]. Serendipitously, falling and struck-by are the top causes of accidents in OSC [25]. In OSC operations, workers face consistent threat of falling from EWPs and struck-by accidents posed by onsite equipment and falling objects. PPEs protect workers from being directly struck-by or hit against machines or objects. Similarly, hazard warning systems predict workers and equipment real-time movements and exact positions on construction sites [68] for avoidance of collision accidents [69]. Generally, construction equipment and machine-related accidents such as crane failure and collapse, use of faulty equipment and tools, collision of machines and failure to safely use machines could be avoided through hazard warning and equipment alert systems. Use of PPEs and hazard warning systems should therefore be promoted in OSC to control common causes of accidents, i.e., human mistakes and struck-by.

5.1.2. First Run Studies

The second overall ranked LMT was FRS with average MS and SD scores of 4.27 and 0.627, respectively. FRS is a systematic method for critically analysing work methods to identify the most appropriate and safest method that matches the ability and skills of the workers [44]. It is employed to minimize accidents caused by lack of training, knowledge and improper operations by operators (14,20]. In countries where OSC is transitioning, safety training and induction in OSC operations is paramount. OSC operations require skilled and experienced workers to execute complex operations. However, due to limited projects, there are only a few skilled and experienced contractors, experts and workers in OSC globally [3]. As such the construction industry relies on in-training workers, who are required to master multiple skills and quickly adapt to new working procedures. FRS offers an opportunity to review work methods and select appropriate methods that correlate with workers abilities, skills and experience. LMP5, i.e., critical analysis of work methods was ranked 5th as more likely to control safety hazards in OSC. LMP10, i.e., illustration of work methods through videos and photos demonstrates how tasks could be performed safely by the novice, and was ranked 10th. The emergent implication of the above finding is that, for countries where OSC is transitioning and the number of skilled and experienced workers in OSC operations is limited, implementation of FRS practices is critical to prevention of safety hazards emanating from lack of training, knowledge and experience.

5.1.3. Daily Huddle Meetings

The third overall ranked LMT was DHM with average MS and SD of 4.23 and 0.623, respectively. It provides a platform for brief daily start-up meetings of project stakeholders to review previous work, discuss good and bad aspects and suggest ways of improving performance [48,51]. It is mainly used to minimize accidents caused by poor communication [16], stressful work [70] and ergonomic hazards [35]. Good communication among project stakeholders is key to safety in OSC, regardless of the industry's' OSC maturity level. The results revealed that two-way communication was the highly ranked LMP among DHM practices with MS = 4.28, SD = 0.569, followed by hazard identification and elimination (MS = 4.23, SD = 0.715 and sharing of information (MS = 4.22, SD = 0.576). According to Ghosh [16] two-way communication improves coordination between employers and employees, raises morale among workers and increases job satisfaction as workers feel to be an important part of the harmonious construction team. This may lead to employee agility in relation to handling of safety issues, where employees develop capabilities to appropriately respond to any safety issues as a result of proactivity, adaptability and resilience [71]. DHM allows workers to deal with challenges with speed, flexibility and decisiveness [72] which is vital in the dynamic OSC processes. Furthermore,

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two-way communication and sharing of information create a supportive environment in which safety issues are handled with a unified front due to the fluid interaction and employee networking fostered by DHM. In consonance with findings of Ghosh [16], Noorzai [64], James et al. [26, Li et al. [20], Sarhan et al. [47], Hwang et al. [42] and Bashir [51], DHM related techniques promote safety awareness, communication and coordination which improves workforce safety behaviour. The emerging results foster the need for adoption of lean tools that promote open communication and sharing of information among a turnover of in-service training workers, with the aim of improving safety awareness and develop capability to respond to safety issues intuitively.

5.1.4. 5S Housekeeping

5S housekeeping was the fourth overall ranked LMT with average MS and SD of 4.23 and 0.651, respectively. 5S housekeeping is a site planning management tool [45], aimed at optimizing the arrangement and formation of various offsite/onsite factors to improve efficiency and eliminate wastes [46]. This lean tool addresses safety hazards related to unsafe site conditions, [46], site congestion [73], and extra steps and confusion [74]. OSC operations demand extensive use of machines such as overhead cranes, loaders and forklifts, with workers being required to work in close proximity with such heavy equipment [25]. This renders thorough analysis on the handling of heavy equipment and the use of cranes important in order to identify safety risks and optimize site layout planning, to minimize safety hazards. 5S housekeeping related practices including organizing, improved circulation around the workplace and cleanliness/orderliness were ranked 11th (MS = 4.25; SD = 0.532), 14th (MS = 4.23; SD = 0.689 and 15th (SD = 4.23; SD = 0.703), respectively. These lean practices ensure that construction assets including materials, tools and plant are placed in regular, illuminated and accessible locations and that the site has clear marked routes and adequate working operating space to improve circulation [75,76]. By providing a conducive workplace, 5S provides a platform for the effective implementation of all other LMTs [70]. In OSC operations where machine and people work in close proximity, optimal site layout becomes a critical site management factor in safety risk management.

5.1.5. Last Planner System

The fifth ranked LMT was LPS with average MS and SD of 4.22 and 0.651, respectively. LPS minimizes waste and improves reliability in production flow through robust planning, control, scheduling and mutual coordination among project stakeholders [15]. Two of the LPS practices were ranked 2nd and 3th as more likely to control safety hazards in OSC. These included involvement of workers in safety planning (MS = 4.35; SD = 0.652) and providing necessary working equipment (MS = 4.30; SD = 0.639). Prominence of LMP2 and LMP3 in safety risk management has been demonstrated in previous studies. According to Camuffo et al. [77], workers involvement in safety planning reduces accidents related to poor work methods, and physical and mental limitations. It also minimises accidents resulting from poor planning and control, as well as unsafe acts of workers [78]. Ghosh [16] affirms that workers involvement in safety planning promotes behavioural tenets critical to safety including workers commitment, enhanced self-esteem, sense of belonging and cohesiveness. Similarly, provision of necessary working equipment is critical for safety and was ranked fifth as the most commonly implemented practice in a study by Enshassi a et al. [44]. Though other LPS practices had low rank, their safety impact cannot be ignored. Pre-task hazard analysis is used to identify and reduce safety risks [51]; selecting and correlating workers abilities with work methods reduce accidents caused by poor work methods [78]; and allocating work to individuals with suitable abilities could reduce accidents related to lack of skills and experience. Overall, involvement of workers in safety planning and provision of appropriate working equipment are critical in safety risk management in OSC.

5.1.5. Improved Visualization

The least ranked LMT was improved visualization with average MS and SD of 4.22 and 0.655, respectively. Use of improved visualization on construction sites eliminates safety hazards caused by poor site awareness, poor communication and extensive use of equipment [35,48,51]. Elimination of such safety hazards is crucial in OSC operations where extensive use of machinery requires good site awareness and proper communication among site workers. Though improved visualization techniques were ranked low, i.e., 9th, 12th, 17th, 25th and 27th, they are relevant in safety risk management in OSC. Enshassi and Saleh [44] and Bajjou et al. [15] found that positioning safety signs at different locations on construction site improves safety awareness and reduce human errors. Safety signs can prevent entry into unauthorized and dangerous areas by workers or members of the public. They can also abate effects of human mistakes through work standardization which improves work proficiency. Visual tools such as signs and labels provide information that is self-explanatory and easy to interpret by workers. The information can be provided in real-time thereby providing the much-needed proactivity and flexibility in dealing with safety issues. Visualization tools are also crucial for safety in machine-related operations ([19].

5. Theoretical and Practical Implications of the Study

[79] acknowledged that empirical research provides theoretical and practical knowledge which provides a bedrock for future research and industrial practice. The current study identified LMPs for safety risk management in OSC in the context of countries where OSC is in early stages. Overall, the study makes a unique contribution to the lean practice body of knowledge through identification of LMPs for safety risk management in OSC. From a theoretical lens, the study constitutes generic research findings on lean practice for safety risk management in OSC, drawing on perspectives from sub-Saharan region. The study provides a rank of LMPs that are considered significant for safety risk management in OSC. Thus, the study provides the basis for future research on LMPs for safety risk management in OSC in countries where OSC is still in its initial stages. This could be regarded relevant to academic researchers in lean practice, safety and OSC.

In the context of practice and management, the ranked LMPs will serve as a guide for implementation of lean practice for safety improvement in OSC. Implementation of top ranked LMPs may help control safety hazards in OSC. Regardless, since all LMPs were rated significant, lean improvement efforts need to be directed at helping companies understand the importance of low ranked LMPs for comprehensive safety performance. Further, since the study was conducted in a country with specific socio-economic characteristics, country specific studies may be conducted for identification of prioritised LMPs. The top ranked LMPs in this study may be associated with contextual issues which may be different in other countries.

6. Conclusions, Contributions and Limitation of the Study

Lean practice leverages significant safety risk management in OSC. Lean practice is considered a mechanism for reducing wastes in the construction industry. Construction accidents are an example of wastes and implementation of LMPs contribute to reduction of accidents. However, studies conducted to identify LMPs for safety risk management in OSC in the context of where OSC is new are limited. The study assessed the impact of 30 LMPs for safety risk management in OSC. A structured questionnaire survey was used to collect quantitative data for statistical analysis on 5-point rating scale. The LMPs with most significant impact on safety in OSC projects based on MS analysis included 2 mistake proofing practices, i.e., use of PPE and use of hazard warning equipment, 2 LPS practices, i.e., involvement of workers in safety planning and providing necessary working equipment and 1 FRS practice, i.e., critical analysis of work methods. The respondents unanimously rated all LMPs as having significant impact on safety in OSC with MS exceeding 4.0. The inclusive findings of the study highlight the significant role of lean practice in promoting safety in OSC and has useful implications. The study has ranked LMPs critical for safety risk management in OSC in the context of countries where OSC is in developing stages. Thus, the study provides a generic checklist of LMPs for implementation in OSC to improve project safety success rate. The results of the study are applicable where OSC is in early stages though bespoke studies are recommended. The current study may provide a basis for future studies to explore how lean practice can enhance safety risk management in OSC. In the main, future studies are recommended to develop a decision-making model for analysis and selection of the most appropriate LMPs for safety improvement in OSC. However, some limitations of the research are worth acknowledging. First, the study provides findings for safety risk management using lean practice in the context of Malawi. However, due to varying economic and social landscape in different countries, generalizability of the study findings may be limited. Regardless, future comparative studies may unravel such differences. Second, since OSC is still in its embryotic development in Malawi, a thin line existed between OSC contractors from whom data was collected and general contractors. Moreover, most of the respondents had a higher cumulative experience in general construction than OSC. As such, some respondents' experiences with LMPs may have been based more on general construction. Regardless, the study provides useful generic findings regarding lean practice for safety risk management in OSC in the context of countries is a new phenomenon.

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