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A MODEL FOR EVALUATING CAUSES OF WASTES AND LEAN IMPLEMENTATION IN CONSTRUCTION PROJECTS

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Abstract. The wastes in construction projects such as wastes in materials, time, resources and achieving customer needs can be minimized using the new philosophy of Lean Construction (LC). This paper proposed a two-level model based on fuzzy logic technique for evaluating Causes of Wastes (CWs) and lean implementation in construction projects. The probability of occurrence and importance of CWs were two input parameters in level 01 of the model, whereas the output was the level of waste. On the other hand, level 02 of the model depended on using three input parameters which were: level of waste, controllability level for CWs and lean implementation level, while the output was the lean effect. Several linguistic variables and logical rules were used for relating inputs and outputs and new indices were introduced. The model was applied and validated for data collected in two countries: Egypt and Kingdom of Saudi Arabia (KSA). Results demonstrated that the expected lean effect is found with a positive correlation with various levels of wastes and can be improved by increasing controllability and lean implementation levels. Regarding the comparative study between the two countries, distinct disparities in lean effect were clarified. Most measured CWs indices were different in both countries while indices values in KSA were higher than in Egypt either in waste, controllability or implementation levels. The results presented an optimum arrangement to reach an effective new lean evaluation model that could be implemented for moving the traditional construction towards LC. Finally, the model can be applied easily in most countries to help decision makers in evaluating CWs and lean implementation in their construction projects.

Keywords: cause of waste, lean construction, lean evaluation, lean effect.

Introduction

The traditional construction field is highly characterized by many challenges such as low productivity, non-added-value generation, time and cost overrun, poor safety conditions, and a high variability of its construction process (Koskela, 1999; Issa, 2013). Nowadays, managing the traditional construction field becomes inadequate to meet the necessities of the construction projects that consume a significant amount of resources (Banawi & Bilec, 2014). Minimizing wastes and maximizing the value added become an essential challenge for all stakeholders. Lean Construction (LC) concept appeared as a new philosophy to cover most of these requirements (Ballard & Howell, 2003; Issa & Salama, 2018). The lean techniques can help in improving the economic impact of the project and reduce the waste in the construction process where different studies from various countries have illustrated that the wastes in construction field equal approximately 47% of the total construction process (Aziz & Hafez, 2013).

Wastes in construction are generally described as physical construction wastes that produced as a result of construction activities. These wastes can be described as non value-adding activities. Wastes should be determined and prioritized for the purpose of eliminating their effect on the project. Waste was defined by researchers in different ways in which it could be classified and recognized. Excess materials, delays, rework and defects are some of those waste (Senaratne & Wijesiri, 2008).

Wastes can be described as controllable or uncontrollable (Aziz & Hafez, 2013). Issa and Salama (2018) identified many causes of wastes and categorized them due to their controllability. The identified controllable causes of wastes were categorized into four groups based on responsible (owner, supervisor, contractor, or common). The effect of using lean techniques on controllable causes of wastes was measured as a case study in Kingdom of Saudi Arabia (KSA).

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Limited previous models concerning LC were developed, but most of them do not refer to LC evaluation. A lean model based on six main principles was developed by Bajjou and Chafi (2018). Client Focus, Waste Consciousness, Quality, Material flow and pull, Organization/ planning /info flow, Continuous improvement, Kaizen were the identified principles. The model shows a classification scheme which helps companies to identify the level of maturity of construction projects. Another model introduced by Nesensohn et al. (2016), namely Lean Construction Maturity Model (LCMM), covered eleven main key attributes (Culture & Behaviour, Customer focus, Processes & Tools, Business Results, Learning and Competency Development, Change, Work Environment, Way of Thinking, Improvement Enablers, Competencies). These key attributes can be divided into six main principles: Learning, People, Philosophy, Processes & System, Leadership, and Outcomes & Outputs. This model was validated through several interviews with LC experts that work as contractors, consultants, or engineers.

Seven LC principles were summarized in an understandable model, to assess the consciousness of the LC principles among Malaysian construction companies. The summarized principles were: Specify value, Identify and map the value stream, Flow, Pull, Perfection/continuous improvement, Transparency, Process variability (Bajjou & Chafi, 2018). Nascimento et al. (2017) developed and applied a new model namely Digital Obeya Room (DOR) that demonstrated the interactions between Building Information Modeling (BIM) and lean principles to improve workflows, data analysis, and 3D visual management of construction planning and control. The lean and non-lean scenarios were compared by Erol et al. (2017) through applying a Monte Carlo simulation model on residential building project. Research findings demonstrated that the utilization of practical LC principles may result in a considerable amount of time reduction in some activities of residential building projects. A lean formwork construction model was proposed by Ko and Kuo (2015) to reduce wastes based on allowing workers to obtain assistance immediately whenever a problem occurs.

A Structural Equation Model (SEM) was designed and applied to explore interrelationships among the critical factors of work flow (Zhang et al., 2017). The model confirmed nine hypotheses and denied three hypotheses. The model considered that studying the impact of all factors together is more insightful than in isolation. Moaveni et al. (2019) proposed a hybrid model including a new approach to the Transformation-Flow-Value framework, in order to pay particular attention to safety in construction projects as one of the factors affecting the success of projects, and achieving optimal value for stakeholders. The model further improved the LC framework. The careful attention of project executives to this model may improve the safety situation in construction projects.

Due to limited evaluation models which can help the decision maker to assess lean effect based on many factors, this study attempted to provide better understanding for Causes of Wastes (CWs) evaluation and LC implementation and their concepts, which will increase the productivity and reduce wastes in construction projects. As an output, the study suggested a model that enables integrating the traditional construction process with LC techniques. The objective of this paper is to design an input-output Lean Construaction Evalution Model (LCEM) in order to evaluate the possibility and level effect of LC implementation. Applying the model in two countries (Egypt and KSA) was one of the main purposes of this study. A compartaive study was also introduced to describe the evaluation of the effectiveness of implementing lean in construction projects.

1. Research methodology

This study appointed a methodology based on field surveys, principally brainstorming sessions and semi-structured interviews. The inputs and outputs of the proposed model and the rules linking them were proposed. The brainstorming is considered one of the best common identification systems for data collection in construction projects (Issa et al., 2014). Three brainstorming sessions were conducted (one in Egypt with five experts and two in KSA with nine experts) to confirm the inputs and outputs that will be used in the model. The most appropriate linguistics for model inputs and outputs were also established through introducing the proposal. The relations among inputs and outputs through the proposed logical rules were presented and confirmed. The results of this step were numerous logical rules relating inputs and outputs.

Secondly, semi structured interviews were organized by professionals based on the results of last step. Additionally, semi structured interview gives the opportunity to ask the target respondents if there are any modifications they can add to improve the survey or results (Issa & Ahmed, 2014). The main objective of these interviews was to complete a questionnaire for selecting the most appropriate linguistics for each cause of waste due to his/her experiences. The results from this step included values for all inputs to feed the model and the two outputs from the two levels of the model.

Finally, two brainstorming sessions (one in Egypt with four experts and the other in KSA with five experts) were directed to apply and validate the model results and its suitability for application in construction projects. More details will be explained in model application and validation sections.

2. Causes of wastes and lean construction implementation

Lean construction is not only interested by the quantity of material wastes on-site but also involved in all waste types that are related to several activities such as overproduction, waiting time, material handling, processing, inventories and movement of workers (Alarcón, 1994). LC philosophy focuses on minimizing all wastes of time and other resources that do not add value to the product or delivered service to the customer (Womack et al., 1991).

All over the world, the construction industry faces many obstacles and CWs. Previous researches specified that up to 30% of costs of construction projects are due to inefficiencies, mistakes, delays, and poor communications (Forbes & Ahmed, 2004). Several studies were conducted to observe problems in construction industry such as; factors affecting projects objectives (cost, time, quality and performance of construction). Other studies conducted to develop qualitative and quantitative models to assess the effects of these factors.

Project definition, lean design, lean supply and lean assembly and use are different phases in the LC implementation process (Ballard & Howell, 2003). Key critical factors for lean implementation are introduced by Crute et al. (2003), Achanga et al. (2006). The most important key factors can be summarized as follows:

1. *Finance*, which represents the company or organization finance state which is considered important for implementation of LC, needed for employee training, external consultation and technical logistics.
2. *Leadership*, which is considered vital through the implementation of the new philosophy to have a certain degree of communication skills, long-term focus of management and strategic team in the company or organization.
3. *Organizational culture*, which is a necessary element in the process of lean application in the company or organization.
4. *Skills and Expertise*, which is very important to overcome the companies experience difficulties after employing people with low skills levels.

LC, which can be implemented in construction projects uses many techniques such as Pull Approach, Push vs. Pull, Multifunctional Task Groups Kaizen (Total Quality Improvement), Benchmarking, A3 Reports, Increased Visualization, First Run Studies, Daily Huddle Meetings (Tool-box Meetings), The 5s Process (Visual Work Place), and lastly the Last Planner System (LPS) which is considered the most famous technique for LC implementation. LPS was confirmed as one of the top most implemented lean practices and about 20 different economic, social and environmental benefits were linked to the implementation of lean practices in the construction industry (Babalola et al., 2019). The objectives for the LPS include many tasks (Ballard, 2000) such as:

- Managing and mitigating the variability;
- Correcting assignments and schedules with regard to their prerequisites;
- Monitoring the completed assignments;
- Identifying and removing causes for failure;
- Using a workable backlog for each crew and production unit;
- Making prerequisites of upcoming assignments to be ready;
- Incorporating traditional push with pull techniques;
- Distributing decision-making powers well among the project team.

Recent researchers applied the lean construction principles in many construction projects. For the purpose of eliminating various types of waste in construction projects, Yin et al. (2014) proposed a lean subcontracting procurement process based on lean construction theory. They introduced a common information platform and cooperative environment that help participating contractors understand the work emphasis of each operation and the whole operation in sequence. The lean conformance including strengths and weaknesses of contractors for a lean construction initiative was predicted by Tezel and Nielsen (2013). Innella et al. (2019) clarified the importance of implementing lean techniques in the modular building industry, including all the production process stages. Moreover, M. Goh and Y. M. Goh (2019) provided and evaluated recommendations to improve modular construction efficiency through application of lean concepts by conducting a detailed simulation for Prefabricated Prefinished Volumetric Construction.

Carvajal-Arango et al. (2019) summerized the relationships and synergies between the philosophies of lean and sustainable constructions, and to determine how the lean construction practices contribute to each dimension of sustainability (i.e., environmental, economic, social) during the construction phase of a project. The Building Information Modeling (BIM) was combined with Lean principles to improve efficiency of construction projects (Heigermoser et al., 2019). A construction management tool linked LPS with the 3D visualization to improve productivity and reduce construction waste.

Lean construction is ongoing to be applied in most countries all over the world. It is recently applied in Egypt and KSA on minor scales. In Egypt, Issa (2013) applied LPS through execution of an industrial project. LC implementation is evaluated by a quantification model. Abdel-Razek et al. (2006) focused on improving construction labor productivity in Egypt by applying two LC principles, namely benchmarking and reducing variability in labor productivity. The role of LC as an innovative approach for reducing wastes in the Egyptian construction industry was investigated (Abo-Zaid & Othman, 2018).

On the other hand, the implementation of LC concepts in large and complex projects in KSA has not yet taken place (Sarhan et al., 2017). Sarhan et al. (2018) investigated the current state of LC implementation in KSA. The level of implementation of LC in the KSA construction industry is increasing. Sarhan et al. (2018) proposed many solutions for overcoming barriers to lean implementation in KSA construction industry. Principal factors that constitute these barriers were found to be traditional practices, client related, technological, performance and knowledge and cost-related barriers in descending order of pervasiveness. Numerous solutions were proposed to overcome these principal barriers. Al-Sudairi (2007) reported that lean practices have significantly improved project performance, especially at the trade level by reducing waste involved in KSA. A method for determining responsibilities for many causes of wastes in KSA before starting to apply LC techniques was proposed by Issa and Salama (2018). They found that nearby 88% of controllable causes of wastes can be affected by lean either completely or partially.

3. Lean Construction Evaluation Model (LCEM)

The main aim of the proposed model is to appraise the CWs in construction as well as LC implementation in an acceptable and easy way. The model is built based on Fuzzy logic concept that depends on fuzzy rule base which is the basis of the composition or reasoning process. Generally, the fuzzy rule base can be represented using IF (antecedent)-THEN (consequent) (Abd El Khalek et al., 2016). The undocumented data and particular behaviors are declared in many researches as problems in construction projects (Khazaeni et al., 2012; Issa & Ahmed, 2014). So, relationships between the inputs and the outputs variables can be represented in terms of linguistic variables instead of mathematical formulae using logical rules. The LCEM is proposed to be developed and applied in two levels as follows.

3.1. Level 01 of the model

In this level of the model, the level of waste is proposed to be determined as a function of waste probability through (Waste Probability Index) *WPI* and Wsate Importance through (Waste Importance Index) *WII*. The inputs in this level are *WPI* and *WII* while the output is level of waste via (Waste Level Index) *WLI*. The proposed linguistic variables are introduced in the brainstorming sessions that explained in the methodology as a first step. The linguistic variables for inputs and outputs as outcomes from this step are summarized in Table 1.

The relation between the two inputs and the output can be represented by a double premise rule such as: *If the Waste Probability and Waste Importance then Waste Level.*

There are many relationships with varying values of *WPI*, *WII*, and *WLI*. These relationships can be represented using proposed Fuzzy Associative Memories (FAMs), using the method and interrelationships comparable to those introduced by Carr and Tah (2001), Issa (2012), Issa et al. (2019). Twenty five logical rules can be readily represented by the matrix shown in Table 2.

3.2. Level 02 of the model

In this level, three premise rules are proposed to combine the three proposed inputs with the model output. First input is waste level which comes as results from level 01 of LCEM. The second input is the controllability which is fed through an index namely Controllability Index (*CI*), while the third input is the implementation level which is provided through proposed 5 levels of expected implementation (10%, 30%, 50%, 70%, and 90%). The output of the model is lean effect through Lean Effect Index (*LEI*). The linguistic variables are used in this level are summarized in Table 3. Using 125 logical rules, the relationships among inputs and outputs can be exemplified using the proposed FAMs as presented in Table 4. The relation among the

Table 1. Linguistic variables for inputs and outputs used in Level 01 of LCEM

Input / Output – Level 01	Selected Linguistic Variable				
Waste Probability	Rare	Unlikely	Moderate	Likely	Very Likely
Waste Importance	Trivial	Minor	Moderate	Major	Extreme
Waste Level	Very Low	Low	Medium	High	Very High

Table 2. FAMs rules for inputs and output in level 01 of LCEM

Scale		Waste Probability				
		Rare	Unlikely	Moderate	Likely	Very Likely
Waste Importance	Trivial	VL	VL	L	L	M
	Minor	VL	L	L	M	M
	Moderate	L	L	M	M	H
	Major	L	M	M	H	VH
	Extreme	M	M	H	VH	VH

Note: VL – Very Low; L – Low; M – Medium; H – High; VH – Very High.

Table 3. Linguistic variables for used inputs and outputs in Level 02 of LCEM

Input / Output – Level 02	Selected Linguistic Variable				
Waste Level	Very Low	Low	Medium	High	Very High
Controllability Level	Very Low	Low	Medium	High	Very High
Implementation Level	Very Low	Low	Medium	High	Very High
Lean Effect	Poor	Acceptable	Good	Very Good	Excellent

Table 4. FAMs rules for inputs and output in Level 02 of LCEM

Lean Implementation Level \ Waste Level	VL	L	M	H	VH	VL	L	M	H	VH	VL	L	M	H	VH	VL	L	M	H	VH	VL	L	M	H	VH
VL	P	P	P	P	P	P	P	P	P	P	Acc	Acc	Acc	Acc	Acc	Acc	Acc	Acc	Acc	Acc	G	G	G	G	G
L	P	P	P	P	P	Acc	Acc	Acc	Acc	Acc	Acc	Acc	Acc	Acc	Acc	G	G	G	G	G	G	G	G	G	G
M	Acc	Acc	Acc	Acc	Acc	Acc	Acc	Acc	Acc	Acc	G	G	G	G	G	G	G	G	G	G	v_G	v_G	v_G	v_G	v_G
H	Acc	Acc	Acc	Acc	Acc	G	G	G	G	G	G	G	G	G	G	v_G	v_G	v_G	v_G	v_G	Exc	Exc	Exc	Exc	Exc
VH	G	G	G	G	G	G	G	G	G	G	v_G	v_G	v_G	v_G	v_G	Exc	Exc	Exc	Exc	Exc	Exc	Exc	Exc	Exc	Exc
Controllability Level	VL					L					M					H					VH				

Note: VL – Very Low; L – Low; M – Medium; H – High; VH – Very High; P – Poor; Acc – Acceptable; G – Good; V_G – Vey Good; Exc – Excellent.

three inputs and the output can be represented by the triple premise rule as follows: *If Waste Level and Controllability Level and Lean Implementation Level then Lean Effect*.

3.3. Membership function

The membership function represents the fuzziness degree of linguistic variables (Zadeh, 1965). Membership functions were established to give a numerical meaning for each label or variable. Each membership function identifies the range of input or output values that corresponds to each label. The membership function of each label does not define boundaries, where the label is fully applied to one side of a cutoff and not at all to the other side of the cutoff.

The membership function used in the model is the triangle shape for all inputs and outputs sources as shown in Figure 1. This membership function was used in many models and frameworks within the field of construction and risk management and was chosen depending on previous researches' work. This shape of membership function was used by Carr and Tah (2001) in their factors' assessment model using the cause and effect diagrams. Moreover, it was used by Dikmen et al. (2007) for rating of the cost overrun risk in international construction projects. Hsieh et al. (2004) also used the same shape of the membership function in selecting planning and design alternatives in public office building. Finally, Issa et al. (2019) conducted many agreement tests to prove that the triangle shape is most suitable in cases similar to current case in this investigation.

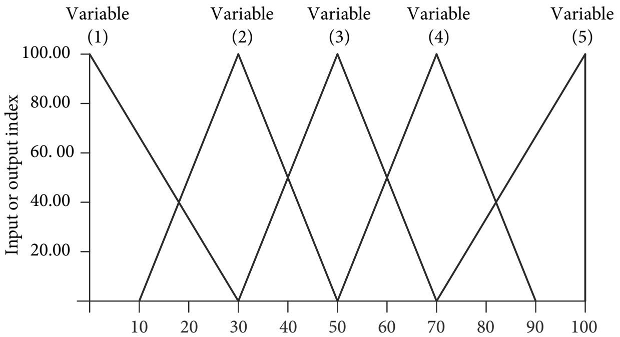

Figure 1. Membership function for inputs and outputs

4. Model applications and results

Forty two CWs were recently identified in developing countries by Issa and Salama (2018) as displayed in Table 5. These CWs were classified through four categories based on the responsible (client, consultant, contractor and common responsibility). In this research, field surveys were conducted to collect data concerning the previous identified CWs in both Egypt and KSA for the purpose of model application and validation. The data were collected from a series of semi structured interviews in consulting organizations and contractors companies. The data collected from all respondents and the model in its two levels was applied.

4.1. Results of level 01 of the model

The average for inputs indices and results for level 01 are shown in Table 6. From this table, it can be observed that the highest probability in Egypt (according to *WPI* value), is for CW No. 6 (Contractor selection before consultant, *WPI* = 0.68). In KSA, it can be noticed that CW No. 3 (Delay in running bill payments to the contractor or consultant) are located together with CW No. 6, in first priority due to their probabilities (*WPI* = 0.86). On the other hand, the peak importance (according to *WII* value) in Egypt is for CW No. 1 (Client slow response and slow decision-making mechanism) with value of *WII* = 0.77, while this value increases in KSA to 0.86 for CW No. 9 (Starting execution although project documents are not completed).

Table 5. The identified CWs (Issa & Salama, 2018)

CW_No.	Causes of wastes
1	Client slow response and slow decision-making mechanism
2	Problems in Client's organization such as bureaucracy and lack of specialists
3	Delay in running bill payments to the contractor or consultant
4	Client's special needs such as additional works and change order
5	Deficiencies and changes in project scope
6	Contractor selection before consultant
7	Unfairness in tendering or method of contractor choice
8	Client's representative problems
9	Starting execution although project documents are not completed
10	Lack in project financing
11	Delay in reviewing or approving design documents
12	Delay samples approval, inspections as well as making decisions
13	Lack of consultants experience in design, supervision and quality control
14	Poor integrated organization structure for consultant
15	Inadequate experiences of contractor
16	Poor management team in performance such as late request for inspections or poor site management
17	Workers problems such as inadequate motivation or improper accommodations
18	Unskilled workers and poor labor productivity
19	Delay in delivery of materials to site
20	Problems resulted in interference among different subcontractor's
21	Delay of regulatory reporting
22	Execution errors that lead to rework
23	Poor evaluation for contract items, tendering documents, and quantities as well as poor scope definition
24	Inadequate modern equipment and low productivity level
25	Dispute resolution delay or lack of dispute resolution methods
26	Poor distribution of personnel
27	Material wastes either due to poor design or poor execution
28	Familiarity with site conditions, location and project complexity
29	Delay due to administrative approvals
30	Poor site safety
31	Inadequate specifications and shortage of design data
32	Changes in core team
33	Language barriers

End of Table 5

CW_No.	Causes of wastes
34	Variations of actual quantities of work compared with quantities in bidding documents and underestimation of cost
35	Supplying poor quality materials
36	Complete familiarity with systems and laws in KSA
37	Conflicts, poor communication and coordination among contractor and other parties
38	Unavailability of qualified sub-contractors
39	Truthfulness of contractor or consultant to get a big gain
40	Side effects due to project activities
41	Scheduling errors and actual execution duration is greater than duration in tender
42	Inadequate definition for authority or responsibility as well as supervision overlapping

Table 6. Inputs and results indices of Level 01 of the model

CW_No	*WPI-EG*	*WPI-SA*	*WII-EG*	*WII-SA*	*WLI-EG*	*WLI-SA*
1	23	71	71.1	71.1	44.2	70.5
2	63	54	53	53	62.4	53.9
3	54	86	72	72	34.8	82
4	41	34	51	51	40.8	34.8
5	17	32	83	83	21.8	53.7
6	68	86	52	52	59.2	66
7	44	49	73	73	52.9	52.7
8	63	52	72	72	42.4	54.1
9	32	70	86	86	32.9	82
10	63	71	72	72	41.6	70.9
11	33	23	73	73	51	44.2
12	48	29	75	75	39.2	49
13	63	70	71	71	42.2	70.5
14	48	30	32	32	38.4	30
15	38	41	72	72	38.4	52.3
16	39	40	73	73	39.2	53.4
17	35	70	72	72	33.9	51.2
18	38	41	71	71	38.4	70.9
19	39	55	74	74	39.2	51.7
20	51	51	62	62	36.7	22.8
21	31	18	42	42	29.1	50
22	29	38	70	70	29.5	51.9
23	35	34	72	72	35.8	32.7
24	63	27	52	52	42.4	32.7
25	38	52	73	73	38.4	54.8
26	41	34	41	41	38.1	35.6
27	27	58	62	62	28.1	58.4
28	35	57	61	61	36.3	58.1

End of Table 6

CW_No	*WPI-EG*	*WPI-SA*	*WII-EG*	*WII-SA*	*WLI-EG*	*WLI-SA*
29	19	71	72	72	23.7	70.9
30	48	19	70	70	38.4	40.9
31	46	30	53	53	42.4	33.8
32	29	42	52	52	28.1	41.6
33	12	31	33	33	14.7	31.4
34	43	30	55	55	28	35.8
35	36	44	73	73	41.6	52.9
36	18	18	32	32	22.8	22.8
37	29	19	32	32	29.5	23.7
38	48	58	61	61	41.6	58.7
39	25	27	54	54	27.6	34.8
40	24	30	33	33	16.5	30
41	29	51	72	72	45.2	52.9
42	23	42	40	40	26.4	40

Notes: *WPI* – Waste Probability Index; *WII* – Waste Importance Index; *WLI* – Waste Level Index.

When the model is applied, the results represent the waste level through *WLI*. Maximum value of waste level in Egypt is for CW No. 2 (problems in Client's organization such as bureaucracy, with *WLI* = 0.624). On the other hand, it is found that two CWs are sharing the same maximum value (*WLI* = 0.82) in KSA for CW No. 3 and CW No. 9 which are identified before. Figure 2 and Table 7 summarize the means and ranges for inputs and outputs for level 01 of the model.

From Figure 2, it is clear that the average means for *WPI* and *WII* in KSA are higher than their counterparts in Egypt by 13.6% and 30%, respectively. The means values for the model result represented in *WLI* show that its value is higher in KSA by about 25% than in Egypt. Table 7 shows the ranges for the inputs and outputs of level 01 of the model. These ranges represent the difference value between the highest and lowest values. It is clear that the range of *WII* in Egypt is higher while ranges of *WPI* and *WLI* are higher in KSA.

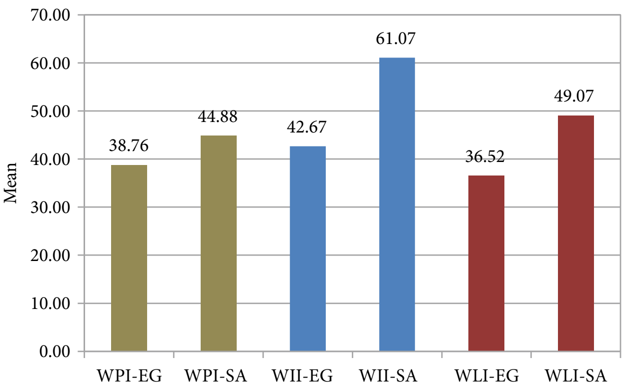

Figure 2. Inputs and outputs mean for level 01 of the model

Table 7. Inputs and outputs ranges for Level 01 of the model

Index	WPI-EG	WPI-SA	WII-EG	WII-SA	WLI-EG	WLI-SA
Range	56.00	68.00	64.00	54.00	47.70	59.20

4.2. Results of level 02 of the model

As explained before, there are three input indices in level 02 of the model lead to lean effect as an output. The first input is the *WLI* which was the result of level 01 of the model. Table 8 illustrates the Controllability Index (*CI*) as the second input for all CWs in both countries. The third input is the implementation level, which is expressed in 5 levels (10, 30, 50, 70 and 90%). The output is Lean Effect Index (*LEI*) which is determined for each implementation level for both countries. From Table 8, it is obvious that, CW No. 5 is considered the most controllable one in Egypt, while the lowest controllable CW is No. 29. On the contrary, in KSA the highest controllable CW is No. 30 while the lowest one is CW No. 3. Each cause of waste has 5 lean effect indices based on the implementation levels as shown in Table 8. Table 9 summarizes the average mean and range for *CI* in Egypt and KSA. It is clear that the average controllability in KSA is higher than in Egypt by about 27%, while the range is almost the same. More analysis for inputs and output for level 02 of the model will be discussed through presenting next figures and tables.

Referring to Figure 3, it is expected that as increase in the level of lean implementation, as the increasing in the mean of lean effect. This expresses that the lean effect is improved with the increase of lean implementation for both countries. However, the lean effect in KSA appears to be higher at the same level of implementation. This may be due increasing the controllability level in KSA, and the waste level in KSA is primarily higher than Egypt. Regarding Figure 4, if the range of lean effect compared in the two countries, it can be found that the lean effect is convergent in cases of lean implementation (levels 10% or 90%), while there are clear disparities in the rest levels. The increase in lean effect range in Egypt especially at level 70% may reach 33% higher than in KSA. It is expected that as increase in the level of lean implementation, as the lean effect range increases in the same country.

4.3. Model validity

The validation process implies determining whether the model accurately represents valid results and reality or not. In this research, two satisfactory validity tests were conducted. First one concerned the logical rules and confirming the relations among inputs and outputs. This step was conducted as explained before in the methodology. In second test, two brainstorming sessions were directed for discussing the model results and four experts were requested to evaluate and identify whether the results is valid or not. The experts agreed that the results are logical and expressive.

Table 8. Lean effect at various implementation levels in the two countries

CW_No.	Controllability Index		Various implementation levels in the two countries									
	CI-EG	CI-SA	EG–10%	SA–10%	EG–30%	SA–30%	EG–50%	SA–50%	EG–70%	SA–70%	EG–90%	SA–90%
1	66	70	30	50	45	50	50	70	63.5	70.2	64.9	89.4
2	34	53	30	34.1	41.9	50	50	53.8	55.3	54.7	61.9	72.3
3	42	32	24.1	40	36.1	50	41.6	53.9	50	53.9	56.1	70
4	66	74	30	33.7	44.3	50	50	53.5	60.6	55.6	64.3	70
5	73	73	25.7	34.8	43.3	52.7	43.3	54.5	53.1	71.4	63.3	72.8
6	83	82	41	43.3	60	60	61	63.3	77.3	77.2	77.3	80.4
7	43	51	30	31.6	42.4	50	50	51.4	54	53.5	62.4	70.8
8	33	86	24.4	44.4	34.3	55.8	41.9	64.4	50	73.4	54.3	73.4
9	72	72	32	52.8	50	52.8	51.9	70	53.7	77.2	70	88
10	44	33	25.3	31	41.3	50	42.8	50.9	50	53.8	61.3	70
11	43	83	30	41	42.4	50	50	61	51.6	61.9	62.4	70
12	43	75	24.5	34.5	39.4	50	41.8	54.3	50	68.5	59.4	70
13	39	52	24	32.9	39.2	50	41.4	52.7	50	70.2	59.2	71.5
14	43	73	24.6	30	38.7	50	42.1	50	50	52.7	58.7	70
15	36	73	21	33.3	37.2	52	38.7	53	50	71.4	57.2	71.7
16	35	74	21.7	34.5	36.6	53.5	39.7	54.3	50	71.9	56.6	71.6
17	55	44	30	30	35.8	43.3	50	50	54.8	51.8	56	62.3
18	42	72	24	51	38.7	51.8	41.5	70	50	70.9	58.7	89.4
19	42	52	23.8	32.5	39.4	50	41.2	52.3	50	52.7	59.4	71.3
20	44	73	25.6	26.4	37.3	44	43.2	44	50	53	57.3	64
21	72	72	29.5	32	49.1	50	49.1	51.8	51.8	70	69	70
22	43	75	24.9	34.5	29.7	52.7	42.4	54.3	49.5	71.4	50	71.4
23	59	73	30	32.9	39.2	50	50	52.7	57.2	53.5	59.2	70
24	36	86	24.4	34.2	37	50	41.9	54.2	50	64.3	57	70
25	38	52	21	32.9	38.5	50	38.7	52.8	50	55.6	58.5	70
26	43	81	24.7	37.8	38.5	50	42.2	57.8	50	59.1	58.5	70
27	49	73	29	38.7	29.3	53.1	48.2	58.7	48.2	71.6	50	76.3
28	25	33	19	30	27.5	38.5	37	50	45.6	54.3	50	58.5
29	23	34	10.6	31	26.5	50	26.8	50.9	40.1	54.8	44.6	70
30	73	90	33.1	40.7	50	50	53.1	60.7	58.7	70	70	70
31	63	82	30	36.4	42.3	50	50	56.4	61.9	60	62.3	70
32	48	41	28.5	23.6	29.1	40.8	47.3	41.1	48.2	50	50	60.8
33	48	81	19	32.7	28.3	50	36.5	52.7	36.5	59.1	50	70
34	59	81	28.9	38	39.2	50	47.7	58	47.7	59.1	59.2	70
35	72	80	32.2	38.2	50	54.6	52.2	58.2	61.3	72.5	70	72.5
36	66	82	26.4	25.3	44	42.5	44	42.5	44.8	60	64	62.5
37	35	80	17.9	26.4	29.8	43.9	35.8	43.9	49.5	58.2	50	63.9
38	49	82	29.2	40	41.3	60	48.3	60	50	77.2	61.3	77.2
39	66	83	28.8	37.2	45.2	50	47.8	57.2	47.8	61	64.9	70
40	49	83	21.3	30	29.1	50	38.5	50	38.5	61	50	70
41	68	82	30	40	47.2	55.3	50	60	64.4	72.9	67.1	72.9
42	41	72	23.2	32.4	28	50	40.8	52.4	46.2	60	50	70

Table 9. Mean and range for CI

Controllability Index	Mean	Range
CI-EG	50.07	60.00
CI-SA	68.93	58.00

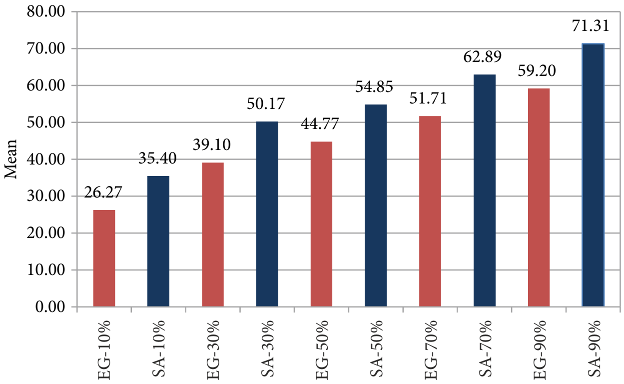

Figure 3. The mean of lean effect at various implementation levels

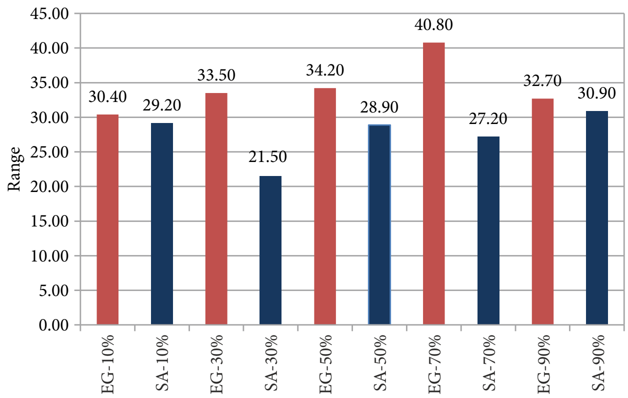

Figure 4. The range of lean effect at various implementation levels

4.4. Variables correlations

A statistical test is suggested to be conducted to show the direction and strength of the relationship among inputs and output. The Spearman's rank correlation coefficient is directed to show this relation. It compares medians rather than means, and gives better results if the data have one or two outliers. The Spearman's Rank Correlation Coefficient (R) ranges from –1 to +1. If $R = +1$, then there is wide-ranging agreement in the order of the ranks and the ranks are in the same direction. If $R = -1$, then there is a complete agreement in the order of the ranks and the ranks are in the opposite direction. If $R = 0$, then there is no correlation. In this study, the Spearman's correlation coefficient was used between inputs in form of (waste level, controllability) and output which is (lean effect) at various implementation levels.

Correlation Coefficient between *WLI* and *CI* is equal to –0.104 and –0.491 in Egypt and KSA respectively. The minus sign is an expected and refers to opposite direction relation which means that as increase in waste level as decrease in controllability. On the other hand, Tables 10 and 11 summarize the values of Correlation Coefficient among waste level and controllability versus lean effect at various implementation levels. It is clear that all values are +ve, which represent that as increase in waste level or controllability as lean effect increases.

Table 10. Correlation coefficient for inputs and output in Level 02 of the model in Egypt

Input	Various Lean Implementation Levels				
	EG_10	EG_30	EG_50	EG_70	EG_90
WL_EG	0.389	0.44	0.399	0.685	0.442
CI_Eg	0.743	0.694	0.732	0.451	0.691

Table 11. Correlation coefficient for inputs and output in level 02 of the model in KSA

Input	Various Lean Implementation Levels				
	SA_10	SA_30	SA_50	SA_70	SA_90
WL_SA	0.466	0.477	0.421	0.358	0.611
CI_SA	0.37	0.313	0.426	0.5	0.097

4.5. Causes of wastes with high levels

All CWs observed in the investigation study may occur to any construction project in the two countries. To evaluate the lean effect, CWs and lean implementation with high expected levels should be ascertained and highlighted. Hence, the top ten ranked CWs are proposed as key indicators in the two countries. In addition a comparative study for CWs and lean implementation in the two countries may help the decision maker to select the most appropriate project in case of comparing two or more projects in several countries. The highest ten wastes are declared in Table 12 in Egypt and KSA and rated based on their *WLI*. It can be observed that only 3 CWs are appeared together in top 10 ranked in the two countries (CWs No. 1, 6 and 13). In Egypt, CW No. 2 is the first followed by CW No. 6. On the other hand, CW No. 3 is the first followed by No. 9 in KSA.

Table 12. Top ten wastes in Egypt and KSA

Rank	CW_No_EG	CW_No_SA
1	2	3
2	6	9
3	7	10
4	11	18
5	41	29
6	1	1
7	8	13
8	24	6
9	31	38
10	13	27

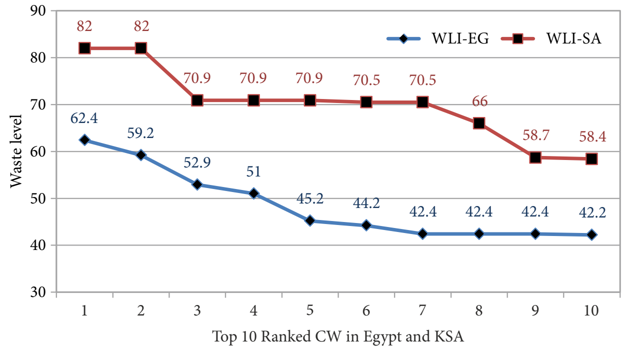

Figure 5. Waste level for top 10 ranked CWs

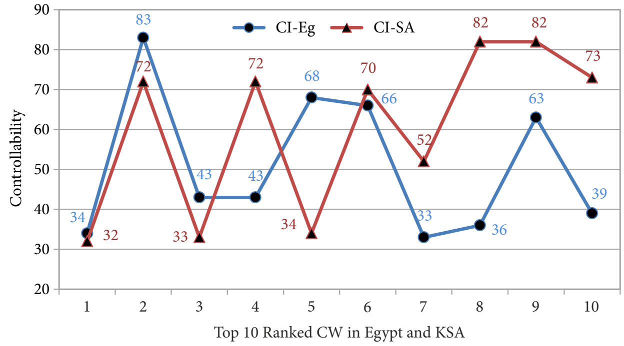

Figure 6. *CI* for top 10 ranked CWs

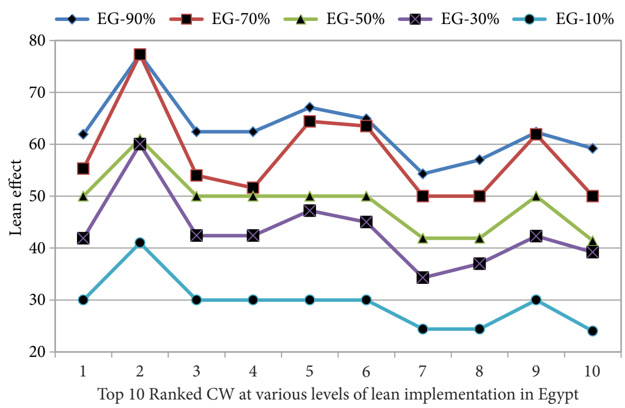

Figure 7. Lean effect for top 10 ranked CWs in Egypt

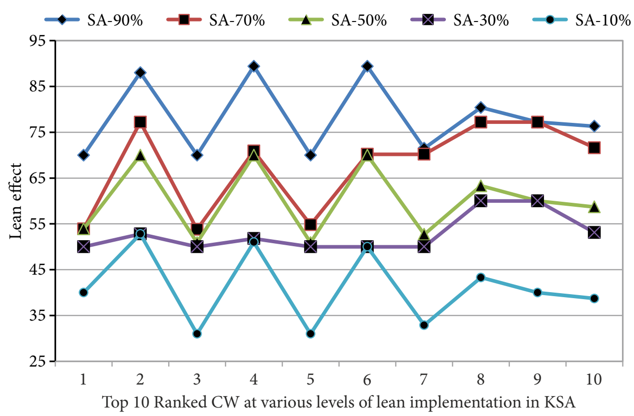

Figure 8. Lean effect for top 10 ranked CWs in KSA

Regarding to Figure 5, it is clear that top 10 ranked CWs in KSA, if arranged based on *WLI*, are higher than their identical in ranking in Egypt. The average increase is about 30%. In Figure 6, the expected controllability for top 10 ranked CWs appear with variations between the two countries. Some factors in Egypt are more controllable (4 factors), while 6 factors are less controllable than in KSA.

Figures 7and 8 illustrate the lean effect at various levels of implementation for top 10 ranked CWs in Egypt and KSA. It is logical when the lean implementation level increase, the lean effect will increase. However in some cases, the lean effect continues at the same level for some CWs. For example, CW No. 2 in Egypt, with the same effect at levels 70% and 90%. Also, in KSA, CW No. 6 keeps the same effect at levels 50 and 70 %. This is a common and expected result and considered one of fuzzy logic models advantages which depends on using linguistic variables and using overlapping in the membership functions.

5. Model limitations

Since models only approximate natural phenomena, most of them are characterized by some limitations. There are three limitations in this study concern the proposed Lean Construction Evaluation Model. Firstly, the number of linguistic variables used in model inputs or outputs is limited to five only. In some cases, using more than five linguistic terms, especially in model inputs, may give more truthful results. Sometimes selecting a linguistic among seven variables may be easier for the respondents. The second limitation concerns inputs range based on fuzzy IF-Then rules. For example, minimum value for input is 0.1, not zero. This means that no selection chance for case of zero waste probability of occurrence, importance or controllability as well as implementation for lean construction. However, this limitation concerns all model based on fuzzy logic. Finally, the third limitation concerns the final decision. The model gives good image for lean effect in a certain country, but the final decision for applying lean or not needs another model for decision making.

Conclusions

Lean Construction which refers to maximizing productivity and minimizing waste generation in construction projects has taking the concern of many researchers, engineering organizations and companies in the field of construction management. In this research, a model was introduced in two levels to evaluate most operations regarding the evaluating of CWs and lean implementation in construction industry. In first level of the model, the evaluation of waste was conducted through combining the probability of occurrence of each cause of waste with its waste importance. Second level of the model, determined lean effect through utilizing three premise rules and several relations among waste level, controllability and lean implementation levels. The model was validated through applying it in Egypt and KSA. The main findings/outputs of this study are presented below:

1. Due to statistical tests, the lean effect can be improved by increasing the levels of controllability and lean implementation as well as decreasing waste levels.
2. The results proved an inverse relationship between waste levels and controllability.
3. The results of the proposed model can be used as an important criterion to help the decision maker in selecting the most appropriate project in case of comparing more than one project in different countries based on waste levels and lean effect.
4. The presented model is not limited to be applied in Egypt or KSA, but it can be applied in all countries using slight modifications. Using the fuzzy logic concept added flexibility and ease of use in handling the problem.

Other conclusions are provided from results of comparative study between Egypt and KSA as follows:

1. Most measured CWs indices are different in both countries and in a few cases they come close to being equal.
2. In many cases, the indices values in KSA are higher than in Egypt such as average mean for *WPI*, *WII* and *WLI* in addition to average controllability ranges of *WPI* and *WLI*. However, only the range of *WII* in Egypt is higher.
3. At the same level of lean implementation, the lean effect in KSA is higher than in Egypt.
4. When studying individual CWs, it is found that *WLI* for most CWs in KSA are higher than their identical in ranking in Egypt. Furthermore, limited CWs in Egypt are more controllable than in KSA.

Author contributions

UI and MA were responsible for the design and development of the data analysis. UI and MA were responsible for data collection and analysis the data. UI and MA were responsible for data interpretation. UI wrote the first draft of the article. UI reviewed, amended and approved the article.

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