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Characterization The Factors Influencing Construction Productivity Using Index System and D-S Evidence Theory

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Abstract
It is a very importance, both theoretically and practically, to create an indicator system to evaluate the factors affecting construction productivity. This paper uses the expert consultation opinion, the questionnaire survey technique, and the documentary research methods to analyze the and prioritizing influencing factors on construction productivity and evaluate it from the aspects of construction, management, special circumstances, and building the evaluation index system of those factors. Based on the principle of Dempster-Schaffer evidence theory to make group decisions by constructing a comprehensive judgment matrix (to effectively gather the opinions of experts and solve the problem of conflicting opinions, then determine the weights of the indicators through the analytical hierarchy process. In the end, an index system was obtained to evaluate the factors affecting construction productivity in Iraqi projects, including three first-level indicators/indicators, seven secondary indicators, and 56 third-level indicators, which provides theoretical guidance for project departments in order to study these factors. And work towards developing a system to effectively increase project productivity. The factor that most influenced the level of productivity was that the operators do not have the skills and experience to perform the task with comprehensive weights reached to 0.0743.

Keywords: Productivity; Factors; Construction; D-S evidence theory; Analytic hierarchy process.

الخلاصة: من الأهمية سواء من الناحية النظرية والعملية، إنشاء نظام مؤشرات لتقييم العوامل التي تؤثر على الإنتاجية الانشائية. يستخدم هذا البحث أسلوب استشارة الخبراء، وأسلوب الاستبيان، وأسلوب البحث الوثائقي لتحليل العوامل المؤثرة لتقييم العوامل المؤثرة على إنتاجية البناء من جوانب البناء والإدارة والظروف الخاصة وبناء نظام مؤشر التقييم لتلك العوامل. ; بناءً على نظرية أدلة ديمبستر-شافر، باستخدام طريقة تركيب الأدلة D-S لاتخاذ قرارات جماعية من خلال بناء مصفوفة حكم شاملة (والتي تحل بشكل فعال مشكلة تجميع آراء الخبراء)، ودمجها مع عملية التسلسل الهرمي التحليلي، حيث يتم تحديد أوزان المؤشرات . وفي النهاية تم الحصول على نظام مؤشر لتقييم العوامل المؤثرة على الإنتاجية الانشائية في المشاريع العراقية، يتضمن ثلاثة مؤشرات/مؤشرات مستوى أول، وسبعة مؤشرات ثانوية، 33 مؤشر مستوى ثالث، والذي يقدم توجيهات نظرية لأقسام المشاريع من أجل دراسة هذه العوامل. والعمل على تطوير نظام لزيادة إنتاجية المشروع بشكل فعال. وكان العامل الأكثر تأثيرا على مستوى الإنتاجية هو عدم امتلاك المشغلين للمهارات والخبرة اللازمة لأداء المهمة بأوزان شاملة وصلت إلى 0.0743.

1. INTRODUCTION

Productivity is defined as the ratio of required quality outputs to inputs [1], and productivity is an effective and vital factor in determining the ability to successfully manage construction projects by predicting financial estimates and the time duration required to perform specific operations. In previous studies, various statistical methods, such as mathematical curves, probability functions, stochastic techniques, and regression analysis, were used to predict productivity and simulate construction operations to improve management [2]. However, the accuracy of the results from using these statistical analyses is limited by several limitations, the most prominent of which is the randomness of the raw data, which ultimately leads to noisy results and unreliable modelling. Unfortunately, the results were the focus of attention for researchers who neglected to prepare the primary data properly. Therefore, it has become necessary to filter and identify problems related to the type of primary data and the preparation method before starting the analysis process. Outliers and missing data are the most common and recurring problems in raw data sets, which should be filtered, identified, and removed. Data mining is the process of obtaining useful information from large-scale data sets. Based on the above, it has become necessary to identify the factors affecting productivity, classify them, and determine which are the most influential.

In this study, an index system will be designed to evaluate the factors affecting productivity. According to the Dempster-Schaffer (D-S) evidence theory, it integrates the opinions of many experts, creating a matrix capable of arriving at a comprehensive judgment for the decision-making group. Through a combination with the analytical hierarchy process, indicator weights are determined for each factor.

2. Aims of This Study

The basic objectives of the research can be summarised as follows:

- Identify the factors and causes that affect construction productivity.
- Presenting, classifying and arranging these factors to be taken into consideration when planning construction projects.

By identifying these factors on construction productivity and arranging them according to priority, the awareness of the project manager or decision makers leads to taking appropriate measures and thus creating a positive impact on the success of construction projects.

3. Literature Review

Productivity is defined as a function of the relationship between the outputs in a construction project and its inputs. Here, productivity is measured and evaluated according to the work completed. In construction projects, inputs refer to the labor hours consumed while outputs refer to the value of the work completed. Therefore, construction productivity is defined as the ratio between the amount of work completed to the period of time spent on it. [3].

Productivity is one of the most important factors that affect the quality of performance, cost and duration of completion of construction projects [4]. Therefore, it has become necessary to improve the productivity of projects, and this can be achieved by understanding and knowing the factors affecting them. The best support that can be provided to project managers or decision makers is through better knowledge of the factors that affect productivity, enhancing worker commitment, and increasing worker motivation by improving productivity.It is important to know what affects on work performance, and business needs as away to improve productivity [5]. There are many factors that can affect construction productivity. Previous studies have extensively reviewed these factors. Table 1 provides a summary of these factors that were developed in this paper as part of the research.

Many previous researches was conducted to explain the impact of different factors on labor productivity. However, most previous studies did not take into account the factors and their complex interactions when analyzing the effect of these factors on productivity. Nasirzadeh [6] used artificial intelligence models to analyze the effect of change orders in construction projects on productivity. Pan [7] used fuzzy logic to evaluate the effect of weather conditions such as rain on construction productivity. Taylor et al. [8] evaluated the impact of overtime in US enterprises on labor productivity.

Enshassi et al. [9] evaluated the effect of change orders on labor performance and productivity using causal links. Hanna et al. [10] identified the relationship among work efficiency, productivity and length of work period; They have shown that shift work can be both harmful and beneficial to labor productivity. Also explored during their study the main work areas and the extent of their impact on organizational commitment and worker job satisfaction, which in the long run affects the worker’s performance and productivity. Zhai et al. [11] used data collected from construction projects to investigate the relationship between information technology and labor productivity.

Goodrum et al. [12] studied the relationship between material technology and productivity by analyzing changes for the period between 1977 and 2004 in 100 construction activities, to study these two variables and indicate the types and strength of relationships. Watkins et al. [13] used categorical regression theory to measure the effect of constructability on labor productivity. Gatti et al. [14] investigated the effect of individual worker-level physical stress on productivity using regression models.

However, factors influencing productivity are rarely independent of each other, as labor productivity is affected by the complex interrelation of multiple related factors, and the realization of one factor may lead to the emergence of others. Nojedehi and Nasirzadeh [15] explained the interactions between factors affecting labor productivity. As a result, changing productivity or its ability to change is the most difficult and complex part to determine its cost among the work parts of the project. Therefore, it has become necessary to study and identify the factors affecting productivity and classify and arrange them according to their importance[16]. However, their study imposes a limitation. They proposed developing a quantitative model to evaluate the effect of different factors on productivity.

This paper will combine Dempster-Schaffer evidence theory and analytical hierarchy process, to build a productivity assessment index system for Iraqi construction projects. In this study, an operable, reasonable, and comprehensive productivity index system is created; According to the D-S theory of evidence, in combination with the analytical hierarchy process, the D-S synthesis method is utilized to collect and synthesize the views of many experts, to determine the weights of indicators by creating a comprehensive judgment matrix that helps effectively the decision makers to make collaborative decisions.

4. Factors Influencing Construction Productivity Index System

Analysis of the framework for evaluating factors affecting construction productivity, relying on the ideas of multi-dimensional and multi-level modelling of complicated systems, as well as combining hierarchical analysis theory and the D-S theory, and driven by purpose of raising the productivity effectiveness of public projects, this paper analyzes the factors influencing construction productivity using three aspects of projects: construction, management, and conditions, which are studied then divided and classified to define the each factors. Influencing factors using as indicators to evaluate construction productivity for Iraqi projects were extracted.

Recent years have witnessed development in building a construction productivity evaluation index system. Some researchers have used AI to evaluate productivity, which provides a certain basis for extracting factors affecting productivity. In addition to considering the policy objectives of the projects also achieving economically effective objectives.

This study relies on the existing indicator system, analyzes and classifies relevant literature, also uses theoretical analysis methods and frequency statistics to establish a framework for evaluating factors influencing productivity from three aspects of projects: construction, management, and conditions. For example, from the construction aspects, materials and tools are important factors in indicating whether the materials have not yet arrived at the site, whether there is a lack of materials in the markets, or a shortage of appropriate tools and equipment on the site, in addition to there being frequent malfunctions of the equipment and tools due to their obsolescence or poor maintenance. etc. The framework structure of the factors influencing construction productivity is shown in Figure 1 below.

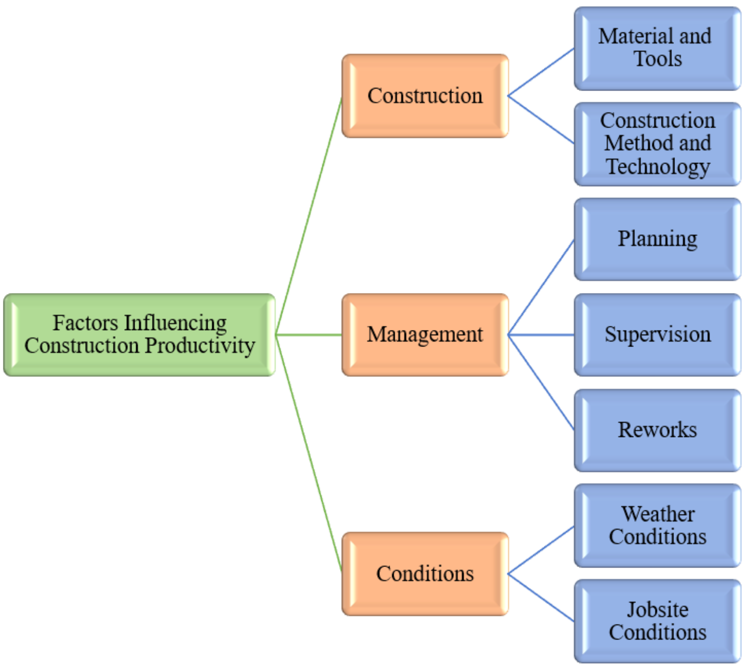

Figure 1. The framework structure of the factors influencing construction productivity.

5. Modelling Various Factors Influencing Construction Productivity Index System

Guided by the goal of improve the productivity in different Iraqi construction projects, according to the concept, significance and proposed evaluation system, this paper integrates a concept to design an index system for factors affecting construction productivity. Using the expert consultation method, the questionnaire survey, and the documentary research technique, a set of indicators is created to evaluate the factors affecting construction productivity. Construction productivity from multiple aspects, construction, management and conditions, including 3 first-level indicators, 7 secondary indicators and 32 tertiary indicators, as presented in Table 1 below.

Table 1. Ranking the factors influencing construction productivity and defined groups

Target Layer	First-Level Indexes	Secondary Indexes	Tertiary Indexes
Factors Influencing Construction Productivity	**Construction** (F1)	**Material and Tools** (S1)	• Materials deliver delay (T1) • There is Materials shortage (T2) • Lack of suitable equipment and tools on-site (T3) • There are poor maintenance produce frequent equipment/tools breakdowns (T4)
		Construction Method and Technology (S2)	• Operators do not have the necessary experience and skills.(T5) • Adopting traditional construction methods and not taking advantage of modern technology. (T6) • Implementing projects of this type for the first time. (T7) • The site is steep or slippery, creating terrible conditions. (T8) • The work requires difficult practice or exceptional effort that workers must have to perform the jobs. (T9)
	Management (F2)	**Planning** (S3)	• There is no scheduling or systematic construction planning. (T10) • Poor planning of tasks. (T11) • Lack of skilled operators or workers. (T12) • Overlap between workers (overcrowding and congestion at the work site). (T13) • Lack of a clear work plan or site layout. (T14) • Management's failure to adopt a smooth plan and safety procedures. (T15)
		Supervision (S4)	• Management does not provide an effective program to train workers in the required skills. (T16) • Inspection delays and resulting stoppages. (T17) • Poor organization of work periods or setting break times. (T18) • The site manager does not have the experience to confront the risks or challenges that arise at the work site. (T19)
		Reworks (S5)	• Rework resulting from damage to works after completion. (T20) • Rework due to failure in quality control testing. (T21) • Rework resulting from manufacturing errors requires corrective measures. (T22) • Rework due to lack of clarity in requirements of specifications, drawings or contract documents. (T23) • Rework resulting from changes in requirements, specifications, drawings or design. (T24)
	Condition (F3)	**Weather Condition** (S6)	• Uncomfortable thermal environment (i.e. humidity, cold, heat).(T25) • Rainy weather. (T26) • Weather fluctuations. (T27)

Jobsite Condition (S7)	• Lack of comfort requirements for workers (rest area, restaurant, water coolers, or covered work area on site. (T28) • Large commuting distance from the campsite or home to the work site. (T29) • The work site is very dusty/noisy. (T30) • Poor ventilation/low lighting/limited access. (T31) • Shortage of electricity supply and water services. (T32)

6. Methodology

This research uses a multi-dimensional and multi-level modelling technique to build a productivity index system for Iraqi projects. Most researchers now calculate index weights using the analytic hierarchy method. There needs to be a more rigorous approach to processing expert opinions because, in building a judgment matrix, researchers usually use a weighted linear method in order to arrive at an aggregation of expert judgment values regardless of how collected and analysed expert opinions effectively. This easily leads to information being distorted and lost.. In this study, we apply the D-S synthesis approach to bring together different experts' views, build a judgment matrix based on the D-S evidence theory, and determine the index weights using the AHP.

6.1 D-S Evidence Theory

As a result of Dempster's research work D-S evidence theory arose from, initially used to resolve the multi-valued assignment issue using upper and lower probability. His student Schaeffer then developed it to deal with uncertain inference by forming a set of mathematical methods. The essence of D-S evidence theory is to integrate multi-source data by providing a synthesis algorithm, which is considered an effective way to solve a problem facing the evaluation process, which is dealing with uncertain information

The framework for recognizing the level of importance that this paper assumes is: $\Theta = \{\alpha_1, \alpha_2, \ldots, \alpha_f, \ldots, \alpha_g\}$(f = 1, 2, …, g); Let k experts perform a different number of pairwise comparisons independently, the result of the comparison is the confidence score θ ($0 < \theta < 1$); Θ can be obtained:

$$\begin{cases} m_d(\alpha_f) = \theta \\ m_d(\Theta) = 1 - \theta \end{cases} \text{ (d=1, 2, …., k) (f= 1, 2, …. , g)} \quad (1)$$

Assuming the comprehensive evaluation result of the importance ratio of the indicator D_i with D_j is e_{ij} (i = 1, 2, _ _ _ , n; j = 1, 2, _ _ _ , n), e_{ij}. It can be obtained:

$$\begin{cases} m(\alpha_f) \\ m(\Theta) \end{cases} \text{ (f= 1, 2, …. , g)} \quad (2)$$

The applying of D-S (technique) rule is:

$$m(A) = [\, m_1 + m_2 + \cdots + m_k](A) = \begin{cases} 0(A = \emptyset) \\ \dfrac{\sum_{A_1 \cap A_2 \cap \ldots A_k = A} m_1(A_1)\, m_2(A_2) \ldots . m_k(A_k)}{1 - \sum_{A_1 \cap A_2 \cap \ldots A_k = A} m_1(A_1)\, m_2(A_2) \ldots . m_k(A_k)} \quad A \neq \emptyset \end{cases} \quad (3)$$

6.2. Use AHP to Determine Indicator Weights

In the early 1970s, Satty (2003) proposed the Analytic Hierarchy Process (AHP) as a quantitative and qualitative multi-criteria decision-making method. The general concept is to break down a complicated problem into smaller parts, organize them in a hierarchical structure, consult experts to determine which indicators are most important for each layer, build a judgment matrix, assign weights to each indicator, and make sure it's consistent. The method can realize a full ranking of different indices and is simple, practical, scientific, and effective. Nevertheless, the majority of researchers currently just build judgment matrices using a linear weighted method to combine the expert opinions as a judgment values. A more stringent method is required to process expert opinions because they do not go into detail about how to successfully incorporate them, which can easily cause information loss and results distortion. In this paper, we combine the aforementioned D-S evidence synthesis method with the AHP method to determine the index weights, build a judge matrix, and fuse the opinions of various experts. The following are the exact procedures:

Step 1: Develop an all-inclusive judgment matrix for use in group deliberation. In the same way that the judgment matrix shows the relative importance of each upper-layer indicator, it does the same for each pair of indicators in

this layer. Typically, the [0,1,2] 3-scale method, the 1.1-1.9 scale method, and it can be utilized to quantify the decision making judgment. [17].
For this study, we'll be using a scale from 1 to 9. Separately, experts evaluate indicators in pairs for each layer and rank their significance. Table 2 below shows the exact definitions. The expert questionnaire data is synthesized using the D-S evidence synthesis method, which is then used to construct the comprehensive group decision-making judgment matrix. Put the all-inclusive judgment matrix for group decisions in order. $A = [a_{ij}]_{nxn}$ (i = 1, 2, … n; j = 1, 2,…, n), a_{ij} is the result of a comprehensive assessment of several factors for comparative importance, between the different indices i and j.

TABLE 2. The 1–9 scale method.

Scale	Meaning
1	Both are equally important.
3	important slightly
5	important evidently
7	important deeply
9	important extremely
2,4,6,8	Mid-value of adjacent judgment
Reciprocal	If the comparison between the factors i and j is judged as a_{ij}, then the judgment of the comparison between the factors j and i is $1/a_{ij}$

Step 2: Calculating index weight.
In most cases, the index weight value can be computed using various methods, such as the square root, characteristic root, sum-product, and least square, etc. The calculation in this paper is done using the square root approach.
a- Multiply the judgment matrix by the entries in each row.:

$$M_i = \prod_{j=1}^{n} a_{ij} \quad (4)$$

b- Calculate n-th root of Mi:

$$V_i = \sqrt[n]{M_i} \quad (5)$$

3- Normalize $V = [V_1, V_2, \ldots, V_n]^T$:

$$W_i = \frac{V_i}{\sum_{i=1}^{n} V_i} \quad (6)$$

Step 3: Testing the consistency of collective decision making using the comprehensive governance matrix.
a- Calculate the characteristic root (maximum).:

$$\lambda_{max} = \sum_{i,j=1}^{k} C_j P V_i \quad (7)$$

b- Calculate consistency index:

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (8)$$

c- Calculate random consistency ratio:

$$CR = \frac{CI}{RI} \quad (9)$$

If CR is less than 0.1, it means that the judgment matrix is sufficiently consistent; if it is not, it has to be modified. Table 3 shows the necessary value of RI, which is the average random consistency index, which is used in the algorithm.

Table 3. Average random consistency index RI.

n	2	3	4	5	6
RI	0.000	0.580	0.900	1.120	1.240

7. Calculation Result

This article employs the D-S synthesis approach to consolidate the views of various experts, build an all-encompassing judgment matrix, using the AHP technique in conjunction with it to compute the index weights, and finally, employ the Delphi method to apply the necessary adjustments. Table 4 below displays the outcomes of the calculations.

Table 4. The comprehensive weights and index weights of factors influencing construction productivity.

Target Layer	First-Level Indexes	Weights	Secondary Indexes	Weights	Tertiary Indexes	Weights	Comprehensive Weights
Factors Influencing Construction Productivity	(F1)	0.45	(S1)	0.45	(T1)	0.20	0.0405
					(T2)	0.30	0.0608
					(T3)	0.35	0.0709
					(T4)	0.15	0.0304
			(S2)	0.55	(T5)	0.30	0.0743
					(T6)	0.17	0.0421
					(T7)	0.23	0.0569
					(T8)	0.20	0.0495
					(T9)	0.10	0.0248
	(F2)	0.30	(S3)	0.40	(T10)	0.12	0.0144
					(T11)	0.28	0.0336
					(T12)	0.22	0.0264
					(T13)	0.17	0.0204
					(T14)	0.08	0.0096
					(T15)	0.13	0.0156
			(S4)	0.30	(T16)	0.31	0.0279
					(T17)	0.15	0.0135
					(T18)	0.34	0.0306
					(T19)	0.20	0.0180
			(S5)	0.30	(T20)	0.26	0.0234
					(T21)	0.22	0.0198
					(T22)	0.17	0.0153
					(T23)	0.12	0.0108
					(T24)	0.23	0.0207
	(F3)	0.25	(S6)	0.60	(T25)	0.32	0.0480
					(T26)	0.46	0.0690
					(T27)	0.22	0.0330
			(S7)	0.40	(T28)	0.18	0.0180
					(T29)	0.22	0.0220
					(T30)	0.18	0.0180
					(T31)	0.25	0.0250
					(T32)	0.17	0.0170

From the results of the calculations in Table 4, it is clear that there are 13 indicators, which are higher than the average indicator weight value of 0.03125625. They are the most important indicators of the factors that must be studied in order to improve productivity.

8. Conclusions

Judging from existing research, studies on the combination of Dempster-Shaffer evidence theory and the analytic hierarchy process are rare, and there is no comprehensive, complete and systematic theoretical system. In activities to evaluate factors affecting productivity, a great part of expert opinions and their judgments represent the fundamental of the study results like classification and evaluation of these factors. Therefore, how to collect and analyse groups of expert opinions more effectively has become one of the fundamental problems to be solved, and the method of collecting different opinions of multiple experts through questionnaires or interviews still needs to be improved. This is due to several reasons,

perhaps the most important of which is the lack of information on the subject of the study or differences in experts' preferences. Sometimes there are potential contradictions and conflicts in the opinions of experts, which need to be further filtered and solutions developed in the future.
The index system in its current form is a tool used by decision makers as an auxiliary tool to transform qualitative judgments and decisions into judgments of a quantitative nature. At present, the mechanism of the scale system is lacking in in-depth studies. It is assumed that in future studies, the applicability of the index system will be scientifically verified, and the scope of application of the index system will be expanded and improved. The factor that most influenced the level of productivity was that the operators do not have the skills and experience to perform the task with comprehensive weights reached to 0.0743, therefore the projects need to develop the skills of their workers according to special training programs or resort to employing specialized skilled workers. While the factor lack of appropriate tools and equipment on site ranked second in terms of impact on productivity with comprehensive weights reached to 0.0709, followed by weather conditions with comprehensive weights reached to 0.0690, especially rainy weather, which impedes the movement of workers and equipment on site.

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