Journal of Civil & Environmental Engineering

Nasrollahzadeh, et al., J Civil Environ Eng 2016, 6:5
DOI: 10.4172/2165-784X.1000247

Research Article | Open Access

Critical Success Factor for Industrialized Building System Process Protocol Map by Lean Construction management

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Abstract

This paper is exploring the process protocol map in industrialized building systems. Several critical success factors were identified and classified in seven groups namely; just-in-time factors, total quality management factors, business process reengineering factors, concurrent engineering factors, last planner system factors, teamwork factors and value based management factors. Using the Delphi technique, factors were established first by experts of construction projects. Afterward, the groups of factors were confirmed by the construction industry experts using the questionnaires based on Fuzzy AHP techniques for factors comparison. Based on the results the lean construction critical success factors are concurrent engineering and just in time factors respectively, which are the most important critical success factors in lean construction projects according to the industrialized building system process protocol map.

Keywords: Fuzzy AHP; Industrialized Building System (IBS); Lean construction; Process protocol map

Introduction

Industrialized Building System (IBS) is one of the technology which can be categorized as an old in developed country but yet considered as a key technology when reached developing countries such as Asian region [1]. Several world major construction industry authorities have recommended the industry to extend the use of modern construction methods and information technology. Specifically, the use of mechanization in construction that leads to the production of Industrialized Building System (IBS) may help to ease the pressures of labour requirements whilst boosting quality and productivity [2]. Badir et al. [3] defined IBS as "technology is the mass factory-produced building components off-site, then they are properly assembled and joined on-site to form the final units". The five standard characteristics of IBS are prefabrication, offsite production, mass production, standardized components and design using modular coordination [4]. One of the other improvement methods or philosophy in construction had been developed by others to overcome the efficiency of construct such as lean construction [5]. Lean Construction is a philosophy based on the concepts of lean production which is developed by Toyota production system. It specifically mentioned that the machine have changed the world [6]. Womack et. Al [7] suggested that lean production is able to reduce the overall cost especially the indirect cost while still maintaining the quality standards and reducing manufacturing cycle time. This paper is to identify the critical success factor in implementation of Lean in construction with specifically focusing on the Industrialized Building System (IBS) method of constructing the building. The content of the paper seek the literature establishment in classifying the critical success factor (CSF) and confirmed it by the experts. The weights of seven groups of CSFs are then analyzed using Fuzzy Analytical Hierarchy process and concluded in the final sections.

Lean Construction

The definition of Lean Construction (LC)

Koskela [8] define LC as "Advantages of the new production philosophy in terms of productivity, quality, and indicators were solid enough in practice in order to enhance the rapid diffusion of the new principles". Howell [9] and Lukowski [10] reflected Koskelas's definition and make a link between them. They defined LC is the practical application of lean manufacturing principles, or lean thinking, to the building environment. Yahya and Mohamad [11] emphasized to the elimination of construction waste. They defined LC as "Lean construction is about managing and improving the construction process to profitability in delivering what the customer needs by eliminating waste in the construction flow by the use of right principle, resources and measure to deliver things right first time".

Process protocol map

The Generic Design and Construction Process Protocol were created by the University of Salford in 1998 in an attempt to improve the prevailing situation. It is a high-level process map that aims to provide a framework to help companies achieve an improved design and construction process. The map was drawn from the principles developed within the manufacturing industry that include stakeholder involvement, teamwork and feedback. It reconstructs the design and construction team in terms of Activity Zones rather than in disciplines to create a cross-functional team. These Activity Zones are multi-functional and may consist of a network of disciplines to enact a specific task of the project, allowing the 'product' to drive the process rather than the function as in a sequential approach. The concept of the Process Protocol was based on a number of issues and deficiencies of the current practices in the construction industry. This enabled the identification of areas for improvement by examining and comparing best practice in manufacturing project processes [12].

The process protocol elements

The process protocol is divided into four main stages as follows:

1. Pre-project stage: relates to the strategic business considerations of any potential, in which it aims to address a client's need.
2. Pre-construction stage: defines how the client's need is developed into an appropriate design solution.
3. Construction stage: production of the project solution.

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Received July 19, 2016; **Accepted** August 01, 2016; **Published** August 03, 2016

Citation: Nasrollahzadeh T, Marsono AK, Tap MM (2016) Critical Success Factor for Industrialized Building System Process Protocol Map by Lean Construction management. J Civil Environ Eng 6: 247. doi: 10.4172/2165-784X.1000247

4. Post-construction/completion stage: aims to continually monitor and manage the maintenance needs of the constructed facility.

According to the above mentioned stage of process, the key concepts of lean construction with process protocol map are shown in Table 1.

Critical success factors and the benefits of lean construction

According to the various researches, some critical factors of adaptation of lean construction are:

1. Improving projects delivery methods [13-16].
2. Supporting the development of team work and transfer the responsibility on the supply chain [17-19].
3. Managing uncertainties in supply [19,20].
4. Continuous improvement within projects [13,21-25].
5. Efficient use of resources [13,16,24,26].
6. Delivery of products and services [13,15,17,27,24].
7. Delivery of products and services on time and within budget [18,23,28].
8. Delivery of custom products instantly without waste [18,20,27].
9. Reduction on direct cost and time in transportation and communication [20,18].
10. Well informed business case design at all project level [17,18,21].
11. Improved quality control and minimization of risks [26,29,30].
12. Minimization of conflicts that can dramatically change budget and schedule [23].
13. Improved reliability, accountability, certainty and honesty within the project environment [15,23,31,32].

Accordingly, it can be summarized that the critical success factors of Lean Construction are highly related to the Just-In-Time factors, Total Quality Management factors, Business Process Reengineering factors, Concurrent Engineering factors, Last Planner System factors, Teamwork factors and Value Based Management factors.

Related research finding to lean construction

Gibb and Isack's [33] explain the outcomes of the interview that rated the benefits in non-direct cost terms, such as minimization of on-site operations, reduction of site congestion and project duration, and improved health and safety. Thus, although off-site production offers direct cost benefits, the main benefits are from indirect cost savings and non-cost value adding items.

Jaillon et al. discuss on the waste reduction potential of using prefabrication in building construction in Hong Kong. They found out that construction waste reduction was one of the major benefits when using prefabrication compared to conventional construction. Lim [5] identify the level of knowledge of local construction practitioners' and compare the potential barriers in implementation of lean construction in Industrialized Building System (IBS) and Conventional type of construction. He identified three potential barriers which most of the respondent's agreed and occurred very frequently on site that are (1) ineffective management practices (in conventional construction), (2) Just-in-time (JIT) delivery of materials on site (for IBS construction) and (3) "Cut and Paste" from previous project (in both conventional and IBS type of construction). Thanoon [34], Zawawi [1] also identified some factors which affect the usage of IBS type of construction. These factors are critical in IBS implementation and saying that they are the demand and the market factors, the government initiatives and also the availability of expertise in IBS construction. Noriwani [35] studied the critical success factor in adopting IBS for Malaysia construction industry. She found that the most critical success factors in adopting IBS were flexibility of IBS components, client expectancy, and market security. Meanwhile, in technical aspect, the design process was the critical factor in successful IBS adoption for construction. Sani and Fazry [36] also identified and ranked the Critical Success Factors (CSFs) for contractors in implementing lBS and also creating a project management guideline for contractor in order to implement IBS construction projects. Anuar et al. [37], mentioned that the CSFs in IBS were essentially training and education for the construction players, leadership and organization structure of the construction organization, cost management, supply chain and procurement, information technology, site management, change management, optimization, design integration, capital expenditure planning and risk assessment. Mirza [38] studying further CFSs and barriers of IBS adoption for local Malaysia industry of construction and mentioned that the flexibility of IBS and initial cost is the main factor in determining the success of IBS projects.

Methodology

The researcher first identified the several critical success factors that related to lean construction in construction process. It was identified as seven group of classification. These factors are included; just-in-time factors, total quality management factors, business process reengineering factors, concurrent engineering factors, last planner system factors, teamwork factors and value based management factors. After this classification, in next step, the identified critical success factors (CSFs) were distributed within the Delphi questionnaire among the construction experts who are divided in two groups of management and construction engineers. These two groups were asked to comment on the factors to obtain the refusal or confirmation to the group of classification. They were also asked to consider adding up some other factors in the questionnaire besides the seven classifications that has been identified before. At this stage, all factors were gathered in the library of studies and were affirmed that no new indicator will be added to previous indicators [39]. After confirming these factors as critical success factors by the experts which are participated in survey, the researcher used another questionnaire based on Fuzzy AHP techniques, to compare these factors and prioritize them from the most effective to the less critical. The analytic hierarchy process, which first proposed by Saaty, (AHP) is a decision making approach that considers both qualitative and quantitative data and combines them by decomposing ill-structured problems into systematic hierarchies to rank alternatives based on a number of criteria. This approach has become one of the most widely used multiple-criteria decision-making (MCDM) methods because it provides a proven, effective means for dealing with complex systems related to making a choice, enables the decision-maker to incorporate subjectivity, experience, and knowledge into the decision process in an intuitive and natural way and computes the weight for each criterion and the final weighted average score for each alternative. Since fuzziness and vagueness are common characteristics in many decision-making problems, a fuzzy AHP (FAHP) is used as a complement approach of CSF to develop the framework of prioritizing IBS systems [40-43].

Findings

In this survey data gathered via questionnaire survey. The questionnaire contains proposed CSF indicators and their criteria.

	Pre-project stage	Pre–construction stage (Design)	Construction	Post-construction (Use)
Just In Time	-	-	Salem et al. [46], Koskela [8]	-
Total Quality Management	-	Small et al, George and Jones [43], Summers [48]	Salem et al. [46], George And Jones [43], Summers [48]	Summers [48]
Business Process Re-Engineering	Salem et al. [46],	Salem et al. [46], George and Jones [43], Summers [48]	Salem et al. [46], George and Jones [43], Summers [48]	-
Concurrent Engineering	Koskela [8]	Koskela [8]	Koskela [8]	-
Last Planner System	-	-	Salem et al. [46]	-
Teamwork	-	-	Excellence [42]	-
Value Based Management	-	-	Bertelsen [6], Koskela [8]	Koskela [8]

Table 1: Key concepts of lean construction with process protocol map.

The questionnaires were distributed among sample and ask them for comparing the importance of each CSF indicator to another one and compare the importance of each criterion under each indicator to the other one at the same indicator. The scale used in this questionnaire is presented in Table 2. After gathering the critical success factors for implementing the Lean and existence of Lean philosophy in construction, in following the critical success factors for implementing the Lean is verified. In order to analyzing the collected data, Fuzzy AHP has been used by converting the linguistic data (qualitative data) into triangular fuzzy numbers (quantitative data) as shown in Table 3 Surveys were sent to 72 managers and engineers in 3 companies which all of them were received back. So the respond rate is approximately 100%. To calculate the final score of each indicator and criterion, the arithmetic operations between triangular fuzzy numbers is used. Then answers are analyzed by FAHP method. To simplify calculations a FAHP program which is developed by the authors is applied [44].

Note:

CSF 1: Just- In-Time factors,

CSF 2: Total Quality Management factors,

CSF 3: Business Process Reengineering factors,

CSF 4: Concurrent Engineering factors,

CSF 5: Last Planner System factors,

CSF 6: Teamwork factors,

CSF 7: Value Based Management factors.

In the next step, S_i vectors have been calculated as follows:

$$S_1=(6.67,18.29,23.23)\otimes(\frac{1}{166.02},\frac{1}{68.37},\frac{1}{29.21})=(0.04,0.27,0.79)$$

$$S_2=(2.28,8.75,21)\otimes(\frac{1}{166.02},\frac{1}{68.37},\frac{1}{29.21})=(0.01,0.13,0.72)$$

$$S_3=(2.06,7.13,17.33)\otimes(\frac{1}{166.02},\frac{1}{68.37},\frac{1}{29.21})=(0.01,0.10,0.59)$$

$$S_4=(5.16,18.29,17.33)\otimes(\frac{1}{166.02},\frac{1}{68.37},\frac{1}{29.21})=(0.03,0.27,0.59)$$

$$S_5=(5.12,12.98,25.83)\otimes(\frac{1}{166.02},\frac{1}{68.37},\frac{1}{29.21})=(0.03,0.19,0.0.88)$$

$$S6=(2.76,5.37,26.61)\otimes(\frac{1}{166.02},\frac{1}{68.37},\frac{1}{29.21})=(0.02,0.08,0.91)$$

$$S7=(5.16,10.54,34.69)\otimes(\frac{1}{166.02},\frac{1}{68.37},\frac{1}{29.21})=(0.03,0.15,1.19)$$

Then Si vectors were compared using the following formulation:

$$V(S_1\geq S_2)=1.........ifS_1\geq S_2$$

$$V(S_1\geq S_2)=\frac{l_2-u_1}{(m_1-u_1)-(m_2-u_2)}...........ifS_2\geq S_1$$

Where:

$$S_1=(l_1,m_1,u_1)$$

$$S_2=(l_2,m_2,u_2)$$

The next step is to establish the d(I) values as follows:

$$d'(I1)=MIN(S_1\geq S_2,S_3,S_4,S_5,S_6,S_7)=MIN(1,1,1,1,1,1)=1$$

$$d'(I2)=MIN(S_2\geq S_1,S_3,S_4,S_5,S_6,S_7)=MIN(0.83,1,0.83,0.92,1,0.97)=0.83$$

$$d'(I3)=MIN(S_3\geq S_1,S_2,S_4,S_5,S_6,S_7)=MIN(0.76,0.95,0.60,0.86,1,0.92)=0.60$$

$$d'(I4)=MIN(S_4\geq S_1,S_2,S_3,S_5,S_6,S_7)=MIN(1,1,1,1,1,1)=1$$

$$d'(I5)=MIN(S_5\geq S_1,S_2,S_3,S_4,S_6,S_7)=MIN(0.91,1,1,0.91,1,1)=0.91$$

$$d(I6)=MIN(S_6\geq S_1,S_2,S_3,S_4,S_5,S_7)=MIN(0.82,0.95,0.98,0.82,0.89,0.93)=0.82$$

$$d(I7)=MIN(S7\geq S_1,S_2,S_3,S_4,S_5,S_6)=MIN(0.91,1,1,0.91,0.97,1)=0.91$$

Values of d(I) make the final matrix:

$$W'=(1,0.83,0.60,1,0.91,0.82,0.91)^T$$

$$W=(0.16,0.14,0.09,0.16,0.15,0.13,0.15)$$

Thus, FAHP method priorities the following CFSs criteria as shown in Table 4.

Conclusion

A prerequisite for the successful implementation of the Lean concept in a business is that management and the experts in construction are positive about the change. Therefore, it would be interesting to investigate and identify the attitude and knowledge about the Lean Construction among the experts and management of the construction industry in the large, medium or small businesses. It would also be of interest to investigate and evaluate ways of how different forms of collaboration can be developed in the application of Lean Construction [45]. Because the organizations that cooperate, exchange information and have openness towards each other are in a better position to improve its productivity and further develop the technology. Accordingly, it can be summarized that the critical success factors of Lean Construction priority are highly related to the Concurrent Engineering, Just in Time factors, last planner system, Value Based Management, Total Quality Management, Teamwork and the Business Process Reengineering factors. Based on the results of analysis in Table 4, the “Concurrent Engineering factors” and “Just in Time factors”, respectively, are the most important CSFs in lean construction projects according to the IBS process protocol map. The last planner system and value factors with same weight is chose as second critical factors which is criteria for implementing the Lean in construction

CSFs	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	CSFs
Just- In- Time Factors	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Total Quality Management Factors
Just- In- Time Factors	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Business Process Reengineering Factors
Just- In- Time Factors	-	-	-	-	-	-	-	-	-	-	- -	-	-	-	-	-	-	Concurrent Engineering Factors,
Just- In- Time Factors	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Last Planner System Factors,
Just- In- Time Factors	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Teamwork Factors
Just- In- Time Factors	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	Value Based Management Factors
Total Quality Management Factors	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Business Process Reengineering Factors
Total Quality Management Factors	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Concurrent Engineering Factors,
Total Quality Management Factors	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Last Planner System Factors,
Total Quality Management Factors	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Teamwork Factors
Total Quality Management Factors	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	Value Based Management Factors
Business Process Reengineering Factors	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Concurrent Engineering Factors,
Business Process Reengineering Factors	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	Last Planner System Factors,
Business Process Reengineering Factors	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Teamwork Factors
Business Process Reengineering Factors	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Value Based Management Factors
Concurrent Engineering Factors,	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	Last Planner System Factors,
Concurrent Engineering Factors,	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	Teamwork Factors
Concurrent Engineering Factors,	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Value Based Management Factors
Last Planner System Factors,	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	Teamwork Factors
Last Planner System Factors,	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Value Based Management Factors
Teamwork Factors		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Value Based Management Factors

Table 2: The questionnaires which is distributed among sample.

Group of Factors	CSF 1	CSF 2	CSF 3	CSF 4	CSF 5	CSF 6	CSF 7
CSF 1	(1, 1, 1)	(1, 2.33, 3)	(3, 3.67, 5)	(0.33, 4.11, 7)	(0.14, 4.05, 7)	(0.2, 1.8,5)	(1, 1.33, 2)
CSF 2	(0.33, 0.43, 1)	(1, 1, 1)	(0.33, 1.44, 3)	(0.14, 1.78, 5)	(0.2, 1.18, 3)	(0.14, 1.8,5)	(0.14, 1, 3)
CSF 3	(0.2, 0.27, 0.33)	(0.33, 1.44, 3)	(1, 1, 1)	(0.14, 1.11, 3)	(0.14, 1.76, 5)	(0.14,1.09, 3)	(0.11, 0.45, 2)
CSF 4	(0.14, 0.24, 3)	(0.2, 4.07, 7)	(0.33, 4.11, 7)	(1, 1, 1)	(3, 3, 3)	(0.33,1.22, 3)	(0.16, 0.67, 2)
CSF 5	(0.14, 0.25, 7)	(0.33, 2.78, 5)	(0.2, 4.73, 7)	(0.33, 0.33, 0.33)	(1, 1, 1)	(3, 1.33, 5)	(0.12, 0.36, 0.5)
CSF 6	(0.2, 0.55, 5)	(0.2, 0.55, 7.14)	(0.33, 0.92, 7.14)	(0.33, 0.82, 3)	(0.2, 0.75, 0.33)	(1, 1, 1)	(0.5, 0.78, 3)
CSF 7	(0.5, 0.75, 1)	(0.33, 1, 7.14)	(0.5, 2.22, 9)	(0.5, 1.5, 6.25)	(2, 2.77, 8.3)	(0.33, 1.3, 2)	(1, 1, 1)

Table 3: Triangular fuzzy numbers extracted from questionnaire data collection.

projects. A prioritized list of CSFs was used to guide vendors to design and develop better systems and also assist managers to improve and justify existing IBS systems [46]. This approach for evaluation provides opportunity for industries and companies to concentrate on key issues and it can also offer beneficial information in strategic planning of IBS.

It should be noted that the most important aspect of effective implementation of lean construction process is training. Paton et al also noted that training is very important in the implementation of lean as it involves teaching stakeholders and practitioners of the lean tools and techniques available to them. Also, the Construction Lean Awareness Workshop (CLAW) which is held in most developed countries should be encouraged. CLAW has proven to be vital in helping companies understand the advantages and opportunities of lean construction and they have also been involved in hands on training with operatives, staff and management of companies on lean tools [47-49].

CSFs	Weight of the CSFs
concurrent engineering factors	0.16
Just- In- Time factors	0.16
Last planner system factors	0.15
Value Based Management factors	0.15
Total Quality Management factors	0.14
teamw ork factors	0.13
Business process Reengineering factors	0.09

Table 4: Final prioritizing CSFs based on the Fuzzy AHP model.

Acknowledgement

This research was supported by UTM Q. J130000.2524.04H75 Reliability Estimation for Industrial Building System (IBS).

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