Improving Productivity in Saudi Arabian Construction Projects: An Analysis based on Lean Techniques

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Abstract

Recently, new techniques have been implemented in many countries for the purpose of achieving significant continuous improvement in construction projects. Furthermore, using these techniques endeavours for minimizing wastes and increasing productivity. Construction projects in Kingdom of Saudi Arabia (KSA) miss using these new techniques. One of the new techniques is "Lean Construction" which is a new philosophy directed to improve construction productivity. It is important to identify and analyze the causes of wastes which can be affected by lean construction in KSA. Determining responsibility is an important ingredient before starting applying the new techniques. In this research, many causes of wastes in KSA construction projects were identified as well as their controllability. The identified controllable causes of wastes were categorized into four groups based on responsible (owner, supervisor, contractor, or common). An acceptable degree of agreement among participant groups was obtained through conducting two agreement analysis tests. The importance of each identified cause of waste was determined by a relative importance index. The effect of using lean techniques on controllable causes of wastes was measured. The study established that the highest responsibility is for the common group while the lowest responsibility is for consultants group. Around 88% of controllable causes of wastes can be affected by lean either completely or partially. The results confirmed the importance of using the lean techniques in minimizing wastes and increasing productivity in KSA construction projects.

INTRODUCTION

There are many wastes in the construction processes which are termed as "non-value-adding". All activities that produce direct or indirect costs and consume time, resources or require storage but do not add value or progress to the product can be called wastes (Koskela, 1992; Alarcón, 1994; Love et al., 1997). These wastes can be measured as a function in costs as well as their opportunity costs. Wastes include other types such as that are related to the efficiency of process, equipment or personnel. Wastes in construction are represented as physical construction waste delivered in construction work.

Construction wastes can be recognized by many approaches. They are identified into five groups as follows: 1- waiting for resources, 2- Travelling time movement (of operator or machine), 3- Idle time (of operator or machine), 4- Resting, and 5- Rework (Serpell et al., 1995). The time wastes such as rework time, inspection time, move time, and wait time are non-value adding activities (Koskela, 1992). While process time is subject to wastes resulting from overproduction, wrong construction method, defects, and poor optimization in performing tasks (Pheng & Tan, 1998).

Many examples of wastes in construction and their effects were introduced by many researchers. Around 10% of total purchased materials are considered wastes (by weight) in the Dutch construction industry, while this percentage may reach 20:30% in Brazilian construction industry (Akintoye, 1995; Bossink & Brouwers, 1996). Controllable wastes can be divided into three different activities, 1- Controllable causes associated with flows 2- Controllable causes associated with conversions and 3- Controllable causes associated with management activities (Alarcón, 1994, 1997). Many causes of wastes are summarized in the construction industry in many countries (Issa, 2013; Aziz & Hafez, 2013). More recent researchers explored causes of wastes. Nine wastes were identified and their causes were explored underlying tensions, and overall relationship to the waste taxonomy that found in a Lean Software Development (Sedano et al., 2017). A Cause-effect relationship between the design choices and construction wastes generation diagnosis was also identified (de Magalhães et al., 2017). Based on a survey that carried out in India, 23 out of 30 major causes of wastes can be effectively eliminated through 13 identified IT applications. The remaining causes of wastes necessitate management intervention for their mitigation (Singh et al., 2017).

Construction projects in KSA represent large investments value (Alsulami et al., 2015). It has perceived a huge increase in construction during the last two decades (Sarhan et al., 2017). KSA as a developing country faces many problems in the construction industry such as time delays, cost overruns and the generation of massive amounts of waste which resulted in the effect of many wastes (Sarhan et al., 2017). The lack of detailed and documented previous data concern causes of wastes in KSA represents another problem. This study aims to identify the causes of wastes in KSA.
construction industry as well as which of them are controllable or not. The aims extend for grouping the causes of wastes based on the responsibility. The effect of using the lean technique on the identified causes and groups are conducted. The strategy used is based on multi-stages field surveys in KSA construction industry.

MANAGING WASTES USING LEAN TECHNIQUES IN CONSTRUCTION

Lean construction consists of a series of flow conversion activities (Koskela, 1992). Lean construction was taken from lean production that can be traced to Toyota Production System (TPS), with its focus on the reduction and elimination of waste (Ohno, 1998). The term lean was first introduced by International Motor Vehicle Program (IMVP) in 1988 (Krafcik, 1988). Though different researchers have their own interpretation of lean, the most common among them is a “production practice that considers the expenditure of resources for any goal other than the creation of value for the end customer to be wasteful, and thus a target for elimination”. However, the most suitable definition can be addressed as “A philosophy that when implemented reduces the time from customer order to delivery by eliminating sources of waste in production flow” (Bhasin & Burcher, 2006).

Construction is a different type of production. It is characterized by greater uncertainty and flow variation than manufacturing. However, construction processes have many similarities with manufacturing processes. For example, from the production point of view, crew tasks within construction activities have equivalent roles similar to machine tasks in manufacturing processes. Accordingly, many production theories could be applied to construction processes under similar principles (Chua et al., 2001). Lean construction deals with construction projects activities as a flow that must generate value to the customer (Santos et al., 1998). Finally, the Lean construction can be defined as a production management strategy for achieving significant continuous improvement, in the performance of the total business process of a contractor through minimizing of 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).

Lean techniques were implemented in many fields of construction projects. One of the famous lean techniques is Last Planner System (LPS). A study in a construction project in Quito, Ecuador was introduced to disseminate the results obtained from an application of LPS (Fiallo & Revelo, 2002). LPS was also utilized in twelve Chilean construction companies in construction companies (Alarcón et al., 2002). Lean concepts and techniques were implemented in manufacturing and management of fabrication processes (Ballard et al., 2002). The lean techniques were used in risk minimizing through implementing LPS in a construction case study in Egypt (Issa, 2013). A field study was conducted to evaluate the effectiveness of some lean construction techniques including LPS, increased visualization, daily huddle meetings, first run studies, the 5s process, and fail-safe for quality (Salem et al., 2006). Many construction methods were evaluated in India and USA by analyzing the methods of minimum wastage and implementation of lean practices (Vedangi, 2016). Recently, lean techniques have been used in Virtual Design and Construction (VDC). A performance model that assess VDC implementation strategies was presented, including lean management as a moderator in companies (Mandujano et al., 2017a) Lean techniques can be used in reducing wastes within the VDC process, in the phase of information flow (Mandujano et al., 2017b).

OBJECTIVES OF STUDY

The main objectives of this study can be summarized as follows:

- To identify the causes of wastes in KSA construction projects and which of them are controllable or uncontrollable.
- To ascertain who is responsible for each cause of waste and categorizing them into groups based on the responsibility.
- To measure the level of lean effect on the identified controllable causes of wastes. Figure (1) summarizes the expected deliverables from this study.

![Figure 1. The main deliverables of the study](image)

RESEARCH METHODOLOGY

The research methodology of this study adopted three phases. In the first one, the researchers reviewed a checklist for causes of wastes through a wide-ranging literature review. Series of Semi-structured interviews regarding the causes of wastes were conducted by professionals in the field of construction projects in KSA. The purpose of these interviews was preparing final causes of wastes list of which largely found in KSA construction industry as well as their controllability. The controllable causes were categorized into four groups based on the responsibility. The output list of the controllable causes under responsible groups will be used in a questionnaire form in the second phase. The main purpose of the second phase was to obtain data concerning the importance of each cause of wastes.
waste based on knowledge available from the professionals in the KSA construction industry. The collected data from questionnaires feedback was analyzed and two ranking agreement tests were applied to ensure that the data collected have a high level of agreement among partners. In the final phase, two brainstorming sessions were conducted for the reason of determining the effect of using lean techniques on causes of wastes.

**Causes of Wastes in KSA Construction Projects**

As explained before, a preliminary list of many causes of wastes in KSA construction industry was prepared based on intensive literature review. A list of widely-reported causes of wastes was prepared using previous studies for factors or causes of wastes in many countries (Alarcón, 1994; Issa, 2013; Sarhan et al., 2017; Graham & Smithers, 1996; Lee et al., 1999). For simplifying giving and receiving data as well as allowing for conversational and two-way communication, the semi-structured interviews were selected to be conducted at this stage (Mosaad et al., 2018) The main objectives of these interviews were to identify the causes of wastes by filtering the preliminary list through adding, merging or writing off causes of wastes to describe the current situation in KSA construction industry. Grouping causes of wastes due to responsibilities is also one of the main objectives in this stage. The output is a final list of causes of wastes under groups due to responsibilities to be used in forming a questionnaire in next step. After the preliminary interviews were conducted, the causes of wastes and the responsibility for each one were identified. Table (1) summarizes the identified causes of wastes based on the four responsible groups.

It is clear that from table (1), the total identified causes of wastes are 46. Four of them are categorized as uncontrollable, while the remaining 42 are controllable and categorized due to responsibility under four groups (owners, consultants, contractors and common). The consultants are responsible for only 4 causes of wastes, while both owners and contractors are responsible for 10 causes of wastes. The responsibility is common for the remaining 18 causes of wastes.

The second phase that was described in the methodology included preparing the final questionnaire form. A questionnaire was designed using the proposed 42 controllable causes of wastes (listed in Table 1). The questionnaire is a famed procedure which is widely used in project and construction management research (Shen et al., 2001; Thomas et al., 2003; Issa & aly, 2014).

<table>
<thead>
<tr>
<th>Table1</th>
<th>THE IDENTIFIED CAUSES OF WASTES BASED ON RESPONSIBLE GROUPS.</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>Causes of Wastes in construction projects in KSA due the responsible</td>
</tr>
<tr>
<td>1</td>
<td>Client slow response and slow decision-making mechanism</td>
</tr>
<tr>
<td>2</td>
<td>Problems in Client’s organization such as bureaucracy and lack of specialists</td>
</tr>
<tr>
<td>3</td>
<td>Delay in running bill payments to the contractor or consultant</td>
</tr>
<tr>
<td>4</td>
<td>Client’s special needs such as additional works and change order</td>
</tr>
<tr>
<td>5</td>
<td>Deficiencies and changes in project scope</td>
</tr>
<tr>
<td>6</td>
<td>Contractor selection before consultant decision</td>
</tr>
<tr>
<td>7</td>
<td>Unfairness in tendering or method of contractor choice</td>
</tr>
<tr>
<td>8</td>
<td>Client’s representative problem</td>
</tr>
<tr>
<td>9</td>
<td>Starting execution although project documents are not completed</td>
</tr>
<tr>
<td>10</td>
<td>Lack in project financing</td>
</tr>
<tr>
<td>11</td>
<td>Consultant’s responsibility</td>
</tr>
<tr>
<td>12</td>
<td>Delay in reviewing or approving design documents</td>
</tr>
<tr>
<td>13</td>
<td>Delay samples approval, inspections as well as making decisions</td>
</tr>
<tr>
<td>14</td>
<td>Lack of consultant’s experience in design, supervision and quality control</td>
</tr>
<tr>
<td>15</td>
<td>Poor integrated organization structure for consultant</td>
</tr>
<tr>
<td>16</td>
<td>Poor management team in performance such as late request for inspections or poor site management</td>
</tr>
<tr>
<td>17</td>
<td>Workers problems such as inadequate motivation or improper accommodations</td>
</tr>
<tr>
<td>18</td>
<td>Unskilled workers and poor labor productivity</td>
</tr>
<tr>
<td>19</td>
<td>Delay in delivery of materials to site</td>
</tr>
<tr>
<td>20</td>
<td>Problems resulted in interference among different subcontractor’s</td>
</tr>
<tr>
<td>21</td>
<td>Delay of regulatory reporting</td>
</tr>
<tr>
<td>22</td>
<td>Execution errors that lead to rework</td>
</tr>
<tr>
<td>23</td>
<td>Poor evaluation for contract items, tendering documents, and quantities as well as poor scope definition</td>
</tr>
<tr>
<td>24</td>
<td>Inadequate modern equipment and low productivity level</td>
</tr>
<tr>
<td>25</td>
<td>Dispute resolution delay or lack of dispute resolution methods</td>
</tr>
<tr>
<td>26</td>
<td>Poor distribution of personnel</td>
</tr>
<tr>
<td>27</td>
<td>Material wastes either due to poor design or poor execution</td>
</tr>
<tr>
<td>28</td>
<td>Familiarity with site conditions, location and project complexity</td>
</tr>
<tr>
<td>29</td>
<td>Delay due to administrative approvals</td>
</tr>
<tr>
<td>30</td>
<td>Poor site safety</td>
</tr>
<tr>
<td>31</td>
<td>Inadequate specification and shortage of design data</td>
</tr>
<tr>
<td>32</td>
<td>Changes in core team</td>
</tr>
<tr>
<td>33</td>
<td>Language barriers</td>
</tr>
<tr>
<td>34</td>
<td>Variations of actual quantities of work compared with quantities in bidding documents and underestimation of cost</td>
</tr>
<tr>
<td>35</td>
<td>Supplying poor quality materials</td>
</tr>
<tr>
<td>36</td>
<td>Complete familiarity with systems and laws in KSA</td>
</tr>
<tr>
<td>37</td>
<td>Conflicts, poor communication and coordination among contractor and other parties</td>
</tr>
<tr>
<td>38</td>
<td>Unavailability of qualified sub-contractors</td>
</tr>
<tr>
<td>39</td>
<td>Truthfulness of contractor or consultant to get a big gain</td>
</tr>
<tr>
<td>40</td>
<td>Side effects due to project activities</td>
</tr>
<tr>
<td>41</td>
<td>Scheduling errors and actual execution duration is greater than duration in tender</td>
</tr>
<tr>
<td>42</td>
<td>Inadequate definition for authority or responsibility as well as supervision overlapping</td>
</tr>
<tr>
<td>43</td>
<td>Force majeure such as (Flash Flood, Earthquake, Fire, wind damage, lightning, soil conditions and landslide)</td>
</tr>
<tr>
<td>44</td>
<td>Severe weather conditions</td>
</tr>
<tr>
<td>45</td>
<td>Fluctuations in the resources prices (materials, laborers,.....)</td>
</tr>
<tr>
<td>46</td>
<td>Unforeseen site conditions such as soil conditions, groundwater,.....</td>
</tr>
</tbody>
</table>

**Sample Composition**

The questionnaires were dispatched to 165 experts (different nationalities but working in the KSA) who had adequate experiences in supervision and execution of construction projects in KSA. Data were collected from October 2017 to January 2018. The experts were asked to respond with respect to the importance level for each cause of waste based on their experiences. The completed questionnaires were delivered to the authors in person or via online questionnaire. The respondents fell into three categories: owners, consultants and contractors. The total number of respondents was 109. Of the 109 returned questionnaires, 34 out of 49 questionnaires were received from owners, 33 out of 51 from consultants, and 42 out of 65 questionnaires were received from contractors, as
shown in Table (2). The response rates were 69.4%, 64.4%, and 64.6% from owners, consultants, and contractors respectively. The frequency of participation is shown in figure (2). Referring to the figure, 31% of the questionnaires were completed by owners, 30% were completed by consultants, and 39% were completed by contractors.

The components of the questionnaire included two sections; the first one was to acquire general information of the respondents, while the second section was specialized to measure the importance of causes of wastes in KSA construction projects. The respondents were asked to select one of five levels for the importance of each cause of waste (very important, important, medium important, low important and not important). More explanations about these levels will be introduced in next sections and their relations by relative importance index calculations.

<table>
<thead>
<tr>
<th>Table 2. Questionnaire returns rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respondents</td>
</tr>
<tr>
<td>Questionnaire distributed</td>
</tr>
<tr>
<td>Responses received</td>
</tr>
<tr>
<td>Response rate (%)</td>
</tr>
</tbody>
</table>

Figure 2. Questionnaire Frequency of Participation

Respondents’ Qualifications
The strength of respondents’ qualifications indicates the degree of reliability of the data provided by them. This will be provided by the actual experiences in construction project as well as high certificates such as (M.Sc., Ph.D., consulting or PMP certificate). In this study, 25% of the professionals who participated in the survey had had over 20 years’ in executing or supervising construction projects. Approximately, 22% of the respondents’ acquired high certificates. The years of experiences and a high percentage of certificates increase the reliability of the collected data. Additionally, to ensure that the survey results were credible, any replies from respondents with less than five years of experience were discarded. As shown in table (3), 32.10% had 15-20 years of relevant experience, 22% of the respondents had between 10 to 15 years of relevant experience, and the rest of the respondents (21.10%) had 5-10 years of relevant experience. The average relevant experience of all respondents was 16.14 years; thus, the opinions are thought to reflect the real situation in this field.

<table>
<thead>
<tr>
<th>Table 3. Years of Experience for the Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Years of experience</td>
</tr>
<tr>
<td>No of respondents</td>
</tr>
<tr>
<td>Percent from sample</td>
</tr>
</tbody>
</table>

Causes of Wastes Relative Importance
The analysis of all the identified causes was conducted to determine the relative importance of each cause of waste. The Cause of Waste Relative Importance Index (CWRII) was introduced to qualify and rank the causes of wastes for the purpose of highlighting the most important of them before implementing the lean techniques.

CWRII was determined for the three participants (owners, contractors, and consultants). The collected data from this section of the questionnaire concerns the identified causes in a five-level format as

\[ CWRII = \frac{\sum R_i N_i}{\sum N_i} \]

(1)

Where:
- \( R_i \) is the importance weight, and equal to 0.9, 0.7, 0.5, 0.3, and 0.1 for \( i = 5,4,3,2, \) and 1, respectively; \( N_i \) is the number of participants who responded to option \( i. \) \( i = 1, 2, 3, 4, 5; N_5 \) is a cause of waste expressing the frequency of the \( i^{th} \) response (ranging between \( N_1 \)=frequency of the ‘not important’ response, and \( N_5 \)=frequency of the ‘very important’ response)

Agreement Analysis using Spearman and Kendall correlations
Due to the variations of the results for each of the three participant groups (owners consultants, and contractors), it is important to get standardized results as well as check the level of agreement among the participants. Therefore, the results can be displayed as a summary of the findings. Spearman’s and Kendall’s correlation coefficient tests are two famous measures of non-parametric rank correlations that are used to discover the strength of a link between any two sets of data. Both correlation coefficients vary from -1 to +1 (Chen & Popovich, 2002; Liebetrau, 1976). A value of ±1 indicates a perfect degree of association between two groups. As the correlation coefficient value drops towards 0, the relationship
between the two groups will be weaker. The (+) sign indicates a positive relationship, while (−) sign indicates a negative relationship. The Spearman’s coefficient can be 1 not only for linearly related variables but also some types of non-linear relationship. However, Kendall’s coefficient can be 1 for even a wider range of scenarios than Spearman’s correlation coefficient. SPSS software was used to calculate both correlation coefficients. Figure (3) shows that there is a high degree of agreement amongst the three participant groups on the level of CWRII. Therefore, further attempts to analyze the problems faced by the different groups of participants were not necessary. All results were positive, which implied good agreements among the different groups. Consequently, the analysis was based on data from all the respondents.

Figure 3. Spearman’s and kendall correlation coefficients for ranking cwrii due to different pairs of groups.

However, referring to figure (3), it is perceived that the strongest relationship was between owners and consultants, with a coefficient value of 0.87 for spearman and 0.70 for Kendall. This result reflects the great agreement between the owners and the consultants related to identifying the causes of wastes. On the other hand, the weakest relationship was between consultants and contractors with a coefficient value of 0.80 for spearman and 0.62 for Kendall even it is still positive. These positive and high values results that obtained from both methods confirm that the results signify high agreements. Difference between any two groups does not exceed 8% and 12% for Spearman and Kendall methods respectively.

RESULTS, DISCUSSION AND ANALYSIS

Ranking Analysis

The ranking analysis is conducted based on the results of agreement tests among the three groups that previously explained. The analysis for ranking causes of wastes in KSA construction projects was presented based on to the total number of respondents. Table (4) through Table (7) summarize the overall ranking for each cause of waste as well as ranking inside the responsibility group.

From these tables, many causes are observed to have high ranks. For example, the cause of waste No. 27 which was expressed as “Material wastes due to poor design or poor execution” appears as a first in order inside common’s responsibility group as well as overall rank with a highest CWRII value of (0.78). It is followed by cause No. 6 which was “Contractor selection before consultant” with CWRII value of (0.77) which is the first in order in owner’s responsibility group and second in overall rank. Causes No. 1 and 4 belong owner’s responsibility group and come in third and fourth orders in overall ranking with CWRII values 0.76 and 0.75 respectively. The fifth and sixth causes of wastes in the overall rank come from the contractor and common groups respectively.

One of the most important observations that all CWRII in consultant’s responsibility group have low values (from 0.45 to 0.52). In spite of their importance, they do not occupy high order in ranking (their ranks range from 21 to 31). This refers to the low responsibility of consultants if compared to other groups.

Table 4

<table>
<thead>
<tr>
<th>No</th>
<th>ランキング</th>
<th>ranking causes of wastes based on consultant’s responsibility</th>
<th>consultant’s responsibility</th>
<th>Owners</th>
<th>Consultants</th>
<th>Contractors</th>
<th>Average</th>
<th>Group</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Contractor selection before consultant</td>
<td>0.89</td>
<td>0.90</td>
<td>0.90</td>
<td>0.89</td>
<td>1</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Client slow response and slow decision-making mechanism</td>
<td>0.87</td>
<td>0.85</td>
<td>0.85</td>
<td>0.87</td>
<td>2</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Client’s special needs such as additional works and change order</td>
<td>0.66</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>3</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Starting cation although project documents are not completed</td>
<td>0.67</td>
<td>0.69</td>
<td>0.69</td>
<td>0.72</td>
<td>4</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Lack in project financing</td>
<td>0.59</td>
<td>0.67</td>
<td>0.67</td>
<td>0.69</td>
<td>5</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Delay in making bill payments to the contractor or consultant</td>
<td>0.53</td>
<td>0.64</td>
<td>0.64</td>
<td>0.66</td>
<td>6</td>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Deficiencies and changes in project scope</td>
<td>0.46</td>
<td>0.63</td>
<td>0.63</td>
<td>0.63</td>
<td>7</td>
<td>19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Problems in Client’s organization such as bureaucracy and lack of specialists</td>
<td>0.40</td>
<td>0.53</td>
<td>0.53</td>
<td>0.48</td>
<td>8</td>
<td>27</td>
<td></td>
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</tr>
<tr>
<td>9</td>
<td>Client’s representative problems</td>
<td>0.35</td>
<td>0.49</td>
<td>0.61</td>
<td>0.41</td>
<td>9</td>
<td>33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Unavoidable wastes of labor and equipment</td>
<td>0.25</td>
<td>0.33</td>
<td>0.41</td>
<td>0.33</td>
<td>10</td>
<td>37</td>
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</table>

Table 5

<table>
<thead>
<tr>
<th>No</th>
<th>ランキング</th>
<th>ranking causes of wastes based on owner’s responsibility</th>
<th>owner’s responsibility</th>
<th>Owners</th>
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<td>3</td>
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<tr>
<td>2</td>
<td>Client slow response and slow decision-making mechanism</td>
<td>0.87</td>
<td>0.85</td>
<td>0.85</td>
<td>0.87</td>
<td>2</td>
<td>3</td>
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<td>3</td>
<td>Client’s special needs such as additional works and change order</td>
<td>0.66</td>
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<td>0.67</td>
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<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Delay in making bill payments to the contractor or consultant</td>
<td>0.53</td>
<td>0.64</td>
<td>0.64</td>
<td>0.66</td>
<td>6</td>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Deficiencies and changes in project scope</td>
<td>0.46</td>
<td>0.63</td>
<td>0.63</td>
<td>0.63</td>
<td>7</td>
<td>19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Problems in Client’s organization such as bureaucracy and lack of specialists</td>
<td>0.40</td>
<td>0.53</td>
<td>0.53</td>
<td>0.48</td>
<td>8</td>
<td>27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Client’s representative problems</td>
<td>0.35</td>
<td>0.49</td>
<td>0.61</td>
<td>0.41</td>
<td>9</td>
<td>33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Unavoidable wastes of labor and equipment</td>
<td>0.25</td>
<td>0.33</td>
<td>0.41</td>
<td>0.33</td>
<td>10</td>
<td>37</td>
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<td></td>
</tr>
</tbody>
</table>

Table 6

<table>
<thead>
<tr>
<th>No</th>
<th>ランキング</th>
<th>ranking causes of wastes based on contractor’s responsibility</th>
<th>contractor’s responsibility</th>
<th>Owners</th>
<th>Consultants</th>
<th>Contractors</th>
<th>Average</th>
<th>Group</th>
<th>Rank</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Contractor selection before consultant</td>
<td>0.89</td>
<td>0.89</td>
<td>0.89</td>
<td>0.89</td>
<td>1</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Client slow response and slow decision-making mechanism</td>
<td>0.87</td>
<td>0.85</td>
<td>0.85</td>
<td>0.87</td>
<td>2</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Client’s special needs such as additional works and change order</td>
<td>0.66</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>3</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Starting cation although project documents are not completed</td>
<td>0.67</td>
<td>0.69</td>
<td>0.69</td>
<td>0.72</td>
<td>4</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Lack in project financing</td>
<td>0.59</td>
<td>0.67</td>
<td>0.67</td>
<td>0.69</td>
<td>5</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Delay in making bill payments to the contractor or consultant</td>
<td>0.53</td>
<td>0.64</td>
<td>0.64</td>
<td>0.66</td>
<td>6</td>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Deficiencies and changes in project scope</td>
<td>0.46</td>
<td>0.63</td>
<td>0.63</td>
<td>0.63</td>
<td>7</td>
<td>19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Problems in Client’s organization such as bureaucracy and lack of specialists</td>
<td>0.40</td>
<td>0.53</td>
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<td>0.48</td>
<td>8</td>
<td>27</td>
<td></td>
<td></td>
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<td>9</td>
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<td>0.49</td>
<td>0.61</td>
<td>0.41</td>
<td>9</td>
<td>33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Unavoidable wastes of labor and equipment</td>
<td>0.25</td>
<td>0.33</td>
<td>0.41</td>
<td>0.33</td>
<td>10</td>
<td>37</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
It is clear from figure (4) that the widest range of CWRII values is for the common group with a total length of 0.54. The most important cause of waste due to CWRII value is included in this group as well as the least important one (causes No. 27 with first overall rank, and cause No. 36 with latest overall rank). Notably, the common group includes maximum numbers of causes (18). The wide range of causes' values and the number of causes refer to the common responsibility of all parties.

Referring to figure (4), there are no causes of wastes are located outliers. Once there are no outliers, a Convergence Percent (CP) can be determined for each group using equation (2)

$$CP = \frac{CWRII_{max} - CWRII_{min}}{number of causes \%} \quad (2)$$

The results using the last equation are summarized in figure (5). The CP value for the common group is only 3% which reflects a convergence of CWRII values among causes of wastes in this group. Figures (4) and (5) show that the Owner's responsibility group range is 0.44 and its CP is the maximum one with a value of 4.4%. This large percentage is due to the wide range related to its cause's numbers (10). The contractors' group occupies the third rank in responsibility due to its range (0.41) and CP = 4.07%. Although the range of contractors and owners are close in values, the length of owners is longer than contractors. Finally, the consultants' group has the least numbers of causes (only 4), with a range of 0.07 and CP = 1.58. This reflects a high convergence among the causes although their limited numbers.

![Convergence percent values for all responsibilities groups](image_url)
proposed levels of lean effect on causes of wastes were (Affected by lean, Partially affected by lean and, Not affected by lean). These sessions were carried out with three consultants engineers and three project managers, with practical experience in executing and supervising these types of projects. Table (8) through table (11) and figure (6) summarize the effect of lean on each identified cause of waste under its responsibility group.

Table 8. The Lean effect on causes of wastes for owner’s responsibility group

<table>
<thead>
<tr>
<th>No</th>
<th>Owner’s responsibility</th>
<th>lean effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Client slow response and slow decision-making mechanism</td>
<td>Affected</td>
</tr>
<tr>
<td>2</td>
<td>Problems in Client’s organization such as bureaucracy and lack of specialists</td>
<td>Affected</td>
</tr>
<tr>
<td>3</td>
<td>Delay in running bill payments to the contractor or consultant</td>
<td>Partially affected</td>
</tr>
<tr>
<td>4</td>
<td>Client’s special needs such as additional works and change order</td>
<td>Affected</td>
</tr>
<tr>
<td>5</td>
<td>Deficiencies and changes in project scope</td>
<td>Partially affected</td>
</tr>
<tr>
<td>6</td>
<td>Contractor selection before consultant</td>
<td>Partially affected</td>
</tr>
<tr>
<td>7</td>
<td>Unfairness in tendering or method of contractor choice</td>
<td>Not affected</td>
</tr>
<tr>
<td>8</td>
<td>Client’s representative problems</td>
<td>Affected</td>
</tr>
<tr>
<td>9</td>
<td>Starting execution although project documents are not completed</td>
<td>Affected</td>
</tr>
<tr>
<td>10</td>
<td>Lack in project financing</td>
<td>Not affected</td>
</tr>
</tbody>
</table>

As a result of these sessions, 24 causes are considered to be affected by lean techniques and 13 will be partially affected while the remaining 5 causes will not be affected by lean techniques. From the observations, it is noticed that the 5 causes of wastes which will not be affected by using lean techniques are: 1- Unfairness in tendering or method of contractor choice (CWRII = 0.33), 2- Lack in project financing (CWRII = 0.72), 3- Workers problems such as inadequate motivation or improper accommodations (CWRII =0.47), 4- Familiarity with site conditions, location and project complexity (CWRII = 0.33), and 5- Complete familiarity with systems and laws in KSA (CWRII = 0.24). Except “Lack in project financing” cause of waste which has high CWRII value, the remaining 4 causes of wastes have low values. This confirms the importance of using the lean techniques in minimizing wastes and increasing productivity.

Table 9. The Lean effect on causes of wastes for consultant’s responsibility group

<table>
<thead>
<tr>
<th>No</th>
<th>Consultant’s responsibility</th>
<th>lean effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Delay in reviewing or approving design documents</td>
<td>Affected</td>
</tr>
<tr>
<td>12</td>
<td>Delay samples approval, inspections as well as making decisions</td>
<td>Affected</td>
</tr>
<tr>
<td>13</td>
<td>Lack of consultant’s experience in design, supervision and quality control</td>
<td>Partly affected</td>
</tr>
<tr>
<td>14</td>
<td>Poor integrated organization structure for consultant</td>
<td>Partly affected</td>
</tr>
</tbody>
</table>

Table 10. The Lean effect on causes of wastes for contractor's responsibility group

<table>
<thead>
<tr>
<th>No</th>
<th>Contractor's responsibility</th>
<th>lean effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>Inadequate experiences of contractor</td>
<td>Partially affected</td>
</tr>
<tr>
<td>16</td>
<td>Poor management team in performance such as late request for inspections or poor site management</td>
<td>Affected</td>
</tr>
<tr>
<td>17</td>
<td>Workers problems such as inadequate motivation or improper accommodations</td>
<td>Not affected</td>
</tr>
<tr>
<td>18</td>
<td>Unskilled workers and poor labor productivity</td>
<td>Affected</td>
</tr>
<tr>
<td>19</td>
<td>Delay in delivery of materials to site</td>
<td>Affected</td>
</tr>
<tr>
<td>20</td>
<td>Problems resulted in interference among different subcontractor's</td>
<td>Affected</td>
</tr>
<tr>
<td>21</td>
<td>Delay of regulatory reporting</td>
<td>Affected</td>
</tr>
<tr>
<td>22</td>
<td>Execution errors that lead to rework</td>
<td>Affected</td>
</tr>
<tr>
<td>23</td>
<td>Poor evaluation for contract items, tendering documents, and quantities as well as poor scope definition</td>
<td>Partially affected</td>
</tr>
<tr>
<td>24</td>
<td>Inadequate modern equipment and low productivity level</td>
<td>Affected</td>
</tr>
</tbody>
</table>
Table 11: The Lean effect on causes of wastes for common's responsibility group

<table>
<thead>
<tr>
<th>No</th>
<th>Common responsibility</th>
<th>Lean effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>Dispute resolution delay or lack of dispute resolution methods</td>
<td>Affected</td>
</tr>
<tr>
<td>26</td>
<td>Poor distribution of personnel</td>
<td>Affected</td>
</tr>
<tr>
<td>27</td>
<td>Material wastes either due to poor design or poor execution</td>
<td>Affected</td>
</tr>
<tr>
<td>28</td>
<td>Familiarity with site conditions, location and project complexity</td>
<td>Not affected</td>
</tr>
<tr>
<td>29</td>
<td>Delay due to administrative approvals</td>
<td>Partially affected</td>
</tr>
<tr>
<td>30</td>
<td>Poor site safety</td>
<td>Affected</td>
</tr>
<tr>
<td>31</td>
<td>Inadequate specifications and shortage of design data</td>
<td>Affected</td>
</tr>
<tr>
<td>32</td>
<td>Changes in core team</td>
<td>Affected</td>
</tr>
<tr>
<td>33</td>
<td>Language barriers</td>
<td>Partially affected</td>
</tr>
<tr>
<td>34</td>
<td>Variations of actual quantities of work compared with quantities in bidding documents and underestimation of cost</td>
<td>Partially affected</td>
</tr>
<tr>
<td>35</td>
<td>Supplying poor quality materials</td>
<td>Affected</td>
</tr>
<tr>
<td>36</td>
<td>Complete familiarity with systems and laws in KSA</td>
<td>Not affected</td>
</tr>
<tr>
<td>37</td>
<td>Conflicts, poor communication and coordination among contractor and other parties</td>
<td>Affected</td>
</tr>
<tr>
<td>38</td>
<td>Unavailability of qualified sub-contractors</td>
<td>Partially affected</td>
</tr>
<tr>
<td>39</td>
<td>Truthfulness of contractor or consultant to get a big gain</td>
<td>Partially affected</td>
</tr>
<tr>
<td>40</td>
<td>Side effects due to project activities</td>
<td>Partially affected</td>
</tr>
<tr>
<td>41</td>
<td>Scheduling errors and actual execution duration is greater than duration in tender</td>
<td>Affected</td>
</tr>
<tr>
<td>42</td>
<td>Inadequate definition for authority or responsibility as well as supervision overlapping</td>
<td>Affected</td>
</tr>
</tbody>
</table>

Figure 6. The percent of lean effect on causes of wastes in KSA construction projects.

The cumulative percentage of the lean effect is shown in figure (7). Causes of wastes that affected by lean represent about 57% from all causes, and causes of wastes that partially affected by lean signify 31%. The accumulated percentage of causes of wastes that affected completely or partially is attained 88% which confirms the importance of using lean techniques in KSA construction projects. The remaining 12% of causes which will not be affected by lean is considered low percent.

Figure 7. The cumulative percentage through pareto chart for lean effect on causes of wastes.

The effect of lean techniques based on responsibility groups is summarized in figure (8). It is clear that the maximum number of causes that affected by lean is under common responsibility followed by contractor, and owner. Moreover, the causes that partially affected by lean due to common responsibility represent the large number, followed by owner and contractors. Causes of wastes that not affected by lean are the same for common and owners (2 causes for each group) and
one cause belongs contractors group. There are no causes of wastes will not be affected by lean under consultant responsibility.

5-Twenty four causes of wastes were expected to be affected by lean techniques if implemented in KSA construction projects while thirteen causes of wastes are expected to be partially affected. On the contrary, there is no expected lean effect on five causes of wastes.

6-The maximum number of causes that will be affected by lean was under common's responsibility followed by contractor, and owner.

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REFERENCES


