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Labor Productivity Model for Reinforced Concrete Construction Projects

Ho Myun Jang[1], Kyong Hoon Kim[2], Sang Hyeon Kim[3], Kyung Hwan Kim[4] and Jae Jun Kim[5]

[1] Ph D. Program, Department of Architectural Engineering, Hanyang University, Korea
[2] Ph.D. Program, Department of Sustainable Architectural Engineering, Hanyang University, Korea
[3] M.S. Program, Department of Architectural Engineering, Hanyang University, Korea
[4] Assistant Professor, Department of Architectural Engineering, Konkuk University, Korea
[5] Professor, Department of Sustainable Architectural Engineering, Hanyang University, Korea
Correspond to greatekkh@hotmail.com

ABSTRACT: This study aims to systematically identify direct and indirect factors that influence labor productivity and to build a model that mathematically quantifies them so as to efficiently manage and increase labor productivity in the construction work. This study was performed based on the productivity model for workers in reinforced concrete construction projects, because it aims to establish a general construction labor productivity model that reflects many factors that influence labor productivity. Using statistical analysis, we found that the components that significantly influence productivity were the worker component, the work characteristic component, the work technique component, the work management component, the equipment & materials component, and the work guide component, while the work delay components did not significantly influence productivity. In addition, a priority analysis was performed based on the components that showed statistically significant effects. The results of the analysis indicated that the influence of work management component and the work technique component is more than that of the worker component and the work characteristic component. The construction labor productivity model that was formulated in this study could be used for the determining the standard productivity during the initial planning stage, so the best strategy for increasing labor productivity could be formulated.

Keywords: Labor Productivity, Factors, Statistical Analysis, AHP(The Analytic Hierarchy Process) Model

1. INTRODUCTION

With today's improved standard of living, the domestic work force is increasingly avoiding 3D (difficult, dirty, and dangerous) jobs, which is deepening the lack of workers in a wide range of fundamental industrial fields. The lack of construction workers is becoming especially severe, and labor cost is increasing because the ages of workers are becoming higher [1]. Productivity is a very important component of the construction industry as an index for measuring the efficiency of production, by which the status of economic growth and its related production are measured from the industrial and corporate viewpoints. Many factors can be used to measure productivity. Managers can create diverse productivity data that take into account the measured productivity and the surrounding factors that influence it. These productivity data could become an index for measuring the performance of a project and could play a great role in decision-making during the project engineering process [3]. With insufficient productivity data management at construction sites, it is difficult to determine the causes of changes in productivity because various factors that influence productivity are not reflected in the analysis of the productivity data. This is because there is no systematic definition and classification of various factors that influence productivity [4]. Basic studies have been conducted that collected and analyzed construction productivity data using information technology, but they neither considered various factors that influence construction productivity nor presented a method of accumulating the productivity data generated from the field [5].

This study aims to systematically identify the direct and indirect factors that influence labor productivity, and to construct a model that mathematically quantifies them so as to efficiently manage and increase labor productivity in construction work. The construction labor productivity model that was formulated in this study could be the basis for the determination of the standard productivity during the initial planning stage so that the best strategy for increasing labor productivity could be formulated.

For this purpose, direct and indirect factors of labor productivity were first analyzed from a review of literature in and out of Korea. Then the scope and method of labor productivity measurement were determined. The final analysis model was derived through a statistical analysis of selected labor productivity factors from those culled from various literature.

The detailed research method is shown below.

(1) Based on previous studies, relevant literature in and out of Korea were examined to derive the factors of construction labor productivity.

(2) Questionnaires were prepared based on the derived factors, and data were collected from field investigations.

(3) Based on the collected data, a data reliability analysis was performed using a statistical analysis tool.

(4) The factors that were correlated with and influenced labor productivity were identified via a

correlation analysis. The factors that ended up below the significance level were removed.

(5) A factor analysis was performed to classify the factors into groups.

(6) A labor productivity model was constructed using regression analysis. Significant factors were analyzed and insignificant factors were removed.

(7) The factors were prioritized using AHP analysis with the help of interested field persons.

2. LABOR PRODUCTIVITY FACTORS

Labor productivity issues are receiving increasing attention within the construction industry [6]. Of the typical project cost components(material, equipment, and labor), labor is considered the project element containing the most risk. The other cost components(material and equipment) are predominately determined by market price and are consequently beyond the influence of the project management. As a result, the management of labor and its productivity becomes paramount in determining the success of a project [7].

When it is necessary to compress a schedule, contractors have to make a decision in selecting a method that accelerates the schedule while minimizing the cost impacts to the project. There are a number of methods of doing this. Frequently, the initial reaction of a contractor to schedule compression is to increase the on-site labor force [8]. Labor productivity is considered one of the best indicators of production efficiency. Higher productivity levels usually translate into superior profitability. However, there is still much that we do not know about this domain area that justifies further research [9].

Previous studies focused on finding out labor productivity factors based on surveys.

Nam [15] classified the labor productivity determinants into (1) education, (2) training, (3) health, (4) age, (5) sex, (6) average experience, and (7) average years of service.

Kim [10] classified the factors that influence construction labor productivity into (1) produced quantity, (2) percentage of prolonged working hours, (3) crew size, and (4) repetition effect by learning.

Pyo [16] classified the labor productivity deterioration factors into (1) design change, (2) work terms, (3) management characteristics, (4) project characteristics, (5) will to work, and (6) position and external conditions.

Thomas [17] classified the factors that influence labor productivity into the working environment and the executed work. He identified the working environment components as (1) crowdedness, (2) work continuity, (3) supervision, (4) factory conditions, (5) information, (6) equipment, (7) tools, (8) materials, and (9) re-work, and the executed work components as the (1) work size, (2) job type, (3) crew size, (4) overtime work, (5) percentage of workers, and (6) concrete pumping.

Sonmez [18] classified the factors that influence labor productivity into the (1) quantity of the completed work, (2) job type, (3) crew size, (4) percentage of overtime work, (5) percentage of laborers, (6) temperature, (7) humidity, (8) precipitation, and (9) concrete pouring.

Hanna [19] classified the factors that influence labor productivity into (1) order changes, (2) weather conditions, (3) trade stacking, (4) schedule compression, (5) work sequencing, (6) material problems, (7) overtime work, (8) labor problems, (9) work shifting, and (10) absenteeism and turnover.

Lu [20] classified the factors that influence labor productivity into the (1) project location, (2) administration, (3) duration of the construction work, (4) province/state, (5) contract type, (6) client, (7) engineering firm, (8) project manager, (9) superintendent, (10) work scope, (11) project type, (12) prefabrication/field work, (13) average crew size, (14) peak crew size, (15) unionization, (16) equipment and materials, (17) extra work, (18) order changes, (19) drawing and specifications quality, (20) location classification, (21) total work quantity, (22) installation quantities, (23) type of materials, (24) method of installation, (25) season, (26) crew ability, (27) site working conditions, (28) inspection, safety, and quality, and (29) overall degree of work difficulty.

Rojas9 classified the factors that influence labor productivity into (1) management systems and strategies, (2) manpower, (3) the industrial environment, and (4) external conditions.

In this study, the factors were reclassified into groups using previous research data. They were reclassified into five components: (1) equipment, (2) workers, (3) work characteristics, (4) materials, and (5) management and control.

(1) Equipment component: Equipment condition, number of equipment, equipment service time, equipment transport environment, equipment procurement delay, and equipment performance

(2) Workers component: Capability, sense of responsibility, health, age, sex, experience, education, training, expertise, motivation, communication, demoralization, conflict, poor work attitude, and overtime work

(3) Work characteristics component: Working space, prefabrication/standardization/field work, field accessibility, advance work, work method, work environment, crew size and composition, work difficulty, and work quantity

(4) Materials component: Material condition, material quantity, materials transport environment, material procurement delay, and material applicability

(5) Management and control component: Manager's capability, management system, field work plan, defects in design documents, permission/approval delay, order errors, strikes/public complaints and claims, safety/accidents, work delay and conversion, rework, work continuity, and information technology and integration

The weather component and the project component were excluded from this study, since many studies have already focused on them. Instead, this study addressed the other five components with many qualitative elements.

3. STATISTICAL ANALYSIS

3.1 Data Collection

The survey was performed via field interviews with the staff and field workers of companies with reinforced concrete construction experience in Korea, of reinforced construction specialty companies, and of contractors.

Table 1. Data Collection Summary

Items	Contents
Survey period	10.6.2008 - 10.25.2008
Participants	1) Construction/Management: 29%, 2) Supervision/CM: 12%, 3) Reinforced concrete construction: 59%
Survey method	Conversation and interview (57 items)
Analysis method	SPSS 12.0 statistical analysis

3.2 Reliability Analysis

The Cronbach's alpha method was used in this study as a statistical analysis method for the reliability analysis. Cronbach's alpha is a method that determines internal consistency based on the average correlation between items for an identical measurement. The alpha coefficient is considered high if it is 0.5 or more at the group level, and 0.9 or more at the personal level. The reliability analysis of 43 factors at the personal level resulted in a value of 0.967, which verifies the reliability of the model used in this study.

3.3 Correlation Analysis

From the correlation analysis, the factors that were not significantly correlated with labor productivity were removed. These were the equipment transport environment, equipment procurement, equipment performance, materials condition, materials applicability, worker communication, and workers' harmony. The significance probability was tested via a two-sided test, considering that a value of 0.05 or more violates the correlation.

3.4 Factor Analysis

The total variance explanation resulted in seven components with 1 or higher eigenvalues. This may indicate that a better analysis can be performed when all the components are classified into more than five components that influence labor productivity, as derived from literature. This is because various literature mention factors that influence general labor productivity, whereas this study addressed only the factors that influence labor productivity in the reinforced concrete construction sector.

An orthogonal factor rotation analysis was performed because the analysis of the loading was difficult in the factor analysis. As a result, the equipment component and the materials component were combined into one component, and the management and control component was divided into more components.

Table 2. Rotated Component Matrix

Factor	Component						
	1	2	3	4	5	6	7
Equipment condition		0.816					
Number of equipment		0.744	0.324				
Equipment service time		0.746					
Materials quantity		0.870					
Materials transport environment		0.864					
Materials procurement		0.822					
Worker capability	0.620	0.630					
Worker sense of responsibility	0.725	0.498					
Worker health	0.627	0.607					
Worker experience	0.574	0.517					
Worker education	0.829						
Worker training	0.821						
Worker expertise	0.810						
Worker determination	0.861						
Worker attitude	0.672			0.371			
Work space			0.616				
Prefabrication			0.762				
Working field accessibility		0.399	0.710				
Advance work		0.391	0.682				
Work method			0.757				
Work environment	0.349		0.731		0.314		
Crew composition	0.507		0.682				
Work difficulty	0.400		0.606				
Work quantity	0.357		0.682				
Manager capability		0.402			0.691		
Management system					0.715		
Construction plan					0.553	0.449	
Design documents			0.322			0.814	
Permission						0.749	
Work order			0.321			0.498	0.398
Claims	0.403			0.355			0.626
Safety/ Accidents	0.507				0.521	0.393	
Work delay			0.395	0.528			0.315
Rework				0.848			
Work continuity	0.362			0.741			
Information technology				0.617	0.447		

The components were redefined as follows, and a reliability analysis was performed for each group. The alpha coefficient is generally considered high if it is 0.5 or more at the group level. The following definitions of the components were made, Cronbach's alpha was obtained, and the reliability of each component was ensured.

- One component: worker (a = 0.949)
- Two components: equipment & material (a = 0.938)
- Three components: work characteristic (a = 0.920)

- Four components: work technique (a = 0.845)
- Five components: work management (a = 0.803)
- Six components: work guide (a = 0.836)
- Seven components: work delay (a = 0.691)

3.5 Regression Analysis

In the variance analysis, the SSR that was explained by the regression equation was 19.157, and the unexplained SSR was 20.563. After these values were divided by each degree of freedom, the mean square (MS) was obtained. The ratio of the two MS values (MSR/MSE) was the F-value of 6.521, and the p-value of the F-value was .000. Therefore, the result dismisses "the null hypothesis that the explanatory power of the regression equation (R^2) is zero ($H_0 : B_1 = B_2 = \dots = B_k = 0$)" and it is useful in the regression equation's explanation of dependent variables. The regression equation has a 48% explanatory power, and the regression model that is statistically significant (sig. < a = 0.05) is expressed as follows.

$$\hat{Y} = 0.179X1 + 0.366X2 + 0.315X3 + 0.236X4 + 4.070$$

(X1: worker component, X2: work characteristics component, X3: work technique component, X4: work management component)

Table 3. R Square

R	R Square	Adjusted R Square	Std. Error of the Estimate
.694 (a)	0.482	0.408	0.64780

Table 4. Variance Analysis

	Sum of Squares	df	Mean Square	F	Sig.
Regression	19.157	7	2.737	6.521	.000
Residual	20.563	49	0.420		
Total	39.719	56			

Table 5. Coefficients

Component	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	4.070	0.086		47.436	0.000
Workers	0.179	0.087	0.212	2.064	0.044
Equipment & materials	0.111	0.087	0.132	1.280	0.207
Work characteristics	0.366	0.087	0.435	4.231	0.000
Work technique	0.315	0.087	0.374	3.635	0.001
Work management	0.236	0.087	0.281	2.732	0.009
Work guide	0.090	0.087	0.107	1.040	0.304
Work delay	0.026	0.087	0.031	0.299	0.766

4. PRIORITY ANALYSIS

4.1 Data Collection

Based on the factors that influence labor productivity, which were derived using statistical analysis, the level of priority of each factor under each influential component was analyzed.

The statistical analysis aimed to establish a labor productivity model according to present conditions in the construction field. The AHP analysis was performed to determine the priority levels of the factors under the influential components that were derived using statistical analysis. Then the actual field conditions and the judgment of interested field personnel were compared.

Based on the derived influential factors, a pair-wise comparison questionnaire was prepared to calculate the priority level of each factor.

Table 6. Data Collection Summary

Items	Contents
Survey period	11.03.2008 - 11.15.2008
Participants	1) Construction/Management: 29%, 2) Supervision/CM: 12%, 3) Reinforced concrete construction: 59%
Survey method	Conversation and interview (57 items)
Analysis method	AHP Analysis

4.2 Pair-wise Comparison Matrix

Table 7. Pair-wise Comparison Matrix by Comparison

(CR = 0.0027)

Component	A	B	C	D
A	1.00	0.57	0.38	0.64
B	1.76	1.00	0.55	1.19
C	2.60	1.83	1.00	2.03
D	1.57	0.84	0.49	1.00

A: workers, B: work characteristics, C: work management, D: work technique

Table 8. Pair-wise Comparison Matrix by Factor A

(CR = 0.0009)

A	A1	A2	A3	A4	A5	A6	A7	A8	A9
A1	1.00	0.97	0.48	0.37	0.84	0.75	0.60	0.71	0.68
A2	1.03	1.00	0.49	0.38	0.86	0.77	0.61	0.72	0.69
A3	2.07	2.04	1.00	0.62	1.88	1.74	1.40	1.66	1.60
A4	2.69	2.66	1.62	1.00	2.50	2.36	2.02	2.28	2.22
A5	1.19	1.16	0.53	0.40	1.00	0.88	0.68	0.82	0.78
A6	1.33	1.30	0.57	0.42	1.14	1.00	0.75	0.93	0.88
A7	1.67	1.64	0.71	0.50	1.48	1.34	1.00	1.26	1.20
A8	1.41	1.38	0.60	0.44	1.22	1.08	0.79	1.00	0.94
A9	1.47	1.44	0.63	0.45	1.28	1.14	0.83	1.06	1.00

A1: worker capability, A2: worker sense of responsibility, A3: worker health, A4: worker experience, A5: worker education, A6: worker training, A7: worker expertise, A8: worker determination, A9: worker attitude

Table 9. Pair-wise Comparison Matrix by Factor B

(CR = 0.0018)

B	B1	B2	B3	B4	B5	B6	B7	B8	B9
B1	1.00	0.37	0.72	0.42	0.34	1.16	0.80	0.78	0.60
B2	2.67	1.00	2.28	1.31	0.77	2.83	2.42	2.39	2.01
B3	1.39	0.44	1.00	0.51	0.39	1.55	1.14	1.11	0.79
B4	2.36	0.76	1.97	1.00	0.62	2.52	2.11	2.08	1.70
B5	2.97	1.30	2.58	1.61	1.00	3.13	2.72	2.69	2.31

B6	0.86	0.35	0.65	0.40	0.32	1.00	0.71	0.69	0.55
B7	1.25	0.41	0.88	0.47	0.37	1.41	1.00	0.97	0.71
B8	1.28	0.42	0.90	0.48	0.37	1.44	1.03	1.00	0.72
B9	1.66	0.50	1.27	0.59	0.43	1.82	1.41	1.38	1.00

B1: work space, B2: prefabrication, B3: field accessibility, B4: advance work, B5: work technique, B6: work environment
B7: crew composition, B8: work difficulty, B9: work quantity

Table 10. Pair-wise Comparison Matrix by Factor C

(CR = 0.0043)

C	C1	C2	C3	C4
C1	1.00	2.72	2.27	0.67
C2	0.37	1.00	0.69	0.31
C3	0.44	1.45	1.00	0.36
C4	1.50	3.22	2.77	1.00

C1: manager capability, C2: management system, C3: construction plan, B4: safety/accidents

Table 11. Pair-wise Comparison Matrix by Factor D

(CR = 0.0015)

D	D1	D2	D3
D1	1.00	2.72	2.27
D2	0.37	1.00	0.69
D3	0.44	1.45	1.00

D1: rework, D2: work continuity, D3: information technology

The pair-wise comparison matrix of the factors that influence productivity are shown in the following table. The pair-wise comparison matrices for the components were first drafted, followed by the pair-wise comparison matrices for the factors. The analysis was performed using the AHP analysis method, based on the pair-wise comparison matrix.

4.3 Priority Analysis about Labor Productivity Model

Table 12. Priority Analysis

Component	Factor	Component Priority	Factor Priority	Total Priority	Rank
A	A1	0.15	0.07	0.01	25
	A2		0.07	0.01	24
	A3		0.15	0.02	13
	A4		0.22	0.03	11
	A5		0.08	0.01	23
	A6		0.09	0.01	22
	A7		0.12	0.02	17
	A8		0.10	0.01	20
	A9		0.10	0.01	19
B	B1	0.24	0.06	0.02	18
	B2		0.18	0.04	8
	B3		0.08	0.02	14
	B4		0.15	0.04	10
	B5		0.21	0.05	5
	B6		0.06	0.01	21
	B7		0.08	0.02	16
	B8		0.08	0.02	15
	B9		0.10	0.02	12
C	C1	0.41	0.31	0.13	2
	C2		0.12	0.05	7
	C3		0.15	0.06	4
	C4		0.42	0.17	1
D	D1	0.21	0.20	0.04	9
	D2		0.57	0.12	3
	D3		0.24	0.05	6

The results of the priority analysis of the influential components are as follows: worker component, 0.15; work environment component, 0.24; work management component, 0.41; and work technique component, 0.21. Table 16 shows the results of the priority analysis of the factors under each component. To compare the priority levels of all the factors, the total factor priority level was calculated, considering both the component priority and the factor priority.

The factor with the highest priority level among the factors that influence labor productivity was the safety/accident factor (0.17), and that with the lowest priority level was the worker capability factor (0.01). Based on the mean priority level of 0.04, the factors with 0.04 or more priority levels were selected. All the factors under the work management component, all the factors under the work technique component, and the prefabrication factor and the work method factor under the work characteristics component were selected. This indicates that the work management component and the work technique component influence productivity more than the worker component or the work characteristics component.

8. CONCLUSIONS

This study aimed to identify the factors that influence labor productivity and to construct a model that mathematically quantifies these factors using regression analysis so as to efficiently manage and increase labor productivity in construction work.

With the establishment of the model, we found that the components that have significant effects on productivity were the worker component, the work characteristics component, the work technology component, and the work management component, whereas the equipment and materials component, the work guide component, and the work delay component were found to have no significant effects.

All the components were considered factors that influence labor productivity, as all of them are important, but the results of the study showed that the worker component, the work characteristics component, the work technique component, and the work management component had a major influence on labor productivity, due to the characteristics of reinforced concrete construction work.

The factors that influence labor productivity were also analyzed using regression analysis, and AHP analysis was performed to calculate the priority level of each factor under the selected components. Thus, the recognition of the interested field personnel of the priority level of each factor, and the realities in the field, were identified.

The results of the AHP analysis indicate that the work management and the work technique influence productivity more than the worker characteristics or the work environment. Although all the factors are definitely needed, it seems that focusing on the management component and the technique component of the work will efficiently increase labor productivity.

The construction labor productivity model that was formulated in this study could be the basis for the determination of the standard productivity during the initial planning stage, so the best strategy for increasing labor productivity could be formulated.

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