Labour productivity model for reinforced concrete construction projects

Article *in* Construction Innovation · January 2011

DOI: 10.1108/14714171111104655

Ju Hyung Kim
Hanyang University

Jaejun Kim
Hanyang University

Received 18 May 2009
Accepted 2 November 2009

Labour productivity model for reinforced concrete construction projects

Homyun Jang
Department of Architectural Engineering, Hanyang University, Seoul, South Korea

Kyonghoon Kim
Department of Sustainable Architectural Engineering, Hanyang University, Seoul, South Korea

Juhyung Kim
Department of Architectural Engineering, Hanyang University, Seoul, South Korea, and

Jaejun Kim
Department of Sustainable Architectural Engineering, Hanyang University, Seoul, South Korea

Abstract

Purpose – This study aims to identify systematically the factors that can often influence labour productivity directly and indirectly, to build a model that can evaluate the significance of these factors. The model can be used as a tool for assisting field construction mangers responsible for productivity.

Design/methodology/approach – The factors were first identified by undertaking a literature review. The scope and method for measuring labour productivity were then determined. The final analysis model was built through a statistical analysis conducted with the chosen factors.

Findings – The results of the analysis indicate that the work management component (e.g. the manager's abilities) and the work technique component (e.g. work continuity) have greater impact than the worker component (e.g. the workers' capability) and the work characteristic component (e.g. work difficulty).

Research limitations/implications – This research focuses on the qualitative perspective of site managers on labour productivity. Although the process of translating qualitative opinions into quantitative data is a matter for debate, the result of this research, when compared to other quantitative studies, can be used to establish a strategy and an action plan for managing labour productivity.

Practical implications – Qualitative aspects that were considered to establish a labour productivity model can be evaluated by site construction managers. Despite the importance of these qualitative aspects, they have, by and large, been neglected, as models to date tend to consider more directly measurable quantitative factors. In particular, they can be used to develop a strategy for increasing labour productivity at the initial planning stage.

Originality/value – This research explores the differences between a subjective perception and the objective reality of labour productivity.

Keywords Labour, Productivity rate, Regression analysis, Analytical hierarchy process

Paper type Research paper

Construction Innovation
Vol. 11 No. 1, 2011
pp. 92-113

1471-4175
DOI 10.1108/14714171111104655

Introduction

Productivity is an important aspect of the construction industry that may be used as an index for measuring the efficiency of production. Consequently, it can also serve to measure the status of economic growth and related production from industrial and corporate perspectives. Many factors can be used to measure productivity. For example, managers can generate diverse productivity data that take into account the measured productivity and the factors that influence it. These data can then be used to define an index for measuring the performance of a project, which in turn plays an important role in decision making during the project engineering process (Yu and Lee, 2002).

The construction industry is labour-intensive and relies heavily on the skills of its workforce. The workforce is the industry's most valuable asset, which, at the very least, accounts for over a quarter of the total project cost. More often than not, owing to its volatile nature, this workforce can significantly influence the cost, schedule, and quality of a construction project (Han *et al.*, 2008). Productivity is defined as the ratio of the quantity of output to the quantity of input. In construction, productivity is measured at different levels of detail for different purposes (Song and AbouRizk, 2008). For example, it is used to identify trends in the industry and to allow comparisons in performance with other industry sectors (Building Futures Council, 2006). Measurements of productivity at a company level or at a project level provide internal and external benchmarks for comparison with company or project norms (Park *et al.*, 2005). For detailed estimation and project scheduling, productivity is measured at an activity level. Because construction is usually labour intensive, productivity at the activity level is frequently referred to as labour productivity; it measures the input in terms of hours of work and the output in terms of the material value of the work achieved (Dozzi and AbouRizk, 1993). The scope of the present study is limited to labour productivity.

For the past 20 years, productivity has been an issue of contention in the construction industry. According to a recent article in the *Civil Engineering* magazine (Bernstein, 2003), construction experts have persistently examined the assumption that productivity in the construction industry lags behind that of other industries. It is widely perceived that labour productivity in the US construction sector has gradually declined since the 1960s. Studies completed in the 1980s reported that the real output (value added) per work hour in this sector had declined by an annual rate of 2.4-2.8 percent between 1968 and 1980 (Dai *et al.*, 2009).

Construction labour productivity is influenced by various factors whose impact can be quantified in productivity models. These models play an important role in estimating cost, in scheduling, and in planning. A number of models have been developed using regression analysis to provide a qualitative evaluation of the impact of different factors on construction labour productivity (Sonmez and Rowings, 1998). The present study intends to quantify these factors and to provide a model for predicting labour productivity. In addition, the priorities of those factors found to be statistically significant have been evaluated from the perspective of people interested in the construction industry.

This study aims to formulate a general model for considering construction labour productivity that considers the many factors that influence it. Although a model of this kind may be used to set a standard for selecting working methods in general, this study focuses on reinforced concrete construction projects. To this end, factors with an impact on labour productivity were first identified by a review of related literature, before determining the scope and method for measuring labour productivity. The final analysis model was derived from the statistical analysis of the chosen factors.

The details of the research method are as follows:

- Relevant factors were identified from a review of the literature around construction labour productivity.
- Questionnaires were prepared on the basis of these factors from which data was collected.
- The reliability of the collected data was assessed by statistical analysis.
- The factors that influenced and showed a correlation with labour productivity were identified by correlation analysis. Factors for which the correlation was less than a certain threshold level were discarded.
- A factor analysis was performed to classify the factors into groups.
- A labour productivity model was constructed using regression analysis. Significant factors were analysed and insignificant factors were discarded.
- The factors were prioritised using analytic hierarchy process (AHP) analysis with the help of relevant field engineers.

Productivity modelling

Issues around labour productivity are increasingly the subject of attention within the construction industry (Haas *et al.*, 2000). Labour is considered to be the most uncertain factor among costly project components (materials, equipment, and labour). The other components, materials, and equipment, are predominantly determined by market prices, and are consequently beyond the influence of project management. The management of labour and its productivity is therefore crucial for determining the success of a construction project (Hanna *et al.*, 2005).

When a compression of a construction schedule is necessary, contractors must select a method that can accelerate the schedule, while at the same time minimising the cost. Several such methods exist. Frequently, a contractor initially increases the on-site labour force (Hanna *et al.*, 2008). Labour productivity is considered to be one of the best indicators of production efficiency. Higher productivity usually yields superior profitability. There is still much scope for further study in this area (Rojas and Aramvareekul, 2003).

The productivity model of construction labour has been studied since 1940 and this technique is still being improved. The model was first developed using statistics, but subsequently went on to address problems associated with this technique by offering alternatives (Kim and Kim, 2001). Labour productivity studies fall into one of the following two categories: those that estimate unit rates using a combination of factors that affect labour productivity; and those that consider the impact of a single factor (or multiple factors) on productivity. While most construction contractors estimate unit rates on the basis of job records, knowledge, and experience, researchers have proposed various structured methods such as regression models and models based on artificial neural networks (ANNs) (Dissanayake *et al.*, 2005).

For example, regression-based models have been used to study the productivity of the earthmoving and the masonry sectors. On the other hand, ANNs have been used to model the relationship between productivity and the factors that influence it in various trades, such as the production of earthmoving equipment, concrete, formwork, and pipe spool fabrication and installation (Song and AbouRizk, 2008).

Table I lists previous studies of the factors that influence productivity within a prediction model. The results indicate a need for systematic classification, for the definition of the various factors, and for studies of existing data that can explain such factors.

To this end, labour productivity data were collected and analysed through field analysis, and the priority levels of the subjects under critical management were determined on the basis of the opinions of the field managers.

Critical factors influencing productivity

Table II displays the factors selected for this study and the components that represent groups of factors. The words in parentheses indicate the terminology adopted in the present work for factors mentioned in previous research. The present study uses existing data and reclassifies the factors into five components: equipment, workers, work characteristics, materials, and management and control. These components are then further classified into those that directly influence labour productivity and are based on the personal capability of the workers (workers component), and those that indirectly influence labour productivity by influencing the work of the workers (the equipment, work characteristics, materials, and management and control components). The equipment component includes the tool factor, the concrete pumping system, hoists, barrows, and cranes. This study does not intend to compare factors that influence the productivity of concrete equipment, but to identify the factors that influence labour productivity in the specific case of reinforced concrete construction,

Methods	Authors	Contents
Factor model	Thomas and Sakarcan (1994)	Prediction of labour productivity using the factor model
Regression models	Smith (1999)	Earthmoving productivity estimation, using linear regression techniques
	Zayed and Halpin (2005)	Productivity and cost regression model for pile construction
	Goodrum and Haas (2002)	Partial factor productivity and equipment technology change at activity level in US construction industry
ANNs models	Karshenas and Feng (1992)	Application of neural networks in earthmoving equipment production estimation
	Sonmez and Rowings (1998)	Construction labour productivity modelling with neural networks
	Portas and AbouRizk (1997)	Neural network model for estimating construction productivity
	AbouRizk *et al.* (2001)	Estimating labour production rates for industrial construction activities
	Lu *et al.* (2000)	Estimating labour productivity using probability inference neural network
	Elazouni *et al.* (2005)	Estimating the acceptability of new formwork systems using neural networks

Table I.
Previous studies

Authors	Factors	Components
Kim and Kim (2001)	Percentage of prolonged working hours (work delay) Crew size (crew size and composition)	Management and control component Work characteristics component
Thomas and Sakarcan (1994)	Crowdedness (working space), crew size (crew size and composition), percentage of workers (crew size and composition), work size (work quantity), job type (work method) Supervision (manager's capability, management system), information (information technology and integration), re-work (rework), work continuity (work continuity), overtime work (work delay) Equipment (factors in equipment component), tools (factors in equipment component), concrete pumping (factors in equipment component) Materials (factors in materials component), factory conditions (material condition, materials transport environment, material procurement delay)	Work characteristics component Management and control component Equipment component Materials component
Sonmez and Rowings (1998)	Percentage of overtime work (work delay) Crew size (crew size and composition), the quantity of the completed work (work quantity), job type (work method), percentage of labourers (crew size and composition) Concrete pouring (factors in equipment component)	Management and control component Work characteristics component Equipment component
Hanna *et al.* (1999)	Order changes (work order), work sequencing (work continuity), work shifting (work continuity), schedule compression (field work plan), overtime work (work delay) Absenteeism and turnover (sense of responsibility), labour problems (teamwork, communication, work attitude), trade stacking (teamwork) Material problems (material condition, material procurement delay, material applicability)	Management and control component Workers component Materials component
Lu *et al.* (2000)	Administration/project manager/superintendent (factors in management and control component), duration of the construction work (field work plan), order changes (work order), drawing and specifications quality (defects in design documents), safety (safety/accidents), inspection (permission/approval delay), location classification (field work plan), extra work (work delay) Prefabrication/field work (prefabrication/standardisation/field work), average crew size and peak crew size (crew size and composition), total work quantity and installation quantities (work quantity), method of installation (work method), site working conditions (work environment), overall degree of work difficulty (work difficulty) Equipment (factors in equipment component) Materials (factors in materials component), type of materials (material applicability) Crew ability (capability)	Management and control component Work characteristics component Equipment component Materials component Workers component
Rojas and Aramvareekul (2003)	Management systems and strategies (factors in management and control component) Manpower (capability) and external conditions (work environment)	Management and control component Workers component Work characteristics component

Table II.
Selecting factors and components by previous studies

by taking into account the opinions of competent field personnel and experts. The effects of these factors on labour productivity will also be examined:

- The equipment component includes factors related to equipment and tools that are relevant to constructions in reinforced concrete: condition of equipment, number of pieces of equipment, equipment service time, equipment transport environment, equipment procurement delay, and equipment performance.
- The workers component includes factors that concern the taskforce in reinforced concrete construction: abilities and skills, sense of responsibility, health, experience, education, training, expertise, motivation, communication, teamwork, and attitude to work.
- The work characteristics component includes the factors that are relevant to the progression of work in reinforced concrete construction: working space, prefabrication/standardisation/field work, field accessibility, advance work, work method, work environment, crew size and composition, work difficulty, and work quantity.
- The materials component includes factors related to the materials used in reinforced concrete construction: material condition, material quantity, materials transport environment, material procurement delay, and material applicability.
- The management and control component includes the factors that concern work management and the adjustment of workers in reinforced concrete construction: managerial abilities, the management system, the field work plan, defects in design documents, delays for permissions and approval, order errors, strikes, public complaints and claims, safety issues, work delay and conversion, rework, work continuity, and the use of information technology and integration.

The weather and the project components were excluded from this study because many previous studies have already focused on them. Instead, this study examined the five other components, which have many qualitative elements.

A large amount of comprehensive and accurate historical data must be collected and stored to develop a productivity model. Unfortunately, the absence of accurate, consistent, and comprehensive data from past projects makes productivity modelling of little use to many contractors (Song and AbouRizk, 2008). Therefore, the labour productivity model established in this study quantifies the qualitative components of present or past projects by conducting an expert questionnaire survey, i.e. by taking into consideration the opinions of experts. The weather component, which must be measured, and the project factor were excluded and could be examined in future studies.

The factors found in the literature were classified into five components and similar factors were unified under representative names. Since these factors and components are subjective and inaccurate, those that are significantly related to labour productivity in reinforced concrete construction were selected from correlation analysis (presented in the next section), and the components were reclassified using factor analysis in order to achieve significance.

Research methodology

Figure 1 shows the method used in the study. Details are as follows:

- *Questionnaire survey*. Data on factors that influences labour productivity satisfaction in reinforced concrete construction were collected.
- *Reliability analysis*. This was conducted for each factor in order to assess the reliability of the questionnaire. Unreliable factors were discarded.
- *Correlation analysis*. Factors that showed a correlation with labour productivity in reinforced concrete construction were identified. Factors for which the correlation did not reach a required threshold level were discarded.
- *Factor analysis*. Factors were classified into components. At this stage, components classified on the basis of the relevant literature review (the equipment, workers, work characteristics, materials, and management and control components). The components that were properly classified were examined, and those that were not classified were reclassified so that the components could properly represent the factors. Then, a reliability analysis was conducted on the factors in each classified component to verify the reliability of the component.
- *Regression analysis*. This was the last stage of the statistical analysis in which the components that significantly influenced labour productivity satisfaction in reinforced concrete construction were identified. The significance of the components was analysed, and insignificant components were discarded at this stage. In addition, the regression model was evaluated, and the impact of each component was analysed.
- *The AHP model.* The importance of the factors in each component was evaluated on the basis of the strength of their impact, derived from the regression analysis. This provided a measure of the subjective perception of those factors by the site personnel.

Data collection for statistical analysis

The survey was performed by conducting field interviews with the staff and field workers working in reinforced concrete construction companies, or contractor companies in Korea, as given in Table III.

Using the survey data, frequency analysis and a technical statistical analysis of the satisfaction of labour productivity gave the following results. A seven-point Likert scale resulted in a mean of 4.0702. Likert scale numbers were represented in Table III.

Reliability analysis

Cronbach's alpha method was used for reliability analysis. This method assesses intrinsic consistency on the basis of the average correlation between data that were measured in an identical manner. This method combines the split-half method and item-total correlation, and calculates the mean value of the reliability, obtained by the split-half method for all the data of the construct. Using this method, both the construction at the group level and the reliability of each item at the individual level can be evaluated. Cronbach's alpha can be calculated as follows:

Figure 1.
Research method

Items	Contents
Survey period	6 October 2008 to 25 October 2008
Participants	Construction/management (the number of persons: 17)
	Supervision/CM (the number of persons: 7)
	Worker (the number of persons: 34)
Survey method	Conversation and interview
Analysis method	SPSS 12.0 statistical analysis
Likert scale	Very dissatisfied
	Moderately dissatisfied
	Slightly dissatisfied
	Neutral
	Slightly satisfied
	Moderately satisfied
	Very satisfied

Table III. Data collection summary for statistic analysis

$$\alpha = \frac{\kappa}{\kappa - 1}\left(1 - \frac{\sum \sigma_i^2}{\sigma_i^2}\right) \tag{1}$$

(κ = number of items, σ_i^2 = variance of each item, $\sum \sigma_i^2$ = total variance).

The α coefficient is considered high if it exceeds 0.5 at the group level or 0.9 at the individual 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.

Correlation analysis

In this analysis, factors that were shown to be insignificantly correlated to labour productivity were discarded. These factors were: equipment transport environment, equipment procurement, equipment performance, materials condition, materials applicability, worker communication, and teamwork. The significance probability was tested using a two-sided test, while a value of 0.05 or more was considered to be a violation of the correlation, as given in Table IV.

Factor analysis

Factor analysis is a statistical technique that explains the common underlying dimensions that compose variables (which are called "components" in this study) by analysing the correlation between the variables.

Factor analysis, according to the statistical package, results in an un-rotated component analysis factor matrix. It shows the basic data in a reduced form, but does not show to what extent a factor is related to a component. Accordingly, the derived component is rotated to find the component structure. This is called orthogonal factor rotation analysis.

In this study, factor analysis was performed to verify that the five components that grouped the factors were statistically significant.

In Table V, the number of components represents the number of groups of factors. From the correlation analysis, 36 factors that were statistically correlated with the labour productivity were selected. If one component were assigned to each factor, there would be a maximum of 36 components.

Factors	Pearson correlation	Significance (two-tailed)
Equipment condition	0.283*	0.033
Number of equipment	0.354**	0.007
Equipment service time	0.290*	0.029
Equipment transport environment	*0.248*	*0.062*
Equipment procurement	*0.239*	*0.073*
Equipment performance	*0.130*	*0.334*
Materials condition	*0.221*	*0.099*
Materials quantity	0.310*	0.019
Materials transport environment	0.297*	0.025
Materials procurement	0.332*	0.012
Materials applicability	*0.221*	*0.099*
Worker capability	0.314*	0.017
Worker sense of responsibility	0.351**	0.007
Worker health	0.289*	0.029
Worker experience	0.445**	0.001
Worker education	0.379**	0.004
Worker training	0.306*	0.021
Worker expertise	0.384**	0.003
Worker motivation	0.328*	0.013
Worker communication	*0.232*	*0.083*
Worker teamwork	*0.133*	*0.323*
Worker attitude	0.365**	0.005
Work space	0.544**	0.000
Prefabrication	0.451**	0.000
Working field accessibility	0.371**	0.004
Advance work	0.362**	0.006
Work method	0.497**	0.000
Work environment	0.478**	0.000
Crew composition	0.515**	0.000
Work difficulty	0.486**	0.000
Work quantity	0.439**	0.001
Manager capability	0.365**	0.005
Management system	0.463**	0.000
Construction plan	0.388**	0.003
Design documents	0.369**	0.005
Permission	0.348**	0.008
Work order	0.337*	0.010
Claim	0.423**	0.001
Safety/accidents	0.436**	0.001
Work delay	0.443**	0.001
Rework	0.450**	0.000
Work continuity	0.540**	0.000
Information technology	0.604**	0.000

Notes: *, ** indicate that correlation is significant at 0.05 and 0.01 levels (two-tailed); the italicized values express the factors that were not significantly correlated to labour productivity. And the factors removed because the numerical value of Sig. (two-tailed) is not less than 0.05 (Sig. > 0.05)

Table IV.
Correlation analysis

Component	Total	Initial eigenvalues Percentage of variance	Cumulative %	Total	Rotation sums of squared loadings Percentage of variance	Cumulative %
1	15.524	43.123	43.123	6.589	18.304	18.304
2	3.436	9.544	52.667	6.321	17.557	35.861
3	2.938	8.162	60.829	5.565	15.459	51.319
4	2.302	6.394	67.223	2.831	7.864	59.184
5	1.373	3.813	71.036	2.693	7.480	66.664
6	1.246	3.462	74.498	2.522	7.005	73.669
7	*1.037*	*2.882*	*77.379*	*1.336*	*3.710*	*77.379*
8	0.926	2.574	79.953			
…	…	…	…			
…	…	…	…			
36	0.023	0.064	100.00			

Note: The italicized values express the total of the rotation sums of squared loadings was one or more in seven components

Table V.
Total variance

The percent of variance is labelled as "% of variance" and the cumulative percent of variance as "cumulative %".

The eigenvalue is an index that represents the explanatory power of the corresponding component, and is usually extracted from the number of the components that have a value of 1 or more. In Table V, there are seven components for which initial eigenvalues are larger than. These are selected for further analysis.

This may indicate that a better analysis can be performed when all the components are classified into more components than the five components that have been derived from the literature.

Rotation sums of squared loadings were examined to find the accurate component structure, as described above. In Table V, the total of the rotation sums of squared loadings was 1 or more in seven components.

An orthogonal factor rotation analysis was conducted to clearly classify the components, and the rotated component matrix was analysed, as given in Table VI.

The explanatory power (eigenvalue) of component 1 was 6.589 (the total of the rotation sums of squared loadings in Table V), which included factors such as the workers' capability, sense of responsibility, health, experience, education, training, expertise, motivation, and attitude.

The explanatory power (eigenvalue) of component 2 was 6.321, which included the factors equipment condition, quantity of equipment, equipment service time, material quantity, materials transport, environment, and material procurement.

The explanatory power (eigenvalue) of component 3 was 5.565, which included the factors working space, prefabrication, field accessibility, advance work, work method, work environment, crew size and composition, work difficulty, and work quantity.

The explanatory power (eigenvalue) of component 4 was 2.831, which included the factors rework, work continuity, and information technology.

The explanatory power (eigenvalue) of component 5 was 2.693, which included the factors manager's capability, management system, construction plan, and safety/accidents.

Factors	Components 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 motivation	*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		

Note: The italicized values express classification of components

Table VI. Rotated component matrix

The explanatory power (eigenvalue) of component 6 was 2.522, which included the factors design documents, permission, and work order.

The explanatory power (eigenvalue) of component 7 was 1.336, which included factors such as claims and work delay.

Once the components were classified and defined, Cronbach's alpha coefficient was calculated to verify whether the factors in each component were internally consistent. An α coefficient > 0.5 at the group level was considered to be high.

The components were redefined as follows, and a reliability analysis was performed for each group. After defining the components as follows, Cronbach's α was computed to assess the reliability of each component:

Component #1	Worker (Cronbach's $\alpha = 0.949$)
Components #2	Equipment and material (Cronbach's $\alpha = 0.938$)
Components #3	Work characteristic (Cronbach's $\alpha = 0.920$)
Components #4	Work technique (Cronbach's $\alpha = 0.845$)
Components #5	Work management (Cronbach's $\alpha = 0.803$)
Components #6	Work guide (Cronbach's $\alpha = 0.836$)
Components #7	Work delay (Cronbach's $\alpha = 0.691$).

As shown in Figure 2, the equipment component and the materials component were combined to form one component, and the management and control component was divided into several new components.

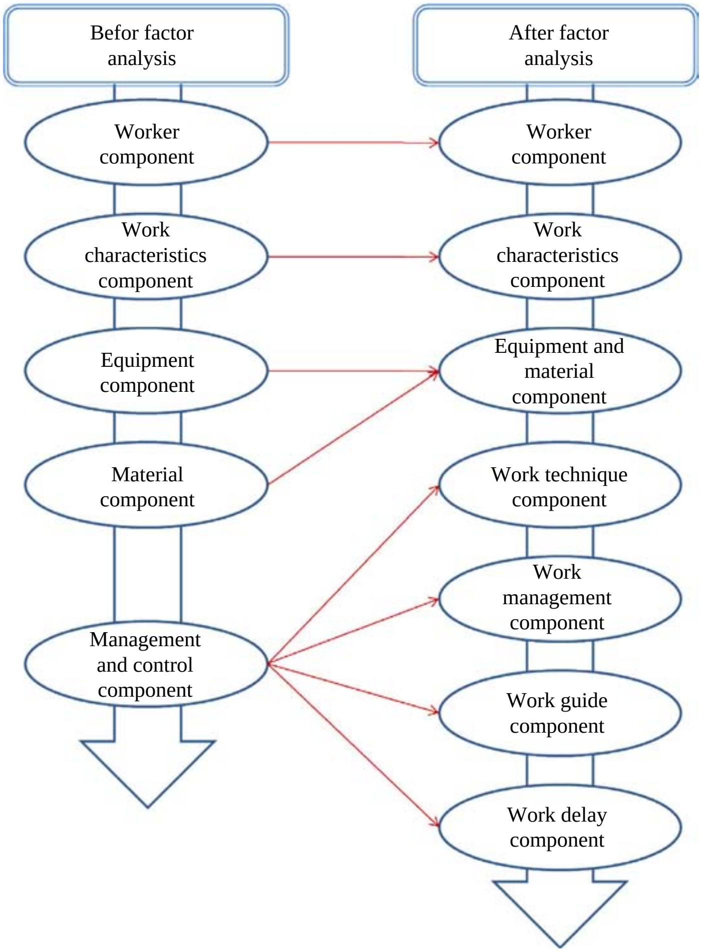

Figure 2.
Change of components

These changes may reflect the fact that whereas various studies in the literature mention factors that influence labour productivity in general, this study focuses on the reinforced concrete construction sector.

Regression analysis

In the variance analysis, the sum of squared residuals and the sum of squared errors that were explained by the regression equation were 19.157 and 20.563, respectively. These values were divided by the degree of freedom (df) to obtain the mean square (MS) values. The ratio of the two MS values (MSR/MSE) gave an *F*-value of 6.521, with a *p*-value of 0.000. Therefore, this result dismisses "the null hypothesis that the explanatory power of the regression equation (R^2) is zero ($H_0 = \beta_1 = \beta_2 = \cdots = \beta_k = 0$)", and it is useful in the regression equation's explanation of dependent variables.

The regression equation has an explanatory power of 48 percent. The regression model that is statistically significant ($Sig. < a = 0.05$) is given in Table VII:

$$\hat{Y} = 0.179X_1 + 0.366X_2 + 0.315X_3 + 0.236X_4 + 4.070 \tag{2}$$

(X_1: worker component, X_2: work characteristics component, X_3: work technique component, X_4: work management component).

The seven components listed in Table VII were derived from the previous stage, and four significant components were determined through the regression analysis.

The statistical analysis in this study shows that the components that strongly influence labour productivity in reinforced concrete construction are:

- the work characteristic component;
- the work technique component;
- the work management component; and
- the worker component, in order of decreasing importance.

This indicates that the working environment, work technique, and management influence labour productivity more than aspects of the work that relate to the workers individually. The material and equipment factors did not have a significant impact,

Components	Unstandardised coefficients B	Standard error	Standardised coefficients Beta	*T*	Significance
(Constant)	4.070	0.086		47.436	0.000
Workers	0.179	0.087	0.212	2.064	*0.044*
Equipment and 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

Note: The italicized values express statistically significant components (Sig. > 0.05)

Table VII.
Coefficients

apparently, because materials and equipment have become standardised in the reinforced concrete construction of apartment buildings in Korea. The impact of the material and equipment factors on labour productivity for constructions other than apartment buildings could be the subject of a future study.

Data collection for the AHP model

On the basis of the factors that influence labour productivity, derived using statistical analysis, the level of priority of each factor within each influential component was analysed.

Figure 3 shows the statistically significant factors. As shown in the figure, in the present study, the significance was calculated on a two-level basis. The first level consists of four components (the work management component, the work technique component, the work characteristic component, and the worker component), and the second level consists of the factors (i.e. sub-items) for each component. The final significance was calculated by multiplying the first level significance by the second level significance.

On the basis of the derived influential factors, a questionnaire was prepared to perform a pair-wise comparison and to calculate the priority level of each factor. The data collection method is summarised in Table VIII.

The statistical analysis aims to establish a labour productivity model in line with present conditions in the construction field. The AHP analysis was performed to determine the priority levels of the factors within the influential components that were derived using statistical analysis. Then, the actual field conditions and the judgement of relevant field personnel were compared. For this purpose, data were collected from identical people, to compare the influence of the factors on labour productivity in actual field conditions and the significance of the influential factors in the perception of relevant field personnel.

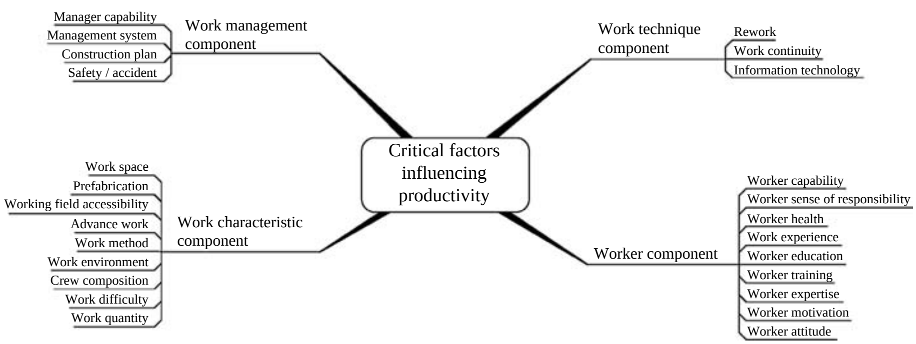

Figure 3. Factors that are statistically significant

Item	Content/s
Survey period	3 November 2008 to 15 November 2008
Participant	Construction/management (the number of persons: 17)
	Supervision/CM (the number of persons: 7)
	Worker (the number of persons: 34)
Survey method	Conversation and interview
Analysis method	AHP analysis

Table VIII. Data collection summary for AHP analysis

Pair-wise comparison matrix for the AHP model

Figure 4 shows the four major steps for the AHP analysis:

(1) The complex problem is broken down into a small number of constituent (decision) elements, which are then structured in a hierarchical form.

(2) A series of pair-wise comparisons of the elements is performed according to the given ratio scale.

(3) The eigenvalue method is used to estimate the relative weights of the elements.

(4) These relative weights are aggregated and synthesised for the final measurement of the given decision alternatives.

The aggregate mean value of all the pair-wise comparisons of all respondents was entered into the matrix table, as given in Table IX:

$$(\text{pair-wise comparison matrix})\, X = \begin{bmatrix} 1.00 & 0.57 & 0.38 & 0.64 \\ 1.76 & 1.00 & 0.55 & 1.19 \\ 2.60 & 1.83 & 1.00 & 2.03 \\ 1.57 & 0.84 & 0.49 & 1.00 \end{bmatrix} \quad (3)$$

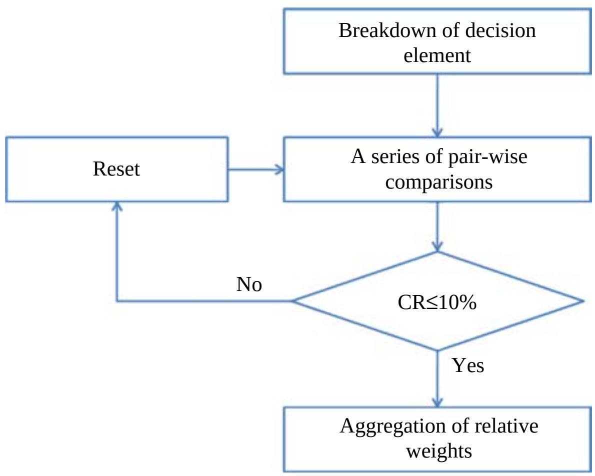

Figure 4.
Steps of AHP analysis

Table IX.
Pair-wise comparison matrix by comparison ($CR = 0.00229 < 0.1\{ok\}$)

Components	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

Notes: A, worker component; B, work characteristics component; C, work management component; D, work technique component

The pair-wise comparison matrix was constructed by dividing each element of the matrix by the total of its column. For example, the value of 0.14 in Table X was obtained by dividing 1 (from Table IX) by 6.93, the sum of the column items in Table X (1 + 1.76 + 2.60 + 1.57). The priority vector in Table X was computed by averaging the rows. For example, the priority of A (Worker component) with respect to the criterion, "component of labour productivity (1 level)", in Table X is 0.14, the average of values in that row (0.14 + 0.13 + 0.16 + 0.13). The priority vector for criterion "component of labour productivity (1 level)" indicated in Table X for each method is 0.14(A), 0.24(B), 0.41(C), and 0.21(D):

$$\text{(Priority vector) W} = \begin{bmatrix} 0.14 \\ 0.24 \\ 0.41 \\ 0.21 \end{bmatrix} \tag{4}$$

The weighted sum matrix was calculated as follows:

$$\text{(weighted sum matrix) a} = \text{X}^{*}\text{W} = \begin{bmatrix} 1.00 & 0.57 & 0.38 & 0.64 \\ 1.76 & 1.00 & 0.55 & 1.19 \\ 2.60 & 1.83 & 1.00 & 2.03 \\ 1.57 & 0.84 & 0.49 & 1.00 \end{bmatrix}^{*} \begin{bmatrix} 0.14 \\ 0.24 \\ 0.41 \\ 0.21 \end{bmatrix} = \begin{bmatrix} 0.57 \\ 0.96 \\ 1.64 \\ 0.83 \end{bmatrix} \tag{5}$$

Then, dividing all the elements of the weighted sum matrix by their respective priority vector element yields:

$$\frac{0.57}{0.14} = 4.00383, \quad \frac{0.96}{0.24} = 4.00656, \quad \frac{1.64}{0.41} = 4.00960, \quad \frac{0.83}{0.21} = 4.00476 \tag{6}$$

The average of these values is:

$$\lambda_{\max} = \frac{(4.00383 + 4.00656 + 4.00960 + 4.00476)}{4} = 4.00619 \tag{7}$$

and the consistency index (CI) is:

Component	A	B	C	D	Priority vector
A	0.14	0.13	0.16	0.13	0.14
B	0.25	0.24	0.22	0.25	0.24
C	0.37	0.43	0.41	0.42	0.41
D	0.23	0.20	0.20	0.21	0.21

Notes: A, worker component; B, work characteristics component; C, work management component; D, work technique component

Table X. Synthesised matrix for component of labour productivity

$$CI = \frac{(\lambda_{max} - n)}{(n - 1)} = \frac{4.00619 - 4}{4 - 1} = 0.00206 \tag{8}$$

The random index (RI) is defined by Saaty (1991) for matrices according to their order n. The authors find that the RI value is 0.90 for a matrix size of four. The consistency ratio (CR) is then calculated as follows:

$$CR = \frac{CI}{RI} = \frac{0.00206}{0.90} = 0.00229 \tag{9}$$

Saaty (2001) suggested that a CR value in the neighbourhood of 0.1 is acceptable. In this study, a CR value ≤ 0.1 may be considered acceptable.

As the value of CR is < 0.1, the judgements are acceptable. All the CR values were 0.1 or less, which indicates that the priority values of the factors proposed in this study are significant.

The pair-wise comparison matrices for the components were drafted first, followed by the pair-wise comparison matrices for the factors. The analysis was performed using the AHP analysis method on the basis of the pair-wise comparison matrix.

Priority analysis for the AHP model

Table XI shows the results of the priority analysis of the factors within 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. For instance, the priority value of worker capability in the worker component is determined as follows.

Total priority of worker capability factor = worker component * worker capability = 0.14 * 0.07 = 0.01.

The results of the priority analysis of the influential components are as follows (average about total priority of each component):

- worker component: 0.014 = (0.01 + 0.01 + 0.02 + 0.03 + 0.01 + 0.01 + 0.02 + 0.01 + 0.01)/9;
- work characteristics component: 0.027 = (0.02 + 0.04 + 0.02 + 0.04 + 0.05 + 0.01 + 0.02 + 0.02 + 0.02)/9;
- work management component: 0.103 = (0.13 + 0.05 + 0.06 + 0.17)/4; and
- work technique component: 0.070 = (0.04 + 0.12 + 0.05)/3.

Among the factors that influence labour productivity, the factor with the highest priority level was the safety/accident factor (0.17), and the factor with the lowest priority level was the worker capability factor (0.01).

The index in Figure 5 shows the priority value of each factor.

The factors with priority levels greater than or equal to the mean value 0.04 were selected. All the factors under the work management or work technique components, and the prefabrication and work method factors 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.

Components	Factors	Component priority	Factor priority	Total priority	Rank
A	A1	0.14	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*

Notes: A, worker component; B, work characteristics component; C, work management component; D, work technique component; 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 motivation; A9, worker attitude; 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; C1, manager capability; C2, management system; C3, construction plan; C4, safety/accidents; D1, rework; D2, work continuity; D3, information technology; the italicized values express components of the high position (high ranking) of the priority analysis

Table XI. Priority analysis

Conclusion

This study aims to identify the factors that influence labour productivity and to construct a model that quantifies these factors using regression analysis so as to improve management efficiency and labour productivity in construction work.

By implementing this model, it was found that, of all the components that can potentially influence productivity, the significant ones are the worker component, the work characteristics component, the work technology component, and the work management component, owing to the characteristics of reinforced concrete construction work. The equipment and materials component, the work guide component, and the work delay component were found to have no significant effect on the productivity.

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

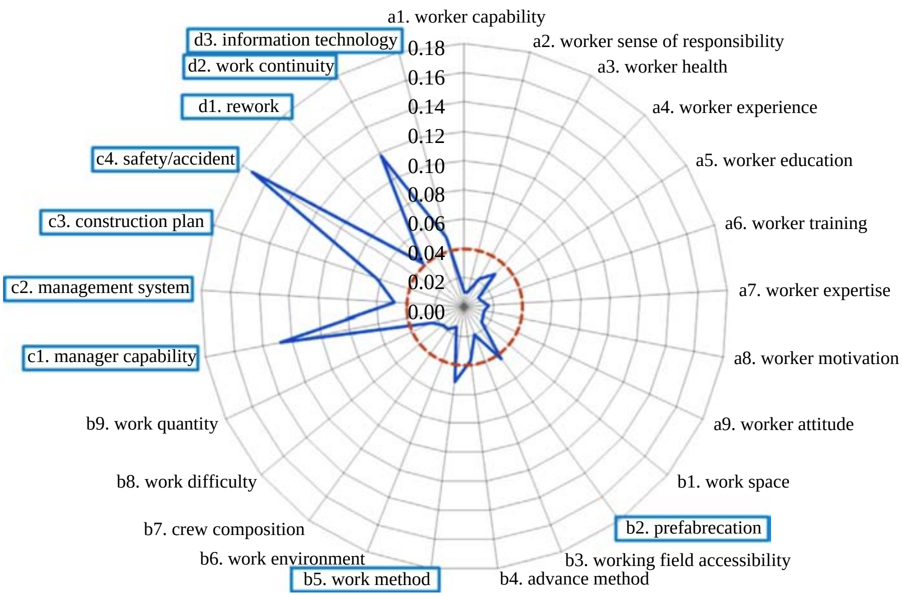

Figure 5.
Index of priority for labour productivity factors

The results of the AHP analysis indicate that work management influences productivity more than work characteristics. The results of the statistics analysis indicate, however, that work characteristics influence productivity more than work management. Result of statistical analysis (impact for labour productivity in decreasing order) was work characteristics (0.366), work technique (0.315), work management (0.236), and worker (0.179). And, result of the AHP analysis (order of component for labour productivity according to the perception of relevant field engineers) was work management (0.103), work technique (0.070), work characteristics (0.070), and worker (0.014).

In the field of reinforced concrete construction in Korea, the work management component may be considered as the most important factor for improving labour productivity. In cases undertaken outside of Korea, Rojas and Aramvareekul (2003) studied productivity drivers and opportunities in the construction industry with support from the *Electrical Contractor* magazine. Results indicated that management systems and strategies and manpower were rated far ahead of the technology and new techniques. The work management component in this study is similar to the management systems studied by Rojas and Aramvareekul (2003), albeit the scope of this study is for reinforced concrete construction projects.

Statistical analysis results based on actual data, however, indicate that the work characteristics component (work space, prefabrication, field accessibility, advance work, work technique, etc.) has a greater impact. The results of this study indicate that the impact of various factors as perceived by field personnel is very different from that in reality. It appears that labour productivity can be improved by controlling the components according to the priority presented in this study. It may be somewhat surprising that the components with an indirect impact on labour productivity have a greater impact than those with direct impact, such as the worker component.

This indicates that it is the work environment, management, and technique, rather than the capability and characteristics of workers that must become efficient in order to improve labour productivity.

The absence of accurate, consistent, and comprehensive data from past projects makes productivity modelling of little use to many contractors (Song and AbouRizk, 2008). This study also has the same research limitations due to the absence of quantitative data. In this respect, this research focuses on the qualitative perspective of site mangers on labour productivity. The process of translating these qualitative opinions into quantitative data is matter for debate. Nevertheless, the result of this research, when compared to other quantitative studies, can serve to establish a strategy and an action plan for managing labour productivity.

References

AbouRizk, S., Knowles, P. and Hermann, U. (2001), "Estimating labor production rates for industrial construction activities", *Journal of Construction Engineering and Management*, Vol. 127 No. 6, pp. 502-11.

Allmon, E., Haas, C.T., Borcherding, J.D., Allmon, E. and Goodrum, P.M. (2000), "US construction labor productivity trends, 1970-1998", *Journal of Construction Engineering and Management*, Vol. 126 No. 2, pp. 97-104.

Bernstein, H.M. (2003), "Measuring productivity: an industry challenge", *Civil Engineering*, Vol. 73 No. 12, pp. 46-53.

Building Futures Council (2006), *Measuring Productivity and Evaluating Innovation in the US Construction Industry*, BFC, Alexandria, VA.

Dai, J., Goodrum, P.M. and Maloney, W.F. (2009), "Construction craft workers' perceptions of the factors affecting their productivity", *Journal of Construction Engineering and Management*, Vol. 135 No. 3, pp. 217-26.

Dissanayake, M., Fayek, R.A., Russell, A.D. and Pedrycz, W. (2005), "A hybrid neural network for predicting construction labour productivity", *Proceeding of ASCE International Conference on Computing in Civil Engineering, 12-15 July, Cancun, Mexico*.

Dozzi, S.P. and AbouRizk, S. (1993), "Productivity in construction", Institute for Research in Construction, National Research Council, Ottawa, ON.

Elazouni, A.M., Ali, A.E. and Abdel-Razek, R.H. (2005), "Estimating the acceptability of new formwork systems using neural networks", *Journal of Construction Engineering and Management*, Vol. 131 No. 1, pp. 33-41.

Goodrum, P.M. and Haas, C.T. (2002), "Partial factor productivity and equipment technology change at activity level in US construction industry", *Journal of Construction Engineering and Management*, Vol. 128 No. 6, pp. 463-72.

Han, S.H., Park, S.H., Jin, E.J., Kim, H. and Seong, Y.K. (2008), "Critical issues and possible solutions for motivating foreign construction workers", *Journal of Management in Engineering*, Vol. 24 No. 4, pp. 217-26.

Hanna, A.S., Taylor, C.S. and Sullivan, K.T. (2005), "Impact of extended overtime on construction labor productivity", *Journal of Construction Engineering and Management*, Vol. 131 No. 6, pp. 734-9.

Hanna, A.S., Chang, C.-K., Sullivan, K.T. and Lackney, J.A. (2008), "Impact of shift work on labor productivity for labor intensive contractor", *Journal of Construction Engineering and Management*, Vol. 134 No. 3, pp. 197-204.

Hanna, A.S., Russell, J.S., Nordheim, E.V. and Bruggink, M.J. (1999), "Impact of change orders on labor efficiency for electrical construction", *Journal of Construction Engineering and Management*, Vol. 125 No. 4, pp. 224-32.

Karshenas, S. and Feng, X. (1992), "Application of neural networks in earthmoving equipment production estimating", *Conference Proceeding Paper of Computing in Civil Engineering*, ASCE, New York, NY, pp. 841-7.

Kim, S. and Kim, Y. (2001), "A study on the construction labor productivity model using neuro-fuzzy network", *Conference of the Architectural Institute of Korea, Ansan, Korea*, Vol. 21 1 pp. 493-6.

Lu, M., AbouRizk, S.M. and Hermann, U.H. (2000), "Estimating labor productivity using probability inference neural network", *Journal of Computing in Civil Engineering*, Vol. 14 No. 4, pp. 241-8.

Park, H., Thomas, S. and Tucker, R. (2005), "Benchmarking of construction productivity", *Journal of Construction Engineering and Management*, Vol. 131 No. 7, pp. 772-8.

Portas, J. and AbouRizk, S. (1997), "Neural network model for estimating construction productivity", *Journal of Construction Engineering and Management*, Vol. 123 No. 4, pp. 399-410.

Rojas, E.M. and Aramvareekul, P. (2003), "Labor productivity drivers and opportunities in the construction industry", *Journal of Management in Engineering*, Vol. 19 No. 2, pp. 78-82.

Saaty, T.L. (1991), *Decision-Making with Dependence and Feedback: The Analytic Network Process*, RWS, Pittsburgh, PA.

Saaty, T.L. and Vargas, L.G. (2001), *Models, Methods, Concepts & Application of the Analytic Hierarchy Process*, RWS, Pittsburgh, PA.

Smith, S.D. (1999), "Earthmoving productivity estimation using linear regression techniques", *Journal of Construction Engineering and Management*, Vol. 125 No. 3, pp. 133-41.

Song, L. and AbouRizk, S. (2008), "Measuring and modeling labor productivity using historical data", *Journal of Construction Engineering and Management*, Vol. 134 No. 10, pp. 786-94.

Sonmez, R. and Rowings, J.E. (1998), "Construction labor productivity modeling with neural networks", *Journals of Construction Engineering and Management*, Vol. 124 No. 6, pp. 498-504.

Thomas, H.R. and Sakarcan, A.S. (1994), "Forecasting labor productivity using factor model", *Journal of Construction Engineering and Management*, Vol. 120 No. 1, pp. 228-39.

Yu, J. and Lee, H. (2002), "Productivity management system for construction projects", *Journal of the Architectural Institute of Korea*, Vol. 18 No. 7, pp. 103-13.

Zayed, T.M. and Halpin, D.W. (2005), "Productivity and cost regression models for pile construction", *Journal of Construction Engineering and Management*, Vol. 131 No. 7, pp. 779-89.

Further reading

Choi, H., Shin, Y. and Kang, K. (2005), "A study on productivity of foreign labors in domestic apartment construction site: focused on evaluation of productivity and productivity impediment factor", *Journal of the Korea Institute of Building Construction*, Vol. 5 No. 1, pp. 75-9.

Kang, S. and Lee, S.K.M. (2007), "AHP-based decision-making for median barrier installation", *International Workshop on Computing in Civil Engineering*, Vol. 24-27, pp. 452-64.

Kim, J., Hyun, C. and Koo, K. (2004), "A labor productivity model for electrical construction of apartment-house projects", *Journal of the Architectural Institute of Korea*, Vol. 24 No. 2, pp. 599-602.

Koskela, L. (1992), "Application of the new production philosophy to construction", Technical Report No. 72, CIFE, Stanford University, Stanford, CA.

Lee, H., Yu, J.-H. and Kim, S.-K. (2004), "Impact of labor factors on workflow", *Journal of Construction Engineering and Management*, Vol. 130 No. 6, pp. 918-23.

Moon, W., Han, S., Kim, Y., Kim, Y. and Kim, S. (2006), "Analysis on the factors influencing construction productivity for management of construction productivity information", *Korean Conference of Construction Engineering and Management, Suwon, Korea*, pp. 422-6.

Oglesby, C.H., Parker, H.W. and Howell, G.A. (1989), *Productivity Improvement in Construction*, McGraw-Hill, New York, NY.

Oh, S., Kim, M. and Kim, Y. (2006), "The application of data warehouse for developing construction productivity management system", *Korean Journal of Construction Engineering and Management*, Vol. 7 No. 2, pp. 127-37.

Son, J., Yoon, J. and Paek, J. (2003), "A study on construction productivity measurement method", *Journal of the Architectural Institute of Korea*, Vol. 19 No. 10, pp. 101-8.

Woo, G., Oh, S., Kim, Y. and Kim, Y. (2008), "The development of a productivity prediction system in the structural framework of apartment housing projects using data mining technique", *Journal of the Architectural Institute of Korea*, Vol. 24 No. 9, pp. 113-22.

Corresponding author
Kyonghoon Kim can be contacted at: greatekkh@hotmail.com