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PRODUCTIVITY PREDICTION MODEL BASED ON PRODUCTIVION INFLUENCING FACTORS: FOCUSED ON FORMWORK OF RESIDENTIAL BUILDING

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ABSTRACT: Construction Productivity is one of the most important elements in construction management. It is used in construction process scheduling and cost management, which are significant sector in construction management. It is important to make appropriate schedule and monitor how works are done within schedule. But construction project contains uncertainty and inexactitude, modifying construction schedule is being an issue to manage construction works well. Even though prediction and monitoring of productivity can be principal activity, it is hard to predict productivity with manager's experience and a standard of estimate. A large number of factors influencing productivity, such as drawing, construction method, weather, labor, material, equipment, etc. But current calculation of productivity depends on empirical probability, not consider difference of each influencing factor. In this research, the aim is to present a productivity predicting regression model of form work, which includes effectiveness of influences factors. 5 variables existed inside form work are selected by interview and site research based on literature review of existed various productivity influencing factors. The effectiveness and correlation of productivity influencing factors are analyzed by statistical approach, and it is used to make productivity regression model. The finding of this research will improves monitoring and controlling of project schedule in construction phase.

Keywords: Productivity; Productivity Influencing Factor, Productivity Prediction, Formwork

1. INTRODUCTION

Construction Productivity is a significant factor which affects on construction project planning with work breakdown system, labor, quantity, and work process. Also Importance of productivity is embossed (Allmon 2000). Labor productivity is major index for evaluating efficiency of production (Rojas 2003).

In general, productivity means input material per produced which is used in planning and monitoring process. Labor productivity in construction industry is calculated by man-hour per quantities installed. Labor productivity in construction site is computed using manager's experience and standard quantities, but it has low reliability to use. Standard quantity which is provided by Construction Economy Research Institute of Korea makes difference in estimating productivity in site (Jeon 2008). So, productivity predicting model is demanded which can be used to manage labor and process in construction site.

Meanwhile, each of productivity Influencing factors has several important position in various situations. Some condition can affect on factors, so productivity prediction model should cover those variation (Lim 2008).

In summary, securement of reliability in productivity information is magnified as an important point. There are many approaches that include productivity measurement, selecting productivity influencing factor, and productivity prediction. To improve reliability of productivity using in process management and labor management, the purpose of this research is to suggest productivity prediction by application of productivity influencing factors by extracting productivity influencing factors and assessing effectiveness.

The process of this research includes; arranging productivity influencing factor in construction sites, extracting PIF of form work, statically analyzing to set up productivity regression model. The proposed methodology is developed in the following four steps:

(1) Modeling of the selection of the variables on the factor of productivity influencing factor from literature review is driven to construct through the list of factors. Factors are extracted by literature reviews and the criteria of selection are effectiveness and importance on form work.

(2) Selected factors measure quantitative to analyze by multiple regression. Qualitative factors are converted

quantitative by measuring loss of time and delayed time from factor.

(3) Multiple regression analysis about productivity is done to analyze relationship and effectiveness. In this phase, step-wise extraction is used to select variables. All variables are statistically validated.

(4) Then regression equation is set up by using coefficients calculated from regression. This equation is used to predict productivity from factors. Validation of equation is done through comparison with result of project.

The object of this research is productivity prediction of form work. The target is form work trade of residential building in Korea. Collected data is from 12 buildings of apartment during 60 days. The detail research process is summarized in following figure 1;

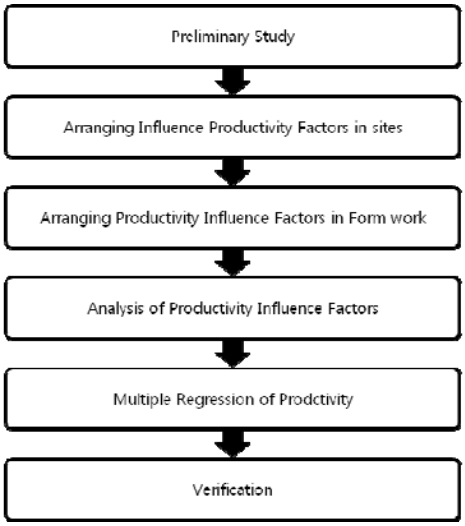


Figure 1. Process of Research

2. PRELIMINARY STUDY

Many researches focused on productivity management and productivity influencing factor assessment. This chapter presents an analysis of definitions, relevant literature, and current indices that indicates the inadequacy of existing research. The need for improved productivity prediction emerges from this analysis.

2.1 Productivity Influencing Factor

Several researches about productivity influencing factors are in various fields. Most of researches define productivity influencing factors as affecting elements existed in sites and out. Productivity influencing factors are divided into productivity improvement factors and productivity impediment factors.

Son(2005) suggests categorization of productivity improvement factors as main target of productivity influencing factor, and sets 17 factors of them. Detail factors are validated by availability and effectiveness of adjustment. This paper emphasizes factors about construction management as the most important point. But it concentrates in improvement of productivity, analysis about scale and application of factors are insufficient. Park(2006) emphasizes continuity of work as productivity influencing factor. Continuity of work can be measured by input of resources. This paper tries to control investment of resources, as improvement method of productivity. Consistency and confidence of work flow should be controlled to manage productivity. Target of consideration is direction of work, rationality of preparation, work order, size of work, and learning of work practice.

Han(2003) analyzed productivity impediment factor of main trades by interview and survey. Among selected 5 main trades of construction, structural work and earth work are the most effective phase, and the reasons of delays in construction are civil complaint and weather condition. However analysis about effectiveness of factor is insufficient. Ahn(2007) classifies productivity impediment factor and extracts effectiveness and seriousness by survey. He suggests lists of emphasis item of management, and says it is necessary to try microscopic management. Lim(2008) selects productivity influencing factors of structural work in residential building. He analyzes relationship of factors and set list of factors which are effective in productivity forecasting. But the list of factors doesn't have categories of problems about material and work progress.

2.2 Productivity Prediction Model

Thomas H.R.(1986) uses data from several projects to analyze effectiveness of weather condition by multiple regression. Temperature and humidity are main variables, and the equation is used to predict productivity achievement. Weather condition makes variation of productivity in same condition, and it shows possibility of productivity prediction by multiple regression method.

Lingguang Song(2008) suggests productivity model based on historical data to analyze and predict productivity. CAD-based quantity and online survey are used in accumulation and application of historical data. He uses ANN modeling to figure out productivity model of rebar work.

Woo(2008) introduces PC, PDA, and RFID to collect construction data, and suggest data-mining method to analyze productivity data. Through the historical data, productivity and working time are forecasted.

2.3 Summary

Researches about productivity influencing factors are concentrated in categorization of factors and calculate importance of them, and research methods are Survey and interview. Composition of productivity influencing factors shows a considerable difference in trades, and some trades are influenced by particular factors.

Productivity Prediction models use historical data to analyze. Each factor show effectiveness and the effectiveness is used to predict productivity in several ways. But most of researches emphasizes on characteristic of project. Through the internal factors of productivity are insufficient, it is hard to analyze problems in material management or construction schedule management. Also, the factors are different between each researches, it is hard to analyze variance of productivity in a construction project.

In this research, productivity influencing factors of form work is categorized, and productivity prediction model using these factors is suggested. The target is limited in internal factors and form work. To analyze effectiveness and relationship of factors, multiple regression method is used. Factors are measured quantitative to increase accuracy of prediction

3. INTERNAL INFLUENCING FACTORS IN CONSTRUCTION SITES

Productivity Influencing factors are existed in sites and out throughout. On account of complexity in construction factors, it is hard to define relationship of each effect of internal and external elements. To assess and analyze factors in construction sites as independent relationship, this research focuses on internal factors.

3.1 Extraction of Productivity Influencing Factors

Internal productivity influencing factors include 7 categories; site characteristic, labor, design, management, material, equipment, and external factors.

Except site characteristic and external factors, extraction of factors about form work by consideration in literature review. Priority of extraction is importance and effectiveness about form work. Result of primary extraction is as follow table 1.

Table 1. Categorization of Productivity Influencing factor

Category	Detail factor
Site characteristic	Building Area
	Structure
	Foundation Work
	Area of Site
	Downtown or not
	Number of Household per building
	Number of Buildings
	Safety Hazard
	Number of Floors
	Design
	Level of Finishing
Labor	Skill of Labor
	Number of Labor
	Labor Organization
	Dependence of Labor
Design	Error of Drawing
	Omission of Drawing
	Delay of Drawing
	Completion of Drawing
	Design Alteration
Management	Unfinished Precedence Work
	Pace of Communication
	Standardization of Work
	Mistake in Work Order
	Re-work
	Overwork
Material	Material Shortage
	Material Error
	Material Stacking
	Material Procurement
Equipment	Inexpedience/Insufficient Equipment
	Inexpedience/Insufficient Tool
External factor	Complaint
	Regulation
	Economic Situation
	Temperature
	Rainfall

3.2 Productivity Influencing factor of Form Work

For using in productivity prediction model, secondary extraction of factors is done by interview. 4 construction managers respond about effectiveness and availability of each factor. First, equipment of form work is stable in work to use in regression. Second, factors of management are hard to assess in quantitative unit, so work related factors are measured by time unit and manager related factors are rejected. Third, drawings are usually finished before construction. Forth, labors work in their own work and there is no multiple workers. Fifth, site area, region, and design are difficult to measure and unsuitable to compare. So those factors are excluded to get availability of productivity prediction. The result of secondary extraction is table 2.

Table 2. Extracted Productivity Influencing factors

Category	Detail factor
Labor	Skill of Labor
	Number of Labor
Design	Error of Drawing
	Design Alteration
Management	Unfinished Precedence Work
	Mistake in Work Order
	Re-work
	Overwork
	Work Break
Material	Material Shortage
	Material Error
External Factor	Temperature
	Rainfall

3.3 Measurement of Influencing Factor

Measurement of each factor is order to reflect effect on productivity of form work. Measurement of each factors are as follow:

- Skill of Labor: it means level of labors which can be measured by the length of work.
- Number of Labor: number of worked crew workers.
- Error of Drawing: loss of working time by error of drawing.
- Design Alteration: loss of working time by alteration in drawing.

- Unfinished Precedence Work: loss of working time by waiting finish of precedence work.
- Mistake in Work Order: loss of working time by error of order
- Re-work: re-worked time of working day
- Overwork: working time over base working time
- Work Break: break time of work owing to undefined reason
- Material Shortage: loss of working time by material shortage
- Material Error: loss of working time by error in material management
- Temperature: temperature of working day
- Rainfall: rainfall of working day

Table 3. Sample of productivity data

DATE	TEMP	RAIN	LBR_n	LBR_SKL	MTR_ERR	MTR_SHRT	DESG_ERR	DESG_CHG	W_BREAK	W_OVER	W_RE	W_REC	PRD.
8-31	22.6	0	2	16	0	0	0	0	0	1	0	1	7.473
9-1	23.7	0	2	16	0	0	0	0	0	2	0	0	11.826
9-2	23.4	0	2	12	0	0	0	0	0	0	0	1	8.834
9-3	23.2	0	2	12	0	0	0	0	0	2	0	1	7.353
9-4	24.3	0	2	16	0	0	0	0	1	0	0	1	11.430
9-5	25	0	2	12	0	0	0	0	0	2	0	0	8.170
9-6	25.2	0	2	16	0	1	0	0	1	1	0	0	7.494
9-7	23.7	0	3	12	0	0	0	0	0	2	0	0	8.600
9-8	23.4	0	2	16	0	0	0	0	0	1	0	5	5.129
9-9	23.2	0	2	16	0	0	0	0	0	0	0	0	9.255

4. Productivity Prediction Model

Based on selected productivity influencing factor, multiple regression analysis is used to estimate influence of each factor and set up an equation of productivity prediction. Dependent variable of this analysis is productivity of form work, and it is calculated by following equation.

$$P_{L_{i,j}} = \frac{Q_{d_{i,j}}}{M_{d_{i,j}} \cdot T_{d_{i,j}}}$$

$P_{L_{i,j}}$: Labor productivity of form work (m^2/manhour)
$Q_{d_{i,j}}$: Quantity of d_i for crew j
$M_{d_{i,j}}$: Number of crew j in d_i
$T_{d_{i,j}}$: Working time of crew j in d_i
i: work day
j: labor crew

Process record of form work is analyzed for multiple regression analysis of productivity. Data collected from a residential site which is composed of 12 building. Except data from 1 building for verifying, analysis used data of 11 buildings in 60 days and part of these are following table 3. Variables measured in interval scale.

4.1 Extraction Model of Variables

Step-wise regression method is used in extraction process of productivity influencing factors to identify the effect of influencing factors and increase accuracy of prediction. Step-wise regression method is select factors which have most effective factor first and add and remove all factors in order of effectiveness continuous. When the R-value is high, which reflect accuracy of regression model, stop modification of variables and set the model of variables for regression model. Result of extraction is 5 models as following table 3. Each model has 1 to 5 factors and each factors R value is presented. By evaluating of R value and standard error, model 5 is most accurate predict model.

Table 4. Summary of models

Model	R value	R square	Adjusted R square	Std. Error of the Estimate

Table 5. Coefficient Correlations

Model		VAR	RAIN	W_PREC	MTR_ERR	W_BREAK	W_OVER
5	Correlations	RAIN	1.000	.003	.036	.012	-.004
		W_PREC	.003	1.000	-.048	.035	.039
		MTR_ERR	.036	-.048	1.000	.048	-.020
		W_BREAK	.012	.035	.048	1.000	-.027
		W_OVER	-.004	.039	-.020	-.027	1.000
	Covariances	RAIN	.000	.000	.000	.000	.000
		W_PREC	.000	.012	-.001	.000	.000
		MTR_ERR	.000	-.001	.053	.001	.000
		W_BREAK	.000	.000	.001	.008	.000
		W_OVER	.000	.000	.000	.000	.011

1	.509(1)	.259	.256	2.492541
2	.673(2)	.453	.448	2.147287
3	.712(3)	.507	.501	2.041427
4	.753(4)	.567	.560	1.917890
5	.761(5)	.579	.570	1.895205

Note: Dependent Variable : Productivity
1. Predictors: (Constant), RAIN
2. Predictors: (Constant), RAIN, W_PREC
3. Predictors: (Constant), RAIN, W_PREC, MTR_ERR
4. Predictors: (Constant), RAIN, W_PREC, MTR_ERR, W_BREAK
5. Predictors: (Constant), RAIN, W_PREC, MTR_ERR, W_BREAK, W_OVER

4.2 Correlation Analysis

Effect of each factor is analyzed by correlation analysis. Following factors line up in order of effectiveness; rainfall, unfinished precedence work, error of material, work break, and overwork. Other variables are removed to enhance accuracy of model. Table 4-3 is coefficient relation analysis of 5 factors. On account of Multicollinearity, all variables should have less than 0.05 to have reliability of regression analysis. All variables are independent.

Selected variables are According to a result of correlation analysis; there are no variables that have multicollinearity. And final list of variables are in table 4-4. Removed factors are temperature, number of labor, skill of labor, material shortage, error of drawing, alternation of drawing, and rework. Temperature and factors about drawing in collected data did not fluctuate enough to find correlation with productivity. Number of labor was not effective in productivity of form work. Rework and material shortage has multicollinearity with material error and work break, so they are reconsistituted with other factors.

Table 6. Summary of Variable

Model	Variable		Variable Explanation
5	Added	RAIN	Rainfall
		W_PREC	Unfinished precedence work
		MTR_ERR	Error of material
		W_BREAK	Work break
		W_OVER	Overwork
	Removed	TEMP	Temperature
		LBR_n	Number of labor
		LBR_SKL	Skill of labor
		MTR_SHRT	Material shortage
		DESG_ERR	Error of Drawing
		DESG_CHG W_RE	Alternation of Drawing Rework

4.3 Analysis of Regression Model

Variance analysis of selected variable model is following table 4-5. F value of the model is 61.762 and p-value is 0.000. It means this model have reliability in significance of 0.01

Table 7. ANOVA

Model		Sum of square	Degree of Freedom	Mean Square	F-value	Sig
	Regression	1155.759	8	231.152	64.355	.000 (5)
	Residual	840.481	234	3.592		
	Total	1996.240	239			

Coefficients of each variable are calculated from regression model. All coefficients are statistically meaningful by significance of 0.01.

Table 8. Coefficients

Model	Coefficient	Unstd. Coefficients		Std. Coefficients	t	Sig.
		B	Std. Error	Beta		
5	(Constant)	11.306	.367		30.847	.000
	RAIN	-.126	.010	-.522	-12.293	.000
	W_PREC	-1.142	.110	-.441	-10.377	.000
	MTR_ERR	-1.321	.231	-.244	-5.728	.000
	W_BREAK	-.508	.089	-.242	-5.686	.000
	W_OVER	-.271	.105	-.110	-2.581	.010

From coefficient analysis of variables, regression equation of productivity prediction is set. The equation includes 5 variables and all coefficients have minus values. It means variables affect negative to productivity.

$$y = 11.306 - 0.126\,x_1 - 1.142\,x_2 - 1.321\,x_3 - 0.508\,x_4 - 0.271\,x_5$$

x_1: RAIN

x_2: W_PREC

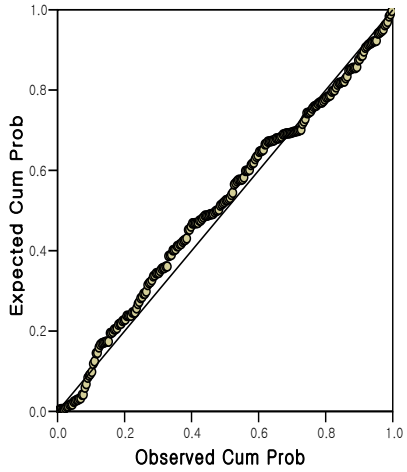
x_3: MTR_ERR

x_4: W_BREAK

x_5: W_OVER

In this equation, 5 quantitative variables are used to prediction productivity. To predict productivity, it is needed to put value of variables in the equation and calculate the equation. If variables have larger value, productivity decreases, especially the value that delay of precedence work and error of material affect. Values of x_2, x_3, x_4, and x_5 have unit of hour, and rain fall is measured by unit of mm.

The plot of regression is as follow fig 4-1.



Dependent Variable: Productivity

Fig 2. Normal P-P plot of Regression Standardized Residual

3. INTERNAL INFLUENCING FACTORS IN CONSTRUCTION SITES

Chapter 5. Verification of Predict Model

In this chapter, the equation of productivity is verified by substituting collected factors in equation and compares with collected productivity data. The regression model has no factor about site characteristic and external problems. Therefore, data used in this chapter is part of 12 buildings which removed from regression modeling to decrease error of those factors. Table 9 includes data for verification.

Table 9. Data for Verification

No.	X1	X2	X3	X4	X5	Productivity
1	0.20	1	0	3	3	6.876
2	0.50	0	0	0	4	10.558
3	0.00	0	0	0	2	10.341
4	21.50	1	1	0	1	7.166
5	0.00	0	1	0	2	10.286
6	0.50	1	0	1	5	7.727
7	0.50	2	0	0	4	8.869
8	0.00	0	0	0	2	10.885
9	0.00	3	0	2	5	4.426
10	0.00	2	0	2	3	6.966

Note; x_1: RAIN

x_2: W_PREC

x_3: MTR_ERR

x_4: W_BREAK

x_5: W_OVER

Table 10. Verification of Prediction

No.	Productivity	Predicted Productivity	Deviation	Error Rate
1	6.876	6.726	0.150	2.18%
2	10.558	10.581	0.023	0.21%
3	10.341	10.266	0.074	0.72%
4	7.166	6.874	0.292	4.08%
5	10.286	10.201	0.085	0.83%
6	7.727	7.371	0.356	4.61%
7	8.869	8.436	0.433	4.88%
8	10.885	11.134	0.250	2.29%
9	4.426	5.131	0.705	15.92%
10	6.966	6.699	0.268	3.84%

Most of results have error rates less than 5 %, but one has more than 15 %. To find out reason of error, data analyses in detail. It has three problems in process; break of work, overwork, and delay of precedence work. Because of reiteration, productivity makes a large amount of deviation. From correlation analysis of factors, there was no dependence between factors. However it makes a synergy of those factors in productivity. Therefore it needs more analyses about reiteration effect of factors. But in this research, number of those problematic data is insufficient to define effect. Quantitative deviation is less.

6. CONCLUSION

To improve reliability of productivity prediction in the construction industry, this paper lists up independent influencing factor of form work from literature and interview. These factors are analyzed in statistical method. Productivity influencing factors are listed in categories and selected for regression. Measurement of factor did quantitative to make easy to measure and adjust simply in regression model. Through multiple regression of productivity and productivity influencing factors, the equation of productivity prediction is set up. It is verified by comparison between predicted productivity and productivity of site result.

This chapter will summarize the research results and examine the possible contributions of the model to the construction industry. A direction for additional study then is indicated.

6.1Result and Discussion

Productivity prediction is a major issue in construction management, but it is hard to reflect all of factors which can affect on productivity. In this research, list of

productivity influencing factor is focused on two parts; form work and internal influencing factors. Analysis of factors finds relation of each factor, and lists up the influencing factors which can use in regression model. The model can predict productivity by using quantitative measured factors. This study suggests a productivity prediction that considers influencing factors that affect on form work internal. The methodology suggested in this study is as follows:

(1) Extracting Productivity Influencing factor

Productivity influencing factors are various in trades. To predict productivity, this research extract internal influencing factor by literature review and site research. Removed factors are related with external condition which can decrease accuracy of result which is carried out internal factors.

(2) Selecting Productivity Influencing factor of Form Work

Form work, which has large amount of portion in construction phase, is important trade in management. To define PIF of form work, this research extracts factors from literature, site research and interview from field. Factors are arranged by availability and accuracy.

(3) Analysis of Productivity Influencing Factor

To find relation of PIFs, multiple regressions are used to analyze. Each factor should be independent to be used in regression. In this phase, some dependent factors are integrated in other factors to analyze.

(4) Suggesting Productivity Prediction Model using Multiple Regression

Using selected factors as variables, productivity prediction model is set up by regression. Coefficients of factors have negative value due to measuring unit of them. Regression equation of productivity has 5 variables and 1 constant which can be measured quantitative.

(5) Validation of Prediction Model

Substituting collected data as variables are used to validate the model. Used data is collected by 1 building which is not inputted in regression data. Comparison of both expected productivity and result of real project shows similarity of output.

6.2Contribution

This research suggest productivity prediction model which can predict productivity by using measured data from site. Data include weather, labor, material, management, and internal problems. By regression, productivity can calculate in equation of productivity influencing factors.

Unlike previous research, this study considers factors which can measure quantitative in site to make prediction accurately. However there are some undisclosed problems in result of field which cannot be explained with factors.

In this research, some internal factors are suggested to be measured in site. These are independent with each other to use in regression predicting model. It shows some factors can be measured in site have abundant effects to productivity. It can be a guide to manage productivity in construction site. Also, it is possible to expect productivity of each work and compare with done work to verify work condition or management. Productivity can be measured and expected both methods; it makes a way to assess productivity in process.

6.3 Further Study

As a result of this study, areas for future, related studies have been identified. They include the following:

(1) Analyzing about Synergy Effect of Productivity Impediment Factors

As mentioned, some influencing factors shows a synergy effect on productivity which cannot be defined by regression. It is needed to analyze about those factors to adjust expected value and result of project. And it can define an uncontrollable productivity impediment which can be misled as an internal problem.

(2) Finding External Influencing factor

In this study, it is focused on internal influencing factors only. If external factors which can explain effect of site characteristic and external condition, the model can be used to compare each project and manage several projects within a combined system.

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