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PROBABILISTIC MODEL-BASED APPROACH FOR TIME AND COST DATA : REGARDING FIELD CONDITIONS AND LABOR PRODUCTIVITY

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ABSTRACT: Labor productivity is a significant factor related to control time, cost, and quality. Many researchers have developed models to define method of measuring the relationship between productivity and various constraints such as the size of working area, maximum working hours, and the crew composition. Most of the previous research has focused on estimating productivity; however, this research concentrates on estimating labor productivity and developing time and cost data for repetitive concrete pouring activity. In Korea, "Standard Estimating" only contains the average productivity data of the construction industry, and it is difficult to predict the time and cost of any particular project; hence, there are some errors in estimating duration and cost for individual activity and project. To address these issues, this research collects data, measures productivity, and develops time and cost data using labor productivity based on field conditions from the collected data. A probabilistic approach is also proposed to develop data. A case study is performed to validate this process using actual data collected from construction sites and it is possible that the result will be used as the EVMS baseline of cost management and schedule management.

Keywords: Labor productivity; Probabilistic model: Field condition; Crew; Time and cost data

1. INTRODUCTION

According to Sanvido [1], "Productivity is defined as the ratio of product output to input." Based on this definition, labor productivity can be determined using input and output data. Furthermore, "accuracy of estimating individual activity time and cost" can be attained by reliable labor productivity data [2]. In Korea, "Standard Estimating" only contains the average productivity data of the construction industry, and it is difficult to predict the time and cost of any particular project; hence, there are some errors in estimating time and cost for individual activity and project.

Previous studies calculated the time and cost using productivity in the early project phase and construction phase. Field conditions such as workable time and space were not considered. Thus, in a remodeling construction project with restricted workable time and space, estimating errors due to the use of average labor productivity can cause such problems as delayed building and going over budget. Among the various construction-related activities, the scope of this study is limited to "concrete pouring," which allows productivity measurement with a focus on the critical path. Furthermore, since measuring the productivity of the activity generates a different result every time, a probabilistic approach considering uncertainty is introduced.

This paper presents a process of building the time and cost data of the activity considering productivity based on the probabilistic approach. The exhaustive model consists of three Phases and is shown in Fig.1. And this study focuses on developing the time and cost data for individual activity, which is the Phase□.

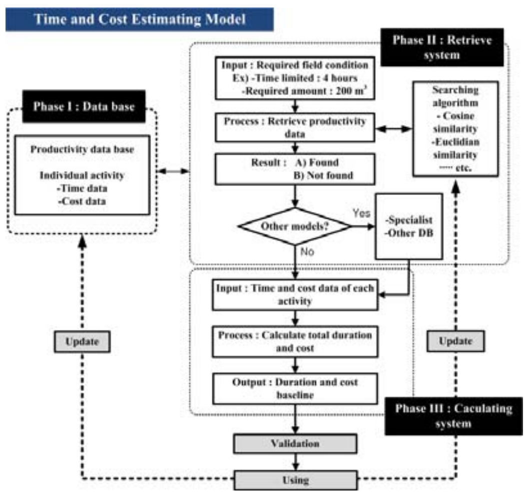

Fig. 1 Time and Cost Estimating Model

2. BACKGROUND OF RESEARCH

In this study, efforts are made to manage and collect certain time and cost data. To provide a basic scheme for such collection and management, this study investigates the definition of productivity, factors influencing productivity, measurement and analysis of productivity, and the uses of productivity information.

2.1 Productivity

Productivity is also considered a significant measure of national economic strength and has been studied and tracked for years (Lester 1998). Estimators routinely used crew productivity during the process of bid preparation, and subsequently, monitored performance during construction, and employed a variety of analytical techniques tempered with judgments, experience, knowledge, and historical data (Portas and AbouRizk 1997).

Productivity is measured by the production volume for the inputted resources, and is categorized into labor, capital, and raw material productivity. In the literature review, productivity is normally considered to be the combination of input and output data. Therefore, it is quantified by the following method:

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}}$$

where “input” is the inputted raw materials, power, tools, labor, cost, and time. And “output” is the volume or quantity of the produced products.

2.2 Factors for Estimating Productivity

In the literature related to the analysis of factors influencing productivity in the construction industry, Hanna et al. (1999) and Osama Moselhi et al. (2005) reported that change orders influenced the productivity of workers. Allmon et al. (2000) described the characteristics of a project, technology, management, labor organization, real wage trend, and construction education as the factors influencing productivity. Goodrum and Haas (2004) and Goodrum et al. (2009) stated the effect of the development of equipment and material technologies on productivity. In addition, the experience of the project manager, the degree of perfection of the design, and time shortening techniques were found to influence productivity. Productivity factors are shown in Table 1.

Most of the existing has studies that analyzed the factors influencing productivity focused on design changes, technology changes, and management techniques. In this study, however, the factors influencing productivity are determined by analyzing the effects of daily work volume and work time on productivity.

2.3 Productivity Measurement and Analysis

Various data-collection techniques are considered. In construction, labor productivity is specialized, and related to operations and activities [3]. There are four methods used to measure labor productivity in construction: (1) Productivity Ratings; (2) Five-Minute Rating; (3) Continuous Time Study; and (4) Work sampling. [4], [3].

Table 1. Productivity Factors

Researchers	Productivity Factors
Hanna et al. (1999)	- Change Orders
Allmon et al. (2000)	- Project Uniqueness - Technology - Management - Labor Organization - Real Wage Trends - Construction Training
Goodrum and Haas (2004)	- Equipment technology
Osama Moselhi (2005)	- Change Orders : Intensity, Timing in relation to project duration, Work type, - Type of impact, Project phase, On-site management
Cottrell (2006)	- Design Completeness - Definition of a Project Vision Statement - Testing Oversight - Project Manager Experience and - Dedication
Hastak et al. (2008)	- Management Techniques - Schedule Reduction Techniques - CII Best Practices
Goodrum et al. (2009)	- Quantitative Factors : Material Weight Reduction, Strength, Curability - Qualitative Factors : Material Installation, Modularity

(1) Productivity Ratings are used for measuring labor performance. It is impossible to record the labor productivity every minute, so a good sample design is needed. (2) The Five-Minute Rating is based on observations made in a short time period. However, if the observations are small, achieving statistical significance may be difficult [3]. In this method, the observations should be longer than five minutes. (3) Continuous Time Study is good method for measuring a specific action in a limited environment. At the start of measurement, the second hand of the watch is set to 0, and the time is recorded only when the composition of labor changes. In this way, the duration of each activity can be determined by comparing the preceding and following records after all measurements have been finished. (4) Work sampling is an analysis method used to quantify the composition ratio of each element comprising a certain type of work. The Association for the Advancement of Cost Engineering (AACE) states that “Work sampling is a statistical technique that can be effectively used for analyzing the construction and maintenance work process [4]”.

2.4 Productivity Information

Estimated productivity data is helpful in managing cost, schedule, and performance. Productivity data is used for the target productivity setting, performance measurement, cost and schedule planning, and integration of cost and schedule information [5].

(1) The accumulated productivity information can be used to set the target production for a specific activity. Specifically, the target production of an activity or project can be set through case studies and a heuristic approach based on past productivity information and the experience

of experts. (2) The performance can be measured by comparing the work volumes at each milestone based on the defined target production. (3) The input cost and time for the target production for each activity can be predicted. Therefore, cost and schedule planning is possible. (4) When cost and schedule plans are established, it is possible to manage the cost and schedule in an integrated way for each activity.

3. TIME AND COST DATA

3.1 Standard Estimating

The standard estimation system that forms the basis of cost data and is used to calculate the expected price of public projects in Korea is based on the "Standard Estimating", which is established by the Economic Planning Board (Budget Control Office) in 1968. It has been the only standard for estimating public and private constructions. This estimating standard numerically indicates the material quantity, labor quantity, and equipment usage time for unit work based on standard and universal work types and methods.

Although there have been many studies confirming the utility of "Standard Estimating" of construction works, the problem of low reliability of the existing cost data in actual projects has been raised repeatedly. In fact, studies analyzing the differences between the cost data used in estimation and the cost data in actual construction sites have been published recently. The problems of "Standard Estimating" presented in these studies can be summarized as follows : Table 2.

Table 2. The problems of "Standard Estimating"

Problems	Details
Establishment and revision process	Lack of a specific, systematic process
Labor	There is a difference between the estimated labor and the actual labor The same Standard Estimating are applied regardless of the field conditions or engineering method
Cost	The equipment cost is unrealistic compared to other countries. There are no criterias for calculating construction equipment costs according to operating hours. The loss is not realistic and there is no clear basis of calculation. Lack of wage characteristics by region. Cost reduction factors according to technology development are not reflected.
Others	There is a difference between the standard data and actual operation time data (lack of clear standard annual operation time) of construction equipment. Hindrance to the application of new technologies and methods. Complexity of calculation and cost omission danger.

Many of these problems are related to the accuracy of labor, however not enough actual measurement data exist to demonstrate how different the labor estimation is from reality. Furthermore, the same estimation system is applied without considering the field conditions and engineering methods in detail. Therefore, it is necessary to examine the current "Standard Estimating", and to analyze overseas cases. If the estimation system can be improved in a constructive way by referring to overseas cases, the reliability of the system as well as the convenience of users will greatly improve.

3.2 Productivity Estimating Concept

To develop time and cost data, a price book of the USA, UK, and Japan is investigated, and the RS Means (Building Construction Cost Data) based on one-day productivity is decided to benchmark [6]. The RS Means offers construction cost information: the daily productivity, input manpower, equipment, and cost data in many different situations. Thus, labor hours and bare cost is measured in this study among the many factors influencing productivity. Furthermore, to build the labor time and cost data for one day's work for each process is focused on this research.

Based on 8 hours per day, daily output has a negative correlation with labor, while bare cost has a negative correlation with labor number and labor cost. These correlations are illustrated in Fig. 2.

In this way, the productivity concept and the duration data can be established by calculating the input labor hours for output. Furthermore, cost data can be established by considering the input labor number and the labor cost. This process is identical to the process of establishing time and cost data of the RS Means, which is used in the USA [6].

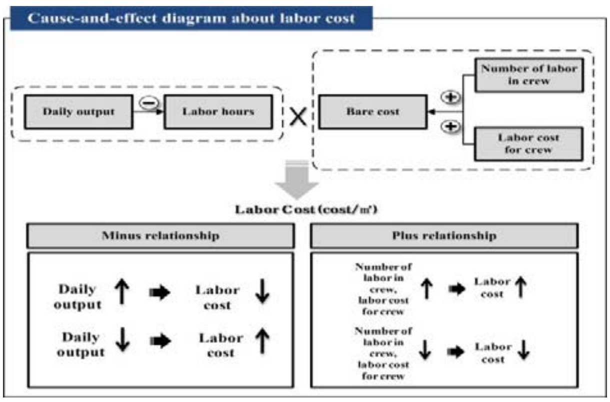

Fig. 2 Cause and effect diagram about labor cost

3.3 Probabilistic Approach

Many factors differentiate models, however when they are classified by the type of result, they can be divided into deterministic or probabilistic models.

The deterministic model derives a single result or a set of results as output data through defined input data sets. The probabilistic model derives various results as output data through input data sets that are defined or have a probability distribution, and it requires statistic interpretation for the results.

The probabilistic model is synonymous with the stochastic model, process, or system. The probabilistic approach mainly uses two methods: the second moment

Table 3. Site information table

Site Information							
Field name	OO District	**Floor**	4 Floors	**Observation date**	2010.5.26	**Weather**	Clear
Building name	307	**Number of households**	3	**Observation start**	PM 1:30		
Activity	Placing concrete						

Start time	1:30	2:45	3:40	4:33	4:41	4:53	5:49	6:25	6:40	**Total time**
End time	2:45	3:40	4:33	4:41	4:53	5:49	6:25	6:40	7:05	5:35
Work	Ready to pump car	1 households placement	2 households placement	Core placement	Rest time	3 households placement	Finishing	Distributor decomposition	Re-finishing	
Labor	**6**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	

Labor	**Material**	**Equipment**	**Others**
1 Labor foreman, 2 Vibrator 2 Cement finisher, 2 Labors	Concrete 162 ㎥	Pump car, Vibrator	

Number of R.M.C.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	.....
Start	2:44:10	2:51:01	14:51:01	15:00:09	15:07:32	15:13:43	15:28:58	15:37:30	15:43:37	15:49:54	15:55:50	16:01:24	16:06:51	16:12:32	.....
End	2:50:59	2:59:49	14:59:49	15:08:00	15:14:08	15:29:09	15:38:17	15:44:02	15:50:27	15:56:10	16:01:55	16:07:13	16:13:03	16:18:15	.....
The time elapsed (minute)	6:49	6:16	6:23	8:09	6:36	5:25	6:10	6:32	6:50	6:16	6:55	5:49	6:12	5:43	.....
Note (Delay time)		14:54:22-14:56:54	15:04:28-15:06:53			15:14:02-15:24:11	15:30:37-15:33:16 15:33:27-15:33:57								.....

approach and the Monte-Carlo method. The former can determine the total cost and total duration through the mean, variance, standard deviation, and correlation coefficients between related variables. As they are easily computed, it is easy to use spreadsheets or a handheld calculator. The Monte-Carlo method derives various results through the simulation of random events(random trials) for input data sets.

This study uses the second moment approach for the convenience and ease of acquiring the application program by users on construction sites.

4. PROCESS DEVELOPMENT

4.1 Data Collection and Analysis

As mentioned previously, the concrete pouring activity is chosen as the target work type. To collect the productivity data of this activity, the target subject, work type, and site are selected. Among potential subjects(contractor, consultant, designer, subcontractor, and owner), the contractor is required to perform cost and schedule planning, and so is selected as the subject.

Since cooperation of the site is essential for collecting time and cost data based on the productivity of a reliable site, a contractor who is cooperative with regard to the provision of field information is chosen. 6 m^3, the capacity of truck used to be a measure of pouring activity. The productivity in the RMC (ready-mixed concrete) pouring truck unit is investigated using the table in Fig. 3. As a result, we acquired lots of data through these processes. The data is shown in Table 3.

4.2 Data Analysis

In order to apply the concept of probabilistic, it is needed to identify the distribution of the collected data.

According to "Central Limit Theorem", it is assumed that collected data followed "Normal Distribution". And then second moment approach is applied. The process can be summarized as follows

(1) Compute mean value, variance, standard deviation
(2) Compute Correlation and Covariance Matrix
(3) Using the computed total mean and variance, with the assumption of Normality, plot the probability distribution for total activity time

In this result, seven-member crew's probabilistic productivity of concrete pouring is from 160 to 195 minutes per 162 m^3. The probability of finishing in 167.7 mimutes is 5%, and the probability of finishing in 180.2 mimutes is 95%. The mean value is 174minutes, and the expected value is 174.4minutes.

4.3 Productivity Data Translation Process

Time and cost data from the estimated productivity (mean value or expected value) largely consists of (1) material information and (2) labor information [7].

(1) The material information is prepared using the "Standard Estimating".
(2) The labor information is developed in the following Sequence of considering the productivity calculated from the site [7].

i) Examine the crew responsible for the activity. In the above example, the crew has 4 workers in LABOR A (concrete labors) and 3 workers in LABOR B(labors).

ii) Determine the total labor hours of the crew based on 8 hours per day.
ex: Total Labor Hour(L.H.) = 7 labors × 8hr = 56hr

iii) Measure area that can be worked by this crew for one day, or the daily productivity of the crew.
The crew in this example can work 162 m^3 per day.

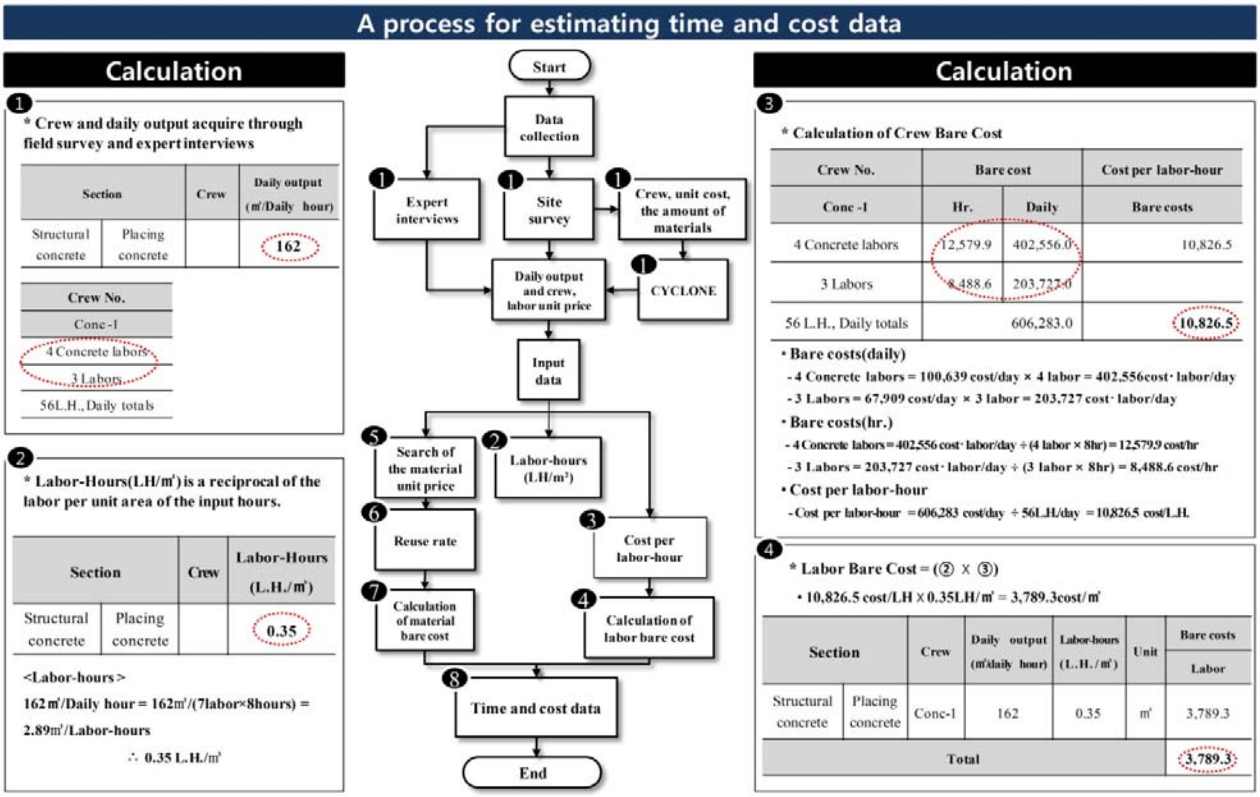

Fig.3 A process for estimating time and cost data

iv) Determine the labor hours by substituting the total labor hours for daily productivity in the formula.

ex: 162 ㎥/daily hour = 162 m^3/(7labor×8hours)
= 2.89 m^3/L.H.

Get the reciprocal of the result of the above formula because the labor hours here are the input hours of the labor per unit area

$$\frac{1}{2.89m^3/\,L.H.} = 0.35\ L.H./m^3$$

This means that 3.5 labor hours are required for crew "Conc-01" to work the construction unit of 10 m^3.

v) Record the labor cost when the Total Labor Hours for the crew is input.

ex: • 4 Concrete labors = 100,639 cost/day × 4labor
= 402,556 cost·labor/day
• 3 labors = 67,909 cost/day × 3labor
= 203,727 cost·labor/day
• Total cost = 603,283 ₩

vi) Divide the cost of the crew by the Total L.H.

ex: Cost Per L.H.= 606,283 cost/day ÷ 56L.H./day
= 10,826.5 cost/L.H.

vii) Determine the time and cost data by multiplying Labor hours by bare cost.

ex:Labor bare costs = 10,826.5cost/ L.H × 0.35 L.H./ m^3 = 3,789.3cost/ m^3

5. VALIDATION

The time and cost data could be established for the concrete pouring activity through the productivity data translation process.

In order to determine whether there are differences between this productivity data and the "Standard Estimating", a t-test is performed. The t-test used to prove that the means of two groups are statistically different from each other[8]. In this study, the two groups are defined as follows:

Group A (μ_1) is the error rate between the other construction site productivity and the productivity of the time and cost data.

Group B (μ_2) is the error rate between the other construction site productivity and the "Standard Estimating".

It is assumed that the mean error rate of Group A is less than that of Group B. Hence, the alternative hypothesis is

$$H_1: \quad (\mu_1 - \mu_2) < 0$$

As usual, the null hypothesis follows :

$$H_0: \quad (\mu_1 - \mu_2) = 0$$

To identify the test statistic, the output between A and B is instructed. There is reason to believe that the population variances are unequal.

Table 4. t-test: Two-Sample Assuming Unequal Variance

Category	T test							
	Mean	Variance	Observations	Hypothesized Mean D.	df	t Stat	P(T<=t) one-tail	t Critical one-tail
GROUP A	43.301	934.824	28	0	54	-6.046	0.00000007	2.397
GROUP B	110.802	2554.978	28	-	-	-	-	-

Consequently, this research use the unequal-variances test statistic. The results are shown in Table 4.

The value of the test statistic is – 6.05. The one-tail p-value is near 0. The p-value of the test is very small and the test statistic falls into the rejection region. As a result, there is evidence to infer that the data of Group A is more precised than Group B.

Overall, the analyses by t-test indicate that the result of this productivity data has a significant precision than the "Standard Estimating". However, contractor should be aware that a significant precision exists among activities when field conditions are considered.

6. CONCLUSIONS

Many studies have suggested methods for productivity data collection, productivity measurement, applications of productivity measures, and productivity prediction. However, development of processes and systems that can be easily used at the site has been insufficient. Thus, a specific algorithm that can be used with spreadsheets is required.

This study developed time and cost data for the concrete pouring activity as the first phase of a research project. The main results of this study are as follows:

(1) To estimate duration and cost with productivity, the process of time and cost estimating model is presented.

(2) The time and cost data for complementing the existing "Standard Estimating" is developed by using a probabilistic approach and considering field conditions.

(3) The statistical test showed that the results are significant. In the future, we will collect data for other construction-related activities.

In addition, the result will be provided as the Earned Value Management System (EVMS) baseline for schedule and cost management and used to calculate more reliable duration and cost data for the time and space limited project.

Since this study only covered the concrete pouring activity, the scope of study should be expanded in the future and more studies are needed with regard to automation methods.

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REFERENCES

[1] Victor E. Sanvido, "Conceptual Construction Process Model", 1988

[2] Mohamed, A. N. "Knowledge based approach for productivity adjusted construction schedule", *Expert systems with applications*, Vol.21(2), pp. 87-97 ,2001

[3] Md. Salim, Leonhard E. Bernold, "Effects of Design-Integrated Process Planning on Productivity in rebar Placement", *J. Constr. Eng. Manage.*, Vol.120(4), pp.720~738, 1994

[4]"Direct Labor Productivity Measurement – As Applied In Construction and Major Maintenance Projects", No. 22R-01, AACE International Recommended Practice, 2004

[5] Cho,K., Hong, T., Hyun,C., "Integrated schedule and cost model for repetitive construction process", *J. Constr. Eng. Manage.*, Vol.26(2), pp.78~88, 2010

[6] RS Means, Building Construction Cost Data, 2010

[7] Ministry of Land, Transport and Maritime Affairs of the Korean government, Development of estimating fair construction cost and building management system, 2010

[8] Keller Warrack, Statistics for management and economics, Thomson Learning, Inc., 2003

[9] Awad S. Hanna, Jeffrey S. Russell, Timothy W. Gotzion, Erik V. Nordheim, "Impact of Change Orders on Labor Efficiency for Mechanical Construction", *J. Constr. Eng. Manage.*, Vol.125(3), pp.176~184, 1999

[10] David S. Cottrell, "Contractor Process Improvement for Enhancing Construction Productivity", *J. Constr. Eng. Manage.*, Vol.132(2), pp.189~196, 2006

[11] Eric Allmon, Carl T. Haas, John D. Borcherding, and Paul M. Goodrum, "U.S. Construction Labor Productivity Trends, 1970–1998", *J. Constr. Eng. Manage.*, Vol.126(2), pp.97~104, 2000

[12] Makarand Hastak, Sanjiv Gokhale, Kartik Goyani, Taehoon Hong, and Bhavin Safi, "Analysis of Techniques Leading to Radical Reduction in Project Cycle Time", *J. Constr. Eng. Manage.*, Vol.134(12), pp.915~927, 2008

[13] Osama Moselhi, Ihab Assem, and Khaled El-Rayes, "Change Orders Impact on Labor Productivity", *J. Constr. Eng. Manage.*, Vol.131(3), pp.354~359, 2005

[14] Paul M. Goodrum, Carl T. Haasm, "Long-Term Impact of Equipment Technology on Labor Productivity in the U.S. Construction Industry at the Activity Level", *J. Constr. Eng. Manage.*, Vol.130(1), pp.124~133, 2004

[15] Paul M. Goodrum, Dong Zhai, and Mohammed F. Yasin, "Relationship between Changes in Material Technology and Construction Productivity", *J. Constr. Eng. Manage.*, Vol.135(4), pp.278~287, 2009