APPLICATION OF AHP IN IDENTIFYING CONSTRUCTION PRODUCTIVITY FACTORS

Ishwar Adhikari[1], Soo-Yong Kim[2] and Young Dai Lee[3]

[1] Master's Student, Interdisciplinary Program of Construction Engineering and Management, Pukyong National Univeristy, Busan, Korea
[2]Professor, Division of Construction Engineering, Pukyong National University, Busan, Korea.
[3] Professor, Division of Construction Engineering, Pukyong National University, Busan, Korea
Correspond to ishwar7@hotmail.com

ABSTRACT: Analytical hierarchy process (AHP) is a potential decision making method in management that can be used in project management as well. Lack of productivity is perhaps the number one problem confronting in the construction industry. There are numerous factors which affect the productivity of a construction project, so it is necessary to find out the critical factors giving birth to productivity. In this paper, construction productivity is taken as example for the demonstration of the AHP application to find out the critical productivity factor in which the Level 1 is taken as selection of critical productivity factor, Level 2 as construction parties and Level 3 as productivity factors group. The outcome of this study is beneficial to the entire constructional professionals for applying the AHP.

Key word: Construction industry, Productivity factor, Analytical hierarchy process (AHP)

1. INTRODUCTION

Thomas and Mathews [20] stated that no standardized productivity definition had been established in the construction industry. Productivity can simply be illustrated by the association of an input and output. Two forms of productivity were used in previous industry studies: (1) productivity = output/input (2) productivity = input/output. The second form has been widely used and existing in literature over the years in the construction industry.

Contractors experience a loss of productivity when their work is disrupted. Gavin and et al. [6] defined disruption as a material difference between the performance conditions that were expected at the time of bid and those actually encountered, resulted in increased difficulty and cost of performance. Tieder and Hoffar [19] provide a list of disruptions including weather, overtime, increases to the number of crews or to the crew size, unavailability of skilled labor, delivery delays. Commencing with the basic Conceptualization of productivity as input/output Prokopenko [15] identified three main productivity factor groups as: job related, resource related and environment related. He also distinguished between *external* (non-controllable) and *internal* (controllable) factors further subdividing the latter into *hard factors* (those related to product, plant and equipment, technology, materials and energy) and *soft factors* (people, organization and systems, work methods and management styles). Lim and Price [10]cited the seven factors identified as affecting overall construction productivity i.e. build ability, structure of the industry, training, mechanization and automation, foreign labor, standardization, building controls. It is necessary to focus on critical factors affecting over all (or total factor) productivity. Maloney [11] suggested that Labor has a significant influence on construction productivity, and that management in turn has a major impact on labor productivity. He identified sets of specific driving, induced and restraining forces acting positively and negatively on productivity levels, and formulated approaches based on such forces to facilitate productivity improvements. Motivation of both management and labor can be hypothesized as a key contributor to the productivity. Methods of motivating personnel to increase productivity have demonstrated by Khan [9] through applications of different human relations theories of motivation. From the existing literature on the construction productivity, five major factors affecting construction productivity are identified.

Manpower: includes recruitment of supervisor and workers, labor turnover, absenteeism, communication problem with foreign worker, alcoholism and labor disruption.

Management: includes material shortage, stop work order because of site accident, stop work order because of infringement of government regulation, stop because of disputes with owner/consultants

Environment: includes health, inclement weather and safety in construction site.

De motivating: includes over crowded work areas, crew interfacing, tool availability, inspection delays, material availability and foreman incompetence

Others: includes relationship with subcontractors, relationship with consultants (Architects/Engineers), data transfer from the jobsite and worker compensation

2. Analytical Hierarchy Process

The AHP developed by Saaty [16] provides a flexible and easily understood way of analyzing complicated problems. It is a multiple criteria decision making techniques that allow subjective as well as objective factors to be considered in decision making process. The AHP allows the active participation of decision makers in reaching agreement, and gives managers a rational basis on which to make decisions. AHP is based on the following three principles: decomposition, comparative judgment, and synthesis of priorities. The AHP theory of measurement for dealing with quantifiable and intangible criteria that has been applied to numerous areas, such a decision theory and conflict resolutions[21].AHP is problem solving formwork and a systematic procedure for representing the elements of any problem[18]. AHP is problem solving formwork and a systematic procedure for representing the elements of any problem. [18].

Decision making is sometimes a team effort, and the AHP is one available method for forming a systematic formwork for group interaction and group decision making [17]. Dyer and Forman [4] describe the advantages of AHP in a group setting as follows :(1) tangible and intangible, individual values, and shared values can be included in an AHP based group decision process.(2)the discussion in a group can be focused on objectives rather than alternatives.(3) discussion can be structured so that every factor relevant to the discussion is considered in turn, and (4) in structured analysis, the discussion continues until all relevant information from each individual member in a group has been considered and a consensus choice of a decision alternative is achieved.

A detailed discussion on conducting AHP based group decision making sessions including suggestions for assembling the group to agree, inequalities of power, concealed or distorted preferences, and implementing the results can be found in Satty [17]and Golden et al.[7]. Problems with using AHP in group decision making can be seen in Islie et.al [8].

Researchers use AHP in various industrial applications. Partovi et al.[14]used it for operations management decision making. Dey et al. [3] used it in managing the risk of projects. Mian and Christine [13] used AHP for evaluation and selection of a private sector project. Meredith and Mantel [12] described AHP as an effective tool for project selection. Dey and Gupta [2] used AHP for cross country petroleum pipeline route selection.

AHP has also been used for benchmarking by Eyrich [5]. His application was for benchmarking computer integrated manufacturing (CIM) sites, and AHP was basically used for determining the success factors, the corresponding requirements, and their importance for a best-of-breed CIM site.

Formulating the decision problem in the form of the hierarchical structure is the first step of AHP. In a typical hierarchy, the top level reflects the overall objectives (focus) of the decision problem.

The elements affecting the decisions are represented in intermediate levels. The lowest level comprises the decision options. Once a hierarchy is constructed, the decision begins a prioritization procedure to determine the relative importance (table1) of the elements in each level of the hierarchy.

Table1. Scale of relative importance for pair wise comparison [1]

Intensity	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the object
3	Moderate importance	Slightly favors one over another
5	Essential or strong importance	Strongly favors one over another
7	Demonstrated importance	Dominance of the demonstrated in practice
9	Extreme importance	Evidence favoring one over another of highest possible order of affirmation
2,4,6,8,	Intermediate values	When compromise is needed

Saaty [16-18] developed the following steps for applying the AHP:

1. Define the problem and determine its goal.
2. Structure the hierarchy from the top (the objectives from a decision-maker's viewpoint) through the intermediate level (criteria on which subsequent level depend) to the lowest level which contains the list of alternatives.
3. Construct a set of pair wise comparison matrices (size n*n) for each of the lower levels with one matrix for each element in the level immediately above by using the relative scale shown in table 1. The pair wise comparisons are done in terms of which element dominates the other
4. There are n (n-1) judgments required to develop the set of matrices in step 3. Reciprocals are automatically assigned in each pair wise comparison.
5. Hierarchical synthesis is now used to weight the eigenvectors entries by the weights of the criteria and the sum is taken overall weighted eigen vector entries corresponding to those in the next lower level of the hierarchy.
6. Having made all the pair wise comparisons, the

consistency is determined by using the eigen value λmax, to calculate the consistency index, CI as follows: CI= (λmax-n)/ (n-1), where n is the matrix size. Judgment consistency can be checked by taking the consistency ratio (CR) of CI with the appropriate value in table 2. The CR is acceptable, if it does not exceed 0.10. If it is more, the judgment matrix is inconsistent. To obtain a consistent matrix, judgments should be reviewed and improved.

7. Steps 3-6 are performed for all levels in the hierarchy.

Table2. Average random consistency developed by Saaty.[16-18]

Size of matrix	Random Consistency
1	0
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

3. Example

A simplified project example of selection of critical productivity factor is demonstrated here for illustration purposes. To simplify the calculations, the factors that will affect the construction productivity are manpower, management, environment, de motivation and others. By following the AHP procedure described in the section 2, the hierarchy of the problem can be developed as shown in figure 1. For step 3, the decision makers have to indicate preferences or priority for each decision alternative in terms of how it contributes to each criterion as shown in table 3. Then the following can be done manually or automatically by the AHP software.

1. Synthesizing the pair-wise comparison matrix.
2. Calculating the priority vector for a criterion such as owner.
3. Calculating the consistency ratio.
4. Calculating λ_{max}
5. Calculating the consistency index, CI
6. Selecting appropriate value of the random consistency ratio from table 2.
7. Checking the consistency of the pair wise comparison matrix to check whether the decision maker's comparisons were consistent or not.

Synthesizing the pair-wise comparison matrix is performed by dividing each element of the matrix by its total column. For example the value 0.08 in Table 4 is obtained by dividing the 1 (from table 3) by 12.5, the sum of the column items in table 3 (1+3+2+6+1/2). The Priority vector in table 4 can be obtained by finding the row averages. For example, the priority of factor manpower with by dividing the sum of the rows (0.08+0.082+0.073 +0.078+0.118) by the number of factors (column).i.e.5.

Table3.Pair wise comparison matrix for owner

Owner	A	B	C	D	E
A	1	1/3	1/2	1/6	2
B	3	1	2	1/2	4
C	2	1/2	1	1/3	3
D	6	2	3	1	7
E	1/2	1/4	1/3	1/7	1

Table 4.Synthesized matrix for owner

Owner	A	B	C	D	E	Priority vector
A	.08	.082	.073	.078	.118	.086
B	.24	.245	.293	.233	.235	.249
C	.16	.122	.146	.155	.176	.152
D	.48	.489	.439	.466	.412	.457
E	.04	.061	.049	.066	.059	.055 Σ=1

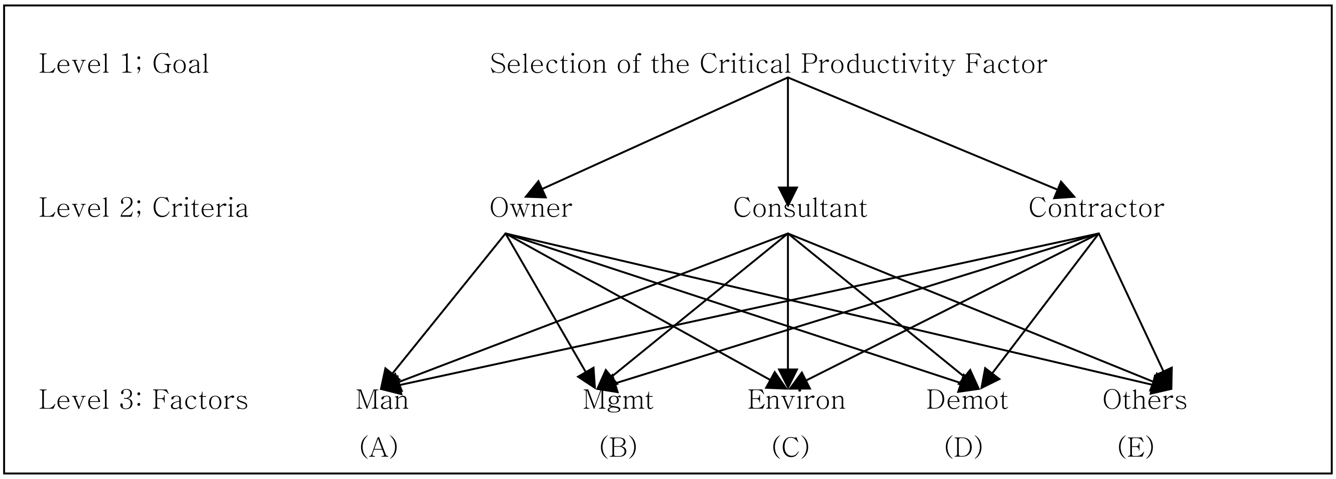
λ_{max}=5.037, CI=0.00925, RI=1.12, CR=0.0082<0.1

Now, estimating the consistency ratio is as follows:

$$0.086\begin{bmatrix}1\\3\\2\\6\\1/2\end{bmatrix}+0.249\begin{bmatrix}1/3\\1\\1/2\\2\\1/4\end{bmatrix}+0.152\begin{bmatrix}1/2\\2\\1\\3\\1/3\end{bmatrix}+$$

$$0.457\begin{bmatrix}1/6\\1/2\\1/3\\1\\1/7\end{bmatrix}+0.055\begin{bmatrix}2\\4\\3\\7\\1\end{bmatrix}=\begin{bmatrix}0.431\\1.259\\0.766\\2.312\\0.276\end{bmatrix}$$

Dividing all the elements of the weighted sum matrices by their respective priority vector element, we get: 0.431/0.086=5.012,1.259/0.249=5.056,0.766/0.152 =5.039, 2.312/0.457=5.059, 0.276/0.055=5.018



(A) Man= manpower, (B) Mgmt= management, (C) Environ=Environment, (D) Demot=Demotivation (E) Others

Fig1. Hierarchy of the example problem of productivity factor

We then compute the average of these values to obtain $\lambda_{max,}$ λ_{max}= 5.012+5.056+5.039+5.095+5.018)/5 = 5.037.
Now, we find the consistency index, CI, as CI= λ_{max}- n/n-1 = 5.037-5/5-1= 0.00925.
Selecting the appropriate value of random consistency ratio, RI, for a matrix size of five using Table 2, we find RI=1.12.
We then calculate the consistency ratio, CR, as
CR= CI/RI=0.00925/1.12=0.0082.
As the value of CR is less than 0.1, the judgments are acceptable. Similarly, the pair wise comparison matrices and priority vectors for the remaining criteria can be found as shown in the table respectively.

Table5.Synthesized matrix for Consultant

consultant	A	B	C	D	E	Priority vector
A	.466	.45	.403	.503	.304	.426
B	.077	.075	.033	.125	.130	.088
C	.155	.30	.134	.083	,217	.177
D	.233	.15	.402	.251	.304	.269
E	.066	.025	.026	.035	.043	.04 Σ=1.0

λ_{max} =5.32, CI=0.08, RI=1.12, CR=0.071<0.1

Overall Priority of the factor Manpower
= 0.525(0.086)+0.334(0.426)+0.141(0.150) = 0.209

Overall Priority of the factor Management
=0.525(0.249)+0.334(0.088)+0.141(0.271)=0.198

Overall Priority of the factor Environment
=0.525(0.152)+0.334(0.177)+0.141(0.444) =0.201

Overall Priority of the factor De motivation
=0.525(0.457)+0.334(0.269)+0.141(0.072)=0.340

Overall Priority of the factor Others
=0.525(0.055)+.334(0.04)+0.141(0.065) = 0.051.

Table6.Synthesized matrix for Contractor

Contractor	A	B	C	D	E	Priority vector
A	.130	.096	.130	.16	.238	.150
B	.26	.192	.173	.4	.333	.271
C	.519	.576	.521	.32	.285	.444
D	.065	.038	.086	.08	.095	.072
E	.025	.096	.086	.04	.08	.065 Σ=1.0

λ_{max}=5.38, CI=0.095, RI=1.12, CR=0.085<0.1

Table7.Synthesized matrix for three Criteria

	Owner	Consultant	Contractor	Priority vector
Owner	.545	.6	.428	.525
Consultant	.272	.3	.428	.334
Contractor	.181	.1	.142	.141 Σ=1.000

λ_{max}=3.052, CI=0.052, RI=0.58, CR=0.089<0.1

4. Conclusion

Project management involves complex decision making situations that require discerning abilities and methods to make sound decisions. This paper has presented the AHP as a decision making method that allows the consideration of multiple criteria. An example of the selection of the critical productivity factor was created to demonstrate AHP application. From the calculation we found out that the de motivation factor was one of the most critical productivity factor which can affect the overall productivity of the construction process and the overall priority of factors are presented in the table 8.

Table8.Priority matrix for productivity factors

	Owner	Consult ant	Contra ctor	Overall priority
Manpower	.086	.426	.150	.209
Management	.249	.088	.271	.198
Environment	.152	.177	.444	.201
De motivation	.458	.269	.072	.340
Others	.055	.04	.065	.051

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