KICEM Journal of Construction Engineering and Project Management
Online ISSN 2233-9582

www.jcepm.org
http://dx.doi.org/10.6106/JCEPM.2014.4.1.045

A Modified-AHP Method of Productivity Analysis for Deployment of Innovative Construction Tools on Construction Site

Soonwook Kwon[1], Gaeyoung Lee[2], Dooyong Ahn[3] and Hee-Sung Park[4]

Received October 24, 2013 / Revised November 21, 2013 / Accepted December 5, 2013

Productivity analysis is the most important and significant method for evaluating management and engineering performance during whole project stage. However, it is very difficult in developing qualitative index to construction industry comparing to other industries. Therefore, analytical hierarchy process (AHP) is one of the methods for overcoming these limitations by checking consistency index using duality comparison. In this study, it is scraped up an application plan and selection for innovative tools by analyzing survey results on tool users and site managers with respect to using Modified-AHP performance measurement method.

Keywords: Innovative tool, Productivity, AHP, Construction site operation

I. INTRODUCTION

Productivity is used as a tool to measure real production activities in all industrial areas (Won, 2008). Productivity is defined as the ratio of input to output when products are manufactured for a certain period of time using a production system (Kim, 1994).

The construction industry is labor-intensive, its work performed largely outside, as a large number of businesses in an area engages in a project together. As a result, the industry has many factors that make it hard to evaluate its productivity. Application of the concept of productivity to the industry is not so simple; therefore, labor productivity is commonly used.

Factors that influence construction productivity are broadly divided into the internal influence factors that may be controlled within a production system and the external influence factors with the opposite concept. Enhancement in productivity is mainly achieved by improving the internal influence factors (Park, 1992).

Internal influence factors are divided into hard factors (product, technology, materials, energy, plant, and equipment) and soft factors (construction controls, work methods, people, organization, systems, and management style) (Jung, 2005). Productivity is enhanced through the removal or improvement of inappropriate internal influence factors (Figure 1) (Yoon, 2010).

High productivity in advanced countries' construction sites was judged to result from the efficient application of advanced construction tools to unit work. Here, innovative construction tools mean high-performance work tools, small equipment, or safety goods that have not been applied to sites in Korea but that are in common use in advanced countries.

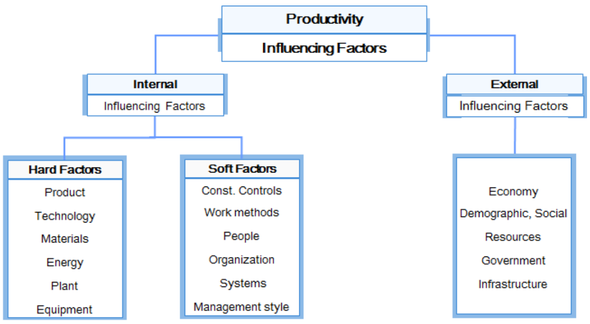


FIGURE I
FACTORS THAT INFLUENCE PRODUCTIVITY OF THE CONSTRUCTION INDUSTRY

Accordingly, this study introduced innovative construction tools for productivity enhancement through improvement in internal influence factors (Gilbreth, 1917). This study also collected and analyzed the opinions of managers and workers at construction sites, using a questionnaire aimed at developing a measure to select and utilize innovative construction tools.

II. METHODOLOGY

A comprehensive evaluation of advanced construction tools was made, with a structure that combined managers' macroscopic insights and managers' microscopic opinions. The questionnaire had two parts, calculating the managers' weight and evaluating workers' degree of satisfaction.

The analysis hierarchy process (AHP), one of the multi-criteria decision making methods, was used for this purpose (Niebel, 1980).

[1] School of Civil, Architectural, and Environmental Engineering, SungKyunKwan University, Suwon, 440-746, Korea, swkwon@skku.edu
[2] R&D Center on Construction Robot & Automation, Samsung C&T Corporation, Seoul, 135-769, Korea, kyle@samsung.com
[3] Samsung M-PJT, Samsung C&T Corporation, Suwon, 443-803, Korea, ahn0305@samsung.com
[4] Department of Civil and Environmental Engineering, Hanbat National University, Daejeon, 305-719, Korea, jackdaniel@hanbat.ac.kr (*Corresponding Author)

AHP, a technique presented by Thomas. L. Satty, is used as a decision support system. The system is widely used in multi-criteria decision making that includes both quantitative and qualitative elements; this method has enabled comprehensive evaluation and integration of quantitative and qualitative elements (Table I) (Lee, 2011).

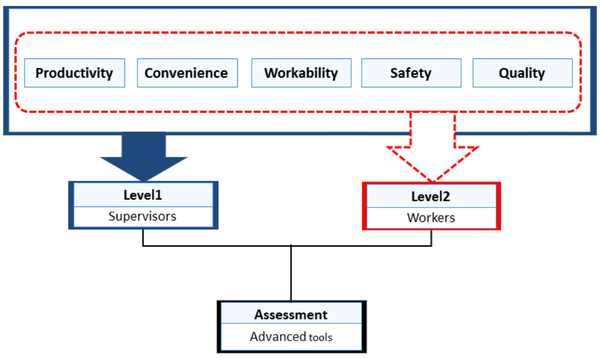
AHP classifies decision making elements into goal, criteria, and alternatives, and it structuralizes and systemizes such elements. In particular, one of the most significant characteristics of AHP is to apply hierarchy to a complicated problem and divide its factors into major factors and sub-factors, making a pairwise comparison of these factors, deriving their weights, and prioritizing them.

TABLE I
PAIRWISE COMPARISON

	A1	**A2**	**A3**	**A4**	**A5**
A1	1	A1/A2	A1/A3	A1/A4	A1/A5
A2	A2/A1	1	A2/A3	A2/A4	A2/A5
A3	A3/A1	A3/A2	1	A3/A4	A3/A5
A4	A4/A1	A4/A2	A4/A3	1	A4/A5
A5	A5/A1	A5/A2	A5/A3	A5/A4	1

Under this pairwise comparison, the value from a comparison between the same two items is 1.0, and a reverse comparison results in a reciprocal number. Further, decision making is made by verifying the consistency of the calculated weights. Thanks to such advantages, AHP is one of the most widely used techniques among existing decision making methods.

This study modified and applied the use of AHP. On the questionnaire, the calculation of the managers' weights aimed at analyzing managers' judgments regarding the introduction of advanced construction tools was classified as Level 1, and a pairwise comparison of these judgments was made (Jo, 2001). The questionnaire that aimed at analyzing the evaluation values of workers who use advanced construction tools was classified as Level 2 (Figure II).



$$Y = \alpha\left(\frac{x_{\alpha1}+x_{\alpha2}+\cdots}{n}\right) + \beta\left(\frac{x_{\beta1}+x_{\beta2}+\cdots}{n}\right) + \gamma\left(\frac{x_{\gamma1}+x_{\gamma2}+\cdots}{n}\right) + \delta\left(\frac{x_{\delta1}+x_{\delta2}+\cdots}{n}\right) + \varepsilon\left(\frac{x_{\varepsilon1}+x_{\varepsilon2}+\cdots}{n}\right)$$

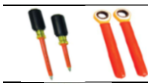
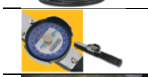
FIGURE II
EVALUATION STRUCTURE CHART

The goals of the two different questionnaires were to introduce and apply innovative construction tools based on the positions of both managers and workers. To this end, a pairwise comparison of the managers' weights was made; the sum of all elements should become 1.0. A survey of workers' evaluation values was made using a seven-point scale questionnaire, and the values were derived using the arithmetic-geometric mean. An equation through which the generalization of the managers' weights and the workers' evaluation values may be made was applied, and scores were derived for comprehensive evaluation, thereby heightening the accuracy and reliability of the Modified-AHP.

III. PRODUCTIVITY EVALUATION OF INNOVATIVE TOOLS

The areas in which innovative construction tools are practically used encompass diverse areas such as construction, electricity, facility, and safety areas (Ahn, 2008). In order to collect opinions of managers and workers on the introduction and application of innovative construction tools, an evaluation was made by conducting a survey on innovative construction tools and the jobs they do. The innovative construction tools evaluated in this study's questionnaires were as follows (Table II).

TABLE II
INNOVATIVE CONSTRUCTION TOOLS

Tools		Feature
	Rated Electrical Insulated Tools	Tools for wiring work
	Wheel Dolly	Heavy weight cargo lifting and fixation
	PVC Bender	PVC pipe bending
	Bx/Flex Conduit cutter	Cable cutting
	Cable Striper	High pressure cable cover removal
	Torque Tester & Calibrator	Torque wrench test
	Dump Cart	Carrying construction scraps and wastes out of a site
	Wet / Dry Vacuum	Site cleaning
	Fume Extractor	Removal of fumes during welding
	Torque Wrench	Bolt tightening
	Brady Boy Safety Barricade	For installation on protect areas boundary
	Self-Retracting Fall Limiters	For prevention of falls during work
	Beam Anchor & Beam Trolley	Movable equipment for prevention of falls
	Anchorage Connectors	Lifesaving loop installed on a concrete structure

		Feature
		
	Reinforced Barricade Tape	For control of access to and warning against a dangerous area
	Portable Eye Shower	For an emergency measure against foreign materials in the eyes

IV. MODIFIED-AHP SURVEY METHOD

The Modified-AHP questionnaire had two parts, one for calculation of the weights that the managers considered important when they decided to introduce innovative construction tools and the other for evaluation of the workers' degree of satisfaction relative to the existing tools (Jo, 1997).

In other words, during the stage of calculating the managers' weights, the geometric mean based on pairwise comparison was calculated, and during the stage of examining workers' degree of satisfaction with innovative construction tools, a seven-point scale was applied and the arithmetic-geometric mean was calculated in order to heighten the accuracy and reliability of the analysis (Figure IV).

Assessment	Very important		Important		Few important		equality	Few important		Important		Very important		Assessment
Convenience	⑦	⑥	⑤	④	③	②	①	②	③	④	⑤	⑥	⑦	Safety
Convenience	⑦	⑥	⑤	④	③	②	①	②	③	④	⑤	⑥	⑦	Workability
Convenience	⑦	⑥	⑤	④	③	②	①	②	③	④	⑤	⑥	⑦	Productivity
Convenience	⑦	⑥	⑤	④	③	②	①	②	③	④	⑤	⑥	⑦	Quality
Safety	⑦	⑥	⑤	④	③	②	①	②	③	④	⑤	⑥	⑦	Workability
Safety	⑦	⑥	⑤	④	③	②	①	②	③	④	⑤	⑥	⑦	Productivity
Safety	⑦	⑥	⑤	④	③	②	①	②	③	④	⑤	⑥	⑦	Quality
Workability	⑦	⑥	⑤	④	③	②	①	②	③	④	⑤	⑥	⑦	Productivity
Workability	⑦	⑥	⑤	④	③	②	①	②	③	④	⑤	⑥	⑦	Quality
Productivity	⑦	⑥	⑤	④	③	②	①	②	③	④	⑤	⑥	⑦	Quality

FIGURE III
THE FORM OF THE QUESTIONNAIRE FOR MANAGERS

Assessment		lowness						highness
Convenience	Portable	①	②	③	④	⑤	⑥	⑦
	Easy to store	①	②	③	④	⑤	⑥	⑦
	Easy to carry	①	②	③	④	⑤	⑥	⑦
Safety	Safe for workers	①	②	③	④	⑤	⑥	⑦
	Safe for related work	①	②	③	④	⑤	⑥	⑦
Workability	Less support works	①	②	③	④	⑤	⑥	⑦
	Less tiresome during the work	①	②	③	④	⑤	⑥	⑦
	Useful	①	②	③	④	⑤	⑥	⑦
	Rapidly work	①	②	③	④	⑤	⑥	⑦
	Easy to grip by hands	①	②	③	④	⑤	⑥	⑦
	Comfortable	①	②	③	④	⑤	⑥	⑦
Productivity	Easy to prepare	①	②	③	④	⑤	⑥	⑦
	Reduce material waste	①	②	③	④	⑤	⑥	⑦
	Reduce time	①	②	③	④	⑤	⑥	⑦
	Flexible for sizes	①	②	③	④	⑤	⑥	⑦
	Helpful for succeed task	①	②	③	④	⑤	⑥	⑦
Quality	Equal quality	①	②	③	④	⑤	⑥	⑦
	Less defects	①	②	③	④	⑤	⑥	⑦
	Excellent quality for work result	①	②	③	④	⑤	⑥	⑦

FIGURE IV
THE FORM OF THE QUESTIONNAIRE FOR WORKERS

TABLE III
SCALES OF RELATIVE IMPORTANCE

Scale	Definition	Description
1	Equally important	Two compared elements have equal importance
3	Slightly important	An element is slightly more important than the other element
5	Important	An element is more important than the other
7	Very important	An element is considerably more important than the other element
2.4.6	Middle values of the above scales	Degree of importance is middle between the above scales
reciprocal	1, 1/2, …1/7	When the value of an element α against β is n, one of the above scales, an element β's importance against the element α is 1/n.

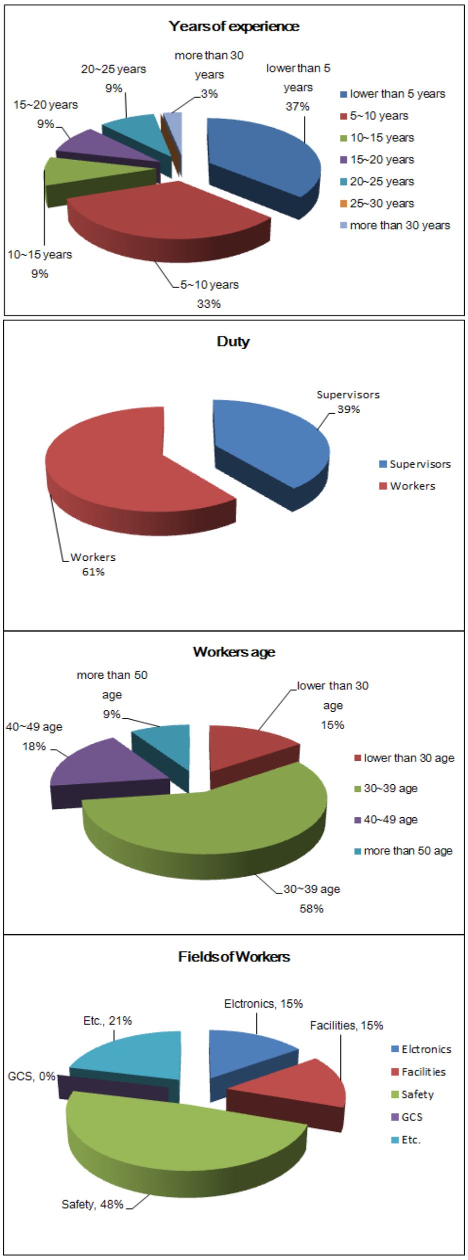


FIGURE V
ANALYSIS RESULT OF THE COLLECTED QUESTIONNAIRES' RESPONDENTS

The survey on the introduction and application of innovative construction tools was conducted between September and November, 2011, by visiting construction sites where the tools had been introduced.

In total, 33 questionnaires were collected from 13 managers (39%) and 20 workers (61%). The safety area accounted for the largest number of respondents at 16 (48%), followed by the facility area at 5 (15%), the electricity area at 5 (15%), and other areas at 7 (21%). Other areas included construction, paint, and interior design areas. The analysis result of the respondents to the 33 collected questionnaires is as follows (Figure V). In this study, it is figured out the effect elements for analyzing results for adoption of innovative construction tools by interviewing of experts. The elements which are convergence, safety, workability, productivity, quality are considered weights which are derived by using analytical hierarchical process (AHP) (Table IV).

TABLE IV
MANAGERS' WEIGHTS FOR EACH INNOVATIVE CONSTRUCTION TOOL

Tools	Convenience	Safety	Workability	Productivity	Quality
Rated Electrical Insulated Tools	0.074	0.537	0.110	0.066	0.213
PVC Bender	0.053	0.348	0.166	0.137	0.296
Bx/Flex Conduit Cutter	0.092	0.415	0.094	0.160	0.239
Cable Striper	0.099	0.287	0.094	0.074	0.446
Torque Tester & Calibrator	0.138	0.284	0.094	0.085	0.399
Wet/Dry Vacuum	0.335	0.157	0.224	0.101	0.183
Fume Extractor	0.262	0.282	0.146	0.159	0.150
Torque Wrench	0.084	0.422	0.139	0.088	0.267
Brady Boy Safety Barricade	0.147	0.420	0.109	0.108	0.216
Flammable Liquid Container	0.129	0.433	0.152	0.136	0.150
Reinforced Barricade Tape	0.214	0.214	0.220	0.163	0.189
Wheel Dolly	0.262	0.292	0.234	0.104	0.109
Dump Cart	0.215	0.221	0.254	0.258	0.053
Anchorage Connectors	0.138	0.515	0.218	0.045	0.084
Self-Retracting Fall Limiters	0.218	0.273	0.202	0.180	0.127
Beam Anchor & Beam Trolley	0.194	0.270	0.189	0.204	0.144
Portable Eye Shower	0.426	0.230	0.145	0.075	0.125

Workers' evaluation values for each innovative construction tool, derived using a seven-scale questionnaire and arithmetic-geometric mean, are as follows (Table V).

TABLE V
WORKERS' EVALUATION VALUES OF EACH INNOVATIVE CONSTRUCTION TOOL

Tools	Convenience	Safety	Workability	Productivity	Quality
Rated Electrical Insulated Tools	4.6	6.2	4.8	4.4	5.2
PVC Bender	2.0	6.0	3.7	4.4	5.0
Bx/Flex Conduit Cutter	6.0	6.0	5.5	4.1	5.3
Cable Striper	6.0	6.0	3.3	4.6	4.1
Torque Tester & Calibrator	4.3	5.5	3.6	4.3	4.3
Wet/Dry Vacuum	4.1	4.3	5.5	4.4	4.2
Fume Extractor	4.6	4.1	5.1	4.4	4.2
Torque Wrench	5.0	5.0	4.2	4.4	4.2
Brady Boy Safety Barricade	4.3	2.8	3.8	2.1	3.7
Flammable Liquid Container	4.3	5.8	3.5	2.9	3.2
Reinforced Barricade Tape	5.9	4.7	5.4	5.0	5.2
Wheel Dolly	5.3	3.7	4.8	3.3	3.8
Dump Cart	5.2	6.0	5.6	5.3	4.9
Anchorage Connectors	5.7	6.5	4.7	4.0	3.5
Self-Retracting Fall Limiters	4.5	6.0	4.5	4.7	4.0
Beam Anchor & Beam Trolley	4.0	5.5	4.5	5.1	6.0
Portable Eye Shower	6.0	4.0	4.5	4.0	4.3

V. ASSESSMENT OF INNOVATIVE TOOLS

A comprehensive evaluation of innovative construction tools was made, with a structure of combining managers' macroscopic insights and managers' microscopic opinions. Prior to the generalization of these two levels, the managers' weights and workers' evaluation values for innovative construction tools derived earlier were substituted into the equation below to derive the Modified-AHP scores.

$$Y = \alpha\left(\frac{x_{\alpha1}+x_{\alpha2}+x_{\alpha3}+\cdots}{n}\right)+\beta\left(\frac{x_{\beta1}+x_{\beta2}+x_{\beta3}+\cdots}{n}\right)$$
$$+\gamma\left(\frac{x_{\gamma1}+x_{\gamma2}+x_{\gamma3}+\cdots}{n}\right)+\delta\left(\frac{x_{\delta1}+x_{\delta2}+x_{\delta3}+\cdots}{n}\right)$$
$$+\epsilon\left(\frac{x_{\epsilon1}+x_{\epsilon2}+x_{\epsilon3}+\cdots}{n}\right)$$

Where,
$Y \leq 7.0$
α = *Manager's weight for convenience*
β = *Manager's weight for safety*
γ = *Manager's weight for workability*
δ = *Manager's weight for productivity*
ε = *Manager's weight for quality*
$x_{\alpha n}$ = *Workers' evaluation value for convenience*
$x_{\beta n}$ = *Workers' evaluation value for safety*
$x_{\gamma n}$ = *Workers' evaluation value for workability*
$x_{\delta n}$ = *Workers' evaluation value for productivity*
$x_{\epsilon n}$ = *Workers' evaluation value for quality*

The sum of the managers' weights is 1.0 and that of workers' evaluation values is 7.0, which translates into Y being 7.0. In order to derive sub-elements of workers' evaluation values for each tool, an arithmetic-geometric mean was used.

The Modified-AHP score of each innovative construction tool derived by applying the above equation is as follows (Table VI).

TABLE VI
MODIFIED-AHP SCORE OF EACH INNOVATIVE CONSTRUCTION TOOL

Tools	M-AHP
Rated Electrical Insulated Tools	5.60
PVC Bender	4.89
Bx/Flex Conduit Cutter	5.48
Cable Striper	4.80
Torque Tester & Calibrator	4.58
Wet/Dry Vacuum	4.49
Fume Extractor	4.44
Torque Wrench	4.62
Brady Boy Safety Barricade	3.25
Flammable Liquid Container	4.47
Reinforced Barricade Tape	5.25
Wheel Dolly	4.35
Dump Cart	5.49
Anchorage Connectors	5.63
Self-Retracting Fall Limiters	4.88
Beam Anchor & Beam Trolley	5.02
Portable Eye Shower	4.97

Their ranks were derived based on the Modified-AHP score of each of the innovative construction tools. Based on the overall ranks of innovative construction tools, the upper 30%, the middle 40%, and the lower 30% were classified into the upper, middle, and lower classes (Table VII).

TABLE VII
EACH INNOVATIVE CONSTRUCTION TOOL'S RANK

Tools	Rank	Class
Anchorage Connectors	1	Upper
Rated Electrical Insulated Tools	2	
Dump Cart	3	
Bx/Flex Conduit Cutter	4	
Reinforced Barricade Tape	5	
Beam Anchor & Beam Trolley	6	Middle
Portable Eye Shower	7	
PVC Bender	8	
Self-Retracting Fall Limiters	9	
Cable Striper	10	
Torque Wrench	11	
Torque Tester & Calibrator	12	
Wet/Dry Vacuum	13	Lower
Flammable Liquid Container	14	
Fume Extractor	15	
Wheel Dolly	16	
Brady Boy Safety Barricade	17	

The study looked at what elements the managers focused on in introducing innovative construction tools and what workers did in using them by analyzing the questionnaires filled in by the managers and the workers.

Further, this study presented a relatively successful example by dividing innovative construction tools into upper, middle, and lower classes based on the Modified-AHP scores of innovative construction tools.

VI. CONCLUSIONS

This study applied the Modified-AHP by focusing on how to enhance labor productivity for productivity improvement as a whole and collected opinions on each innovative construction tool from managers and workers. In this study, it is found to overcome limitations of analyzing traditional method for selection of qualitative construction tools by suggesting the construction tools selection method using AHP, since there are no quantitative analysis methods for innovative construction tools. This study was able to calculate what major elements managers and workers considered for each innovative construction tool.

However, the number of survey samples was small, which resulted in relatively low reliability. Therefore, future study should derive weight by categories such as electricity, facilities, and safety in order to create measures for the introduction of each innovative construction tool. Moreover, reliability should be heightened by increasing the number of survey samples on innovative construction tools.

REFERENCES

[1] J.S. Won, "An Analysis of the International Competitiveness of Productivity in the Korea", *Journal of Korea Institute of Construction Engineering Management, KICEM*, Vol. 9, no. 4, pp. 75-83, 2008.

[2] Y.S. Kim, "Analysis of the Factors Influencing Construction Productivity", *Journal of the Architectural Institute of Korea, AIK*, vol. 10, no. 10, pp. 267-272, 1994.

[3] S.H. Park, "A Study on Accuracy Analysis of Based on Work Factor System and Setting-up a Work-time of MODAPTS", Proceedings of Korean Institute of Industrial Engineers (KIIE) Spring Conference, pp. 545-554, 1992.

[4] H.K. Jung, "A Study on Productivity Analysis on Formworks using Work Measuring Method", *Journal of Korea Institute of Building Construction, KIC*, vol. 5, no. 4, pp. 131-137, 2005.

[5] B.S. Yoon, "Quantitative Analysis on Relation between Work Management Method, Condition and Efficiency", Master's Thesis of KwangWoon University, 2010.

[6] F.B. Gilbreth, "Motion Study: A Method for Increasing the Efficiency of the Workman (1911)", Kessinger Publishing, 2010.

[7] B.W. Niebel, K. Cho, S. Lee, Y. Cho, "A Case Study for Assembly Line Analysis with MTM", *Journal of the Korean Institute of Industrial Engineers, KIIE*, vol. 6, no. 1, pp. 39-44, 1980.

[8] M.N. Lee, "Introduction, Application, and Productivity Evaluation of Advanced Tools", Proceedings of Korea Institute of Construction Engineering Management (KICEM), vol. 11, p. 33, 2011

[9] H.H. Jo, "A Study on Development of Work-analysis and Evaluation Model on Building Construction", *Journal of the Architectural Institute of Korea, AIK*, vol. 17, no. 10, pp. 145-152, 2001.

[10] S.H. Ahn, "A Study on Work Condition Management Method for Improving Work Efficiency," *Journal of the Architectural Institute of Korea, AIK*, vol. 24, no. 4, pp. 183-190, 2008.

[11] H.H. Jo, "A Study on the Motion Analysis and AHP Evaluation Method in Construction Works", *Journal of the Architectural Institute of Korea, AIK*, vol. 17, no. 2, pp. 1423-1429, 1997.