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Quantified Impact Analysis of Construction Delay Factors on Steel Staircase Systems

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Abstract

Construction projects have become so large, complicated and incredibly high-tech that process management is currently considered one of the most important issues. Unlike typical manufacturing industries, most major construction activities are performed in the open air and thus are exposed to various environmental factors. Many studies have been conducted with the goal of establishing efficient techniques and tools for overcoming these limitations. Productivity analysis and prediction, one of the related research subjects, must be considered when evaluating approaches to reducing construction duration and costs. The aim of this research is to present a quantified impact analysis of construction delay factors on construction productivity of a steel staircase system, which has been widely applied to high rise building construction. It is also expected to improve the process by managing the factors, ultimately achieving an improvement in construction productivity. To achieve the research objectives, this paper analyzed different delay factors affecting construction duration by means of multiple regression analysis focusing on steel staircase systems, which have critical effects on the preceding and subsequent processes in structure construction. Statistical analysis on the multiple linear regression model indicated that the environment, labor and material delay factors were statistically significant, with 0.293, 0.491, and 0.203 as the respective quantified impacts on productivity.

Keywords : delay factor, productivity, multiple linear regression, steel staircase, high-rise building

1. Introduction

1.1 Research background and objective

As the construction process, unlike other forms of manufacturing and production, is usually done in an open space or outdoors, it has been subject to many limitations in terms of predicting results such as productivity and cost in advance. In particular, there are many variables and risks that should be considered in analyzing and predicting productivity, one of the major indicators utilized for assessing the performance of the construction process[1,2]. As construction projects become larger and more complex, construction delays can bring huge losses to the sectors involved. To prevent such losses, it is critical that the preliminary plan for the construction process be established in a more accurate and precise manner. The analysis and prediction of construction productivity is one of the factors required to establish a more effective and reliable preliminary plan for the construction process[1]. For this reason, construction specialists, including construction managers, should strive to establish a reasonable plan for the construction process. To do this, an accurate analysis and precise prediction of

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construction productivity is required[3].

The need for an analysis of construction productivity is closely related with construction duration. Other than quality, cost and safety, construction duration is one of key managerial factors that have a great impact on a construction project, and a more effective plan should be prepared to improve construction productivity as well as construction technologies in order to meet the construction deadline and reduce the construction duration[4].

Working ratio, one of the productivity measurement factors, indicates a linear relationship with construction productivity. For this reason, to improve working ratio, the construction delay factors should be comprehensively analyzed, and direct and indirect interdependence between works should be examined as well[5].

Therefore, this research aims to analyze interrelations with construction productivity through an analysis of construction delay factors, the substructure in construction productivity analysis, required for the improvement of construction performance. This paper presents a quantified impact analysis of construction delay factors on construction productivity, which makes it possible to understand the specific construction delay factors to be intensively managed, and this is expected to improve the process by managing the factors and ultimately achieving an improvement in construction productivity.

1.2 Research method and scope

The staircase installation work currently adopted in high-rise building construction in Korea was selected, in order to select an appropriate research subject in consideration of the keen interest in high-rise building construction projects in Korea and overseas. In particular, of the structural works considered as major works in a high-rise building construction project, staircase installation work was selected because of its great influence on the other works connected, including the preceding and following work processes. Another reason for selecting staircase installation work was that all specific events in this work were conducted in a sufficiently separate manner to be easily observed[7,8]. The construction techniques related to staircase installation work applied in high-rise building construction projects in Korea largely fall into RC (reinforced concrete) staircase and steel staircase systems[7,8,9]. The steel staircase system was selected to specifically study construction delay factors and measurement of construction productivity, as it has gained in popularity in high-rise building construction sites due to its advantages, including its capacity to secure a higher level of safety and a reduced construction duration compared to the conventional RC staircase system[7,8].

Two research approaches were presented in this study. One is the evaluation of construction delay factors by observers, including construction managers. The other is the application of the multiple linear regression model, one of the statistical methods used to analyze correlations between independent and dependent variables.

In detail, this study was composed of a total four steps, as follows.

Step 1: Determination of construction delay factors through literature review

Step 2: Evaluation by interval scale based on construction delay factors

Step 3: Determination of correlation equation using the multiple linear regression model

Step 4: Suggestion of quantified impact of construction productivity by factor

In Step 1, the literature was reviewed to derive construction delay factors, and the representative construction delay factors used in MPDM (Method Productivity Delay Model) presented and studied by Adrian were selected, since the delay factors were clear and concrete, and were appropriate to be quantified[10,11,12].

In Step 2, delay factors selected in Step 1 were evaluated by construction personnel and site visitors using a Likert Scale, which is widely used not only in the social sciences but also in engineering science.

In Step 3, a multiple linear regression model analysis was conducted by setting the results of the Likert Scale evaluation by professionals as independent variables and the productivity values measured at an actual site as independent variables. The result was drawn as a correlation equation between dependent variable y and multiple independent variables x.

In Step 4, the impact on the productivity of each factor was quantified and analyzed based on the multiple linear regression model drawn in Step 3.

2. Review of previous studies

2.1 Multiple linear regression model analysis

A regression model analysis is a statistical analysis method that explains the relationship between variables by assuming some of the variables as causes and the others as results on the premise that diverse continuous variables are correlated. The variables set as causes are termed as explanatory variables or independent variables, while the variables set as results are termed as response variables or dependent variables. The multiple linear regression analysis provides a one-dimensional explanation for one response variable with various explanatory variables[13].

The multiple linear regression model is expressed as in Eq.(1)[13].

$$\widehat{Y} = \widehat{\beta_0} + \widehat{\beta_1} X_1 + \widehat{\beta_2} X_2 + \cdot\cdot\cdot + \widehat{\beta_k} X_k + \epsilon \qquad (1)$$

$\widehat{Y}$: *dependtdent variable*

$\widehat{\beta_k}$: *constant*

X_k : *independent variable*

ϵ : *error*

Multiple linear regression models provide a numerical equation as a result, and have been widely used as a methodology for predicting similar phenomena based on existing data. The regression model analysis has been used as a prediction technique in the social sciences to perform a factor analysis has been applied in the construction field since the 1980s, and is widely applied to predict result values to this day. Focusing on the construction area, the multiple linear regression model is used in wide range of fields, such as for earthmoving productivity estimation based on actual quantities[14,15], performance analysis and prediction of new technologies based on simulation[16,17], and construction cost estimation for 42 apartment buildings[18]. Most of the studies mentioned above presented a result value using the regression analysis model, but they have some restrictions in terms of statistical verification for each independent variable and presentation of quantified impact. Accordingly, this research put an emphasis on the presentation of a quantified impact of each of the construction delay factors that affect the construction productivity, the result value, rather than prediction of the result value using the multiple linear regression model. The validity of the multiple linear regression equation drawn in this research was examined through a comparison between the expected values and the result values of test data.

2.2 Construction delay factors in the MPDM

Many methods for estimating and assessing construction productivity have been presented by many researchers. Since a quantified method for productivity measurement was accepted as a method to raise efficiency in construction sites, it has been widely studied in academia and industry[12,19]. Of the diverse methods presented, the MPDM is a method for measuring the working time of each cycle for a small-scale work process directly carried out at a site while simultaneously analyzing the factors causing a delay in working time. The MPDM is different from other productivity measurement methods in that it not only sets and analyzes the delay factors but can also indirectly express the impact of delay factors on productivity in an numerical manner by separately expressing the expected productivity: overall productivity under a delayed condition and ideal productivity under no delay condition[12,19].

Table 1. Definitions of construction delay factors [12]

Name of delay factors	Example
Environment	Delay caused by environmental issues such as heavy rain, snow or strong wind
Labor	Delay caused by labor issues such as idle attitude, fatigue
Equipment	Delay caused by equipment issues such as stationary, malfunctions
Material	Delay caused by material issues such as supply, defects
Management	Delay caused by managerial issues such as plan, control, communications

Table 1 indicates five delay factors generally used in the MPDM. The five factors presented in the MPDM were applied to the steel staircase system in this research.

3. Analysis of the working process of steel staircase system

3.1 Outline of the target project

The major activities involved in the installation of the steel staircase system selected as the research subject are as follows. The steel staircase system is first prefabricated in a factory, and then is delivered to the site. Next, the mold of the RC stair landing is installed and connects the steel stairs with the stair landing using a stair anchor.

The steel staircase system reduces construction duration because of its simple installation process, guarantees quality due to its prefabrication in a factory, and prevents safety accidents by securing sufficient work spaces while installing, which are recognized as relative advantages compared to the conventional RC staircase system[7,8,20].

To collect the actual quantities of the steel staircase system, preliminary research was conducted including a visit to a manufacturer of steel staircase systems, a review of the related literature, and an interview with personnel. Through the preliminary research, candidate sites appropriate for the objective of this research were selected. The target site was selected based on the criteria that the work process would be clear and the process could be easily measured. We visited the target site to collect the data of process measurement, workload, and the composition of workers by videotaping the work process and conducting interviews with persons concerned. The target site was located in Haewundae-gu, Busan, where three high-rise residential buildings were built, which had 70, 75 and 80 floors above ground and five underground. The structural works in 8-9 stories were in progress during the visit. The outline of the target site is indicated in Table 2.

Table 2. Construction site outline [7,8,20]

Division	Descriptions
Construction Name	Residential complex co-housing
Location	Pusan City Haeundae-gu
Period	2007.12 ~ 2012.01
Purpose	Residential, Office, Commercial spaces
Number of floors	5th basement floor ~ 70th floor / 80 floors, 3 buildings, 1788 households
Area	42,478.10m^2

3.2. Work process of the steel staircase system

Through the site observation and interviews with people at the site, the equipment used in the work for the steel staircase system was found to be crane for material lifting, truck mixer for concrete placement on the landing and concrete conveying pipes. In addition, 7 workers were required for the work: two carpenters, one rodman for rebar placement, two laborers for concrete placement, one cement finisher and one foreman. Pictures of the detailed work process for the steel staircase system are presented in Table 3[7,8,20].

Table 3. Installation process of steel staircase systems [7,8,20]

		
① Preparation	② Formwork installation of landing area	③ Installation of stair anchor
		
④ Installation of temporary staircase	⑤ Steel reinforcement of landing space	⑥ Concrete placing of landing area
		
⑦ Staircase installation	⑧ Staircase installation	⑨ Finish

Table 4. Actual data by site observation and measurement of construction operation steel staircase systems

Work	Labor	Equipment	Time(hr.)						
			WorkLabor Equipment 1	2	3	4	5	6	7
Direction	C, L1, L2	-	0.2	0.1	0.1	0.1	0.0	0.1	0.2
Moving	L1, L2	-	0.8	1.4	1.7	1.3	1.5	0.7	1.1
Scaffolding installation	L1, L2	-	0.5	0.3	0.4	0.4	0.8	0.7	0.6
Space formwork landing	L1, L2	-	1.4	1.6	1.7	1.5	1.8	1.3	1.8
Stair anchor installation	L1	-	0.4	0.5	0.6	0.2	0.2	0.3	0.3
Queuing crane	-	-	1.0	0.3	0.5	0.8	0.5	0.2	1.8
Temporary staircase installation	L1, L2	Crane	1.2	0.9	1.0	0.9	0.8	1.0	1.1
Checking	C, L1	-	0.2	0.2	0.2	0.1	0.1	0.2	0.1
Queuing crane	-	Crane	0.6	1.0	0.4	1.4	0.4	0.3	1.2
Moving steel	L3	Crane	0.5	0.3	0.4	0.3	0.4	0.5	0.4
Reinforcement	L3	-	2.0	1.7	3.9	1.9	2.3	1.8	2.0
Checking	C, L3	-	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Queing crane	-	Truck mixer	1.1	0.5	0.2	0.3	0.8	1.4	0.9
Pumping preparation	-	Truck mixer, concrete pump	0.1	0.2	0.1	0.1	0.1	0.1	0.1
Placing preparation	L4	-	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Landing space concrete placing	L4, L5	Truck mixer, concrete pump	0.8	0.6	0.3	0.8	0.6	0.7	0.7
Checking	C, L4	-	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Queuing crane	-	-	0.2	0.5	0.6	0.1	0.6	0.8	0.9
Disassembling temporary staircase	L1, L2	Crane	0.6	0.5	0.4	0.5	0.5	0.8	0.3
Staircase installation	L1, L2	Crane	0.8	0.9	0.8	0.7	0.7	1.4	0.8
Checking	C, L1	-	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Formwork Separation	L1	-	1.4	1.8	1.5	1.7	1.8	1.3	1.1
Concrete Exposure	L6	-	0.4	0.5	0.6	0.5	0.8	0.5	0.5
Checking	C	-	0.3	0.3	0.5	0.3	0.4	0.5	0.3
Overall			14.9	14.5	16.1	14.1	15.1	14.6	16.3
Productivity(cycle/hr.)			0.06696	0.06912	0.06205	0.07092	0.06615	0.06857	0.06141

Note: C(foreman); L1, L2(carpenters); L3(rodman); L4, L5(laborers); L6(cement finisher)

4. Data collection

4.1 Productivity measurement

The process data cluster was collected 7 times for 1 month from October 1 through October 31, 2011 to analyze the construction delay factors of the steel staircase system, the research subject, as shown in Table 4. The entire process of installing the steel staircase system was divided into observable minimum work units, which are shown in Table 5. The information of workers and equipment is expressed with the type and number of equipment used and the type and the number of workers input in each unit. In the process data cluster collected 7 times, the time taken for each work unit was listed and productivity by time expressed with the total time taken for the work and the number of cycles per hour was also presented. The average time of 7 cycles was 15.09 hours, and 2 days were usually spent finishing a cycle of a work unit. To measure the time taken for a cycle in an accurate manner, a team was composed of three members to make cohesive judgments and measurements. The team measured the time taken for the cycles[9].

4.2 Analysis of construction delay factors

The information on the time taken for each cycle and productivity per hour presented in Table 4 is used as dependent variables in a statistical method to analyze the quantified impact of factors influencing productivity presented in this chapter. The observance group that consisted of 3 observers (researchers), 1 supervisor and 1 manager for the work unit conducted an analysis of the factors influencing productivity presented in 2.2 using the Likert scale (1 very poor; 2 poor; 3 fair; 4 favorable; 5 very favorable) during each cycle. The results are shown in Table 5. Of the analyses of

Table 5. Analytic data collected by site observers

Observer	Cycle	Environment	Equipment	Labor	Material	Management
A	1	7	5	3	3	5
	A 2	5	5	7	7	1
	A 3	3	7	3	5	3
	A 4	7	5	7	7	7
	A 5	3	3	5	5	3
	A 6	5	5	7	1	5
	A 7	1	5	3	5	1
B	1	7	5	5	3	5
	B 2	5	5	5	7	1
	B 3	5	7	1	5	3
	B 4	7	7	7	7	7
	B 5	1	3	5	5	3
	B 6	5	5	7	3	5
	B 7	1	5	1	5	1
C	1	7	7	1	3	5
	C 2	5	5	7	5	1
	C 3	3	7	3	5	3
	C 4	7	7	7	7	7
	C 5	3	3	5	5	3
	C 6	7	5	7	1	5
	C 7	1	5	1	5	1
D	1	7	5	5	5	5
	D 2	3	5	7	7	1
	D 3	3	7	5	5	3
	D 4	5	7	7	7	7
	D 5	1	1	7	5	3
	D 6	5	5	7	1	5
	D 7	1	5	5	5	1
E (Data Verification)	1	5	5	3	3	7
	E (Data Verification) 2	5	5	5	7	5
	E (Data Verification) 3	3	7	3	5	5
	E (Data Verification) 4	7	5	7	7	7
	E (Data Verification) 5	3	3	5	5	7
	E (Data Verification) 6	5	5	5	1	5
	E (Data Verification) 7	1	5	3	5	5

the 7 cycles by five people, one analysis by one person was kept as test data for verification of the multiple linear regression model. Therefore, a total of 28 input data evaluating delay factors for the 7 cycles by 4 people was used as a data set for the multiple linear regression model[9].

5. Deduction and analysis of a multiple linear regression model

5.1 Selection of variables

The values of the factors influencing productivity evaluated by the observance group were set as independent variables in the composition of the multiple linear regression model (x_1 ⋯ x_5), consisting of a total of 5 factors: environment, equipment, labor, material and management. More specifically, the environment factor (x_1) encompasses delay factors related with weather, etc.; the equipment factor (x_2) encompasses delay factors related with inappropriate use or breakdown of equipment including crane; the labor factor (x_3) encompasses delay factors related with activities of the workers other than work; the material factor (x_4) encompasses delay factors related with damage to defects in the material including any damage to steel stairs or delivery problem of the material (not delivered on time); and the management factor (x_5) encompasses delay factors arising from interference by other works or work plan[9].

The dependent variable (y) that corresponded to the independent variables was the productivity per hour actually measured at site.

5.2 Deduction of a multiple linear regression model

To analyze the quantified impact of each independent variable by deducing a multiple linear regression model, the process below and result values should be statistically estimated.

First, regression coefficient β_0(a constant) and β_k($k=1,\ldots n$; correlation coefficient between independent variable and dependent variable) should be estimated. The value is estimated using the least squares method, as shown below[13].

$$Q=\sum_{i=1}^{n}\epsilon^2=\sum_{i=1}^{n}(y_i-\beta_0-\beta_1 x_i)^2 \quad \text{------} \quad (2)$$

β_0 and β_k that make Q minimized in Eq.(2) above are presented as estimated values using a partial differential, on which basis the relation of the partition of sum of squares is drawn[13].

$$\sum_{i=1}^{n}(y_i-\bar{y})^2=\sum_{i=1}^{n}(\hat{y_i}-\bar{y})^2+\sum_{i=1}^{n}(y_i-\hat{y_i})^2 \quad \text{------} \quad (3)$$

The left–hand side is the total sum of squares (TSS), the first term on the right–hand side is expressed as the sum of squares due to regression(SSR), and the second term on the right–hand side is expressed as the sum of squares due to error (SSE)[13].

The coefficient of determination (R^2) mainly used in discussions of the multiple linear regression model is drawn in Eq.(3) above and determined as shown in Eq. (4)[13].

$$\frac{SSR}{TSS}=1-\frac{SSE}{TSS} \quad \text{---------------} \quad (4)$$

The coefficient of determination (R^2) is between 0 and 1. It is interpreted that as the value approaches 1, a better explanation of variation is being provided by the model. However, when the number of samples is increased, the coefficient of determination tends to be greater. For this reason, an adjusted R^2 is usually used in the multiple linear regression model instead of R^2. T–test was used to verify the statistical significance of each independent variable, and F–test was used to verify the statistical significance of the entire model. p value is considered as an indicator to determine statistical significance in both of the tests. When p value is lower than 0.05, it is statistically significant at a 95% confidence level[13].

To efficiently deduce the multiple linear regression model mentioned above, PASW Statistics 18, a statistics program, was used in this research.

To cope with the low number of data and independent variables, multiple linear regression analysis was performed. All the independent variables were entered to select variables included in the regression model.

The multiple regression model fit was test by comparing p value by F value to the significance level at R^2 of 0.7 or higher. In addition, individual regression coefficient was compared to p value of t value of the test statistics set at the significance level of 0.05.

Based on the verification above, the coefficient of determination (R^2) was 0.854, as shown in Table 6, which explained about 85.4% of the variance. In particular, the adjusted coefficient of determination used for explanation of the multiple linear regression model was 0.821. The difference between the coefficient of determination (R^2=0.854) and the adjusted coefficient of determination (Adjusted R^2=0.821) was within 10%, and the model is evaluated to provide a good statistical explanation and to be a stable model that is not significantly affected by individual variables[13].

To detect the autocorrelation in the residuals from the regression analysis (independence of residuals), the Durbin–Watson statistic was used. A value of 2 means there is no autocorrelation in the sample, showing standard distribution. In addition, values approaching 0 indicate a positive autocorrelation and values toward 4 indicate a negative autocorrelation. If the values of the Durbin–Watson statistic are closer to 0 or 4, the errors are correlated, which means the model is inappropriate. As indicated in Table 6, the value of the Durbin–Watson statistic is 2.751, which is close to 2, and the residuals can be considered independent[13].

Table 6. Summary of statistic model fitness

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin–Watson
1	.924	.854	.821	.0014258	2.751

The impact of independent variables can be estimated by comparing absolute values of standardized coefficients (Beta value). Of the variables, the variable that had the greatest impact on productivity was environment, followed by labor, equipment, material and management, in that order. If collinearity is found in the multiple linear regression model, the impact on dependent variables of independent variables is not explained appropriately. Therefore, when a multiple linear regression analysis is conducted, collinearity should be checked. To detect collinearity, the variance inflation factor (VIF) is identified. If the VIF is 10 or higher, it indicates that collinearity is high. Therefore, if the VIF is lower than 10 and approaching 1, it indicates that the collinearity is low. The variables shown in Table 7 satisfy these criteria, and there is no collinearity found between independent variables[13].

Figure 1 shows a normal probability plot of standardized residuals of a linear regression model. The regression line closely passes through 28 data points. Figure 2 shows the scatter plot of the standardized residuals, which are relatively evenly distributed on both sides of 0. Thus, the model is valid and homoscedasticity is established.

Of the variables, the p-values of environment, labor, and material were below the significance level of .05, which was statistically significant. On the other hand, the p-values of equipment and management were higher than the significance level of .05, which was not statistically significant.

Using the non-standardized coefficient in Table 7, the multiple linear regression model was drawn as shown in Eq.(5)[9].

Table 7. Summary of multiple linear regression

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics
Model		B	Std. Error	Beta	t	Sig.	VIF
1	Constant	.0591	.001		41.189	.000	
	Env.	.0009	.000	.593	4.720	.000	2.387
	Equ.	-.0005	.000	-.208	-2.029	.055	1.583
	Lab.	.0008	.000	.491	4.934	.000	1.493
	Mat.	.0004	.000	.203	2.325	.030	1.153
	Mgmt.	.0001	.000	.078	.644	.526	2.212

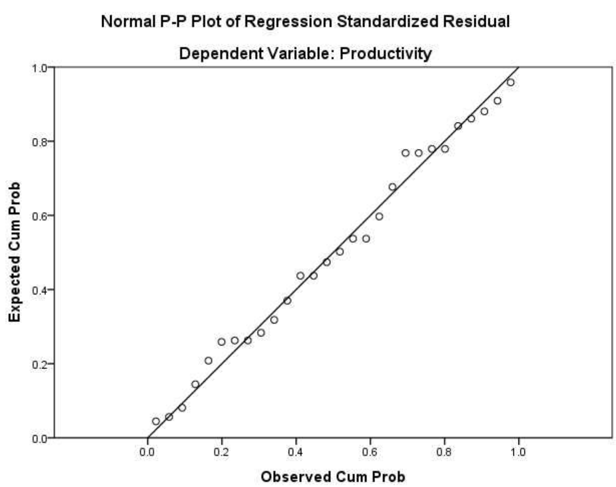

Figure 1. Normal P-P plot of regression standardized residual

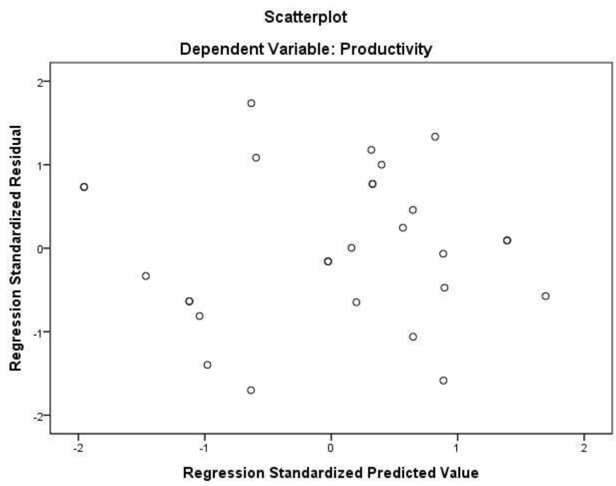

Figure 2. Scatter plot of regression standardized residual

$$Productivity(Y) = 0.0591 + 0.0009 \times X1 + 0.0008 \times X2 + 0.0004 \times X3 \quad (5)$$

$$X1 = Environment$$
$$X2 = Labor$$
$$X3 = Material$$

To conduct a quantified impact analysis of construction delay factors on productivity, a multiple linear regression analysis was used, and the model is drawn in Eq.(5). Of the independent variables: environment, equipment, labor, material and management, variables of environment, labor, and material were determined to have a statistical impact on productivity($p<0.05$). The three factors had a positive impact on productivity. In particular, it was found that the better the environment, the higher the impact on productivity. The standardized coefficient of environment, labor and material was 0.593, 0.491 and 0.203, respectively, as shown in Table 7, each of which is the impact on productivity. The environment, labor and material factors presented in the model above explained about 85.4% of the variance.

Thus, based on the analysis above, it would be more effective to increase the productivity of the steel staircase system installation by strictly managing and controlling environmental and labor factors rather than equipment or management factors. In addition, the equipment used in the steel staircase system such as crane, truck mixer and concrete pump are usually used in other work processes, and are used for only a small amount of time in the staircase work; therefore, the impact of equipment is believed to be small or not statistically significant. Due to the characteristics of the steel staircase system, such as prefabrication in a factory and delivery to the site, and the simple process, the impact on productivity of management factors is believed to be slight.

5.4 Application and verification of the multiple linear regression model

To verify the performance of the multiple linear regression model drawn in this research, expected productivity was drawn using the data of Observer shown in Table 8 and compared to the actual productivity measured at the site. The error(%) presented in Table 8 was calculated using Eq. (6).

$$Error(\%) = \frac{|Actual\ value - \text{Expected}\ value|}{Actual\ value} \times 100 \quad (6)$$

From the comparison between actual productivity and expected productivity, the average of error and standard distribution were 3.02% and 2.29%, respectively, as shown in Table 8. In addition, using PASW Statistics 18, a T-test (two-sided test) was conducted for correspondence between the samples of actual productivity and expected productivity. P-value of a T- test was 0.028. It was verified that this was lower than 0.05 at a 95% confidence level and higher than 0.025 at a 97.5% confidence level. The two result values were determined to show no statistical difference under a 97.5% confidence level. However, it also indicated in statistical views that the productivity values predicted through the model were slightly higher than the actual productivity, at a 95% confidence level. Table 9 indicates the t-test of two result value clusters.

Table 8. Comparisons between actual and predicted productivities

Cycle no.	Actual productivity	Predicted productivity	Error(%)
1	0.06696	0.0672	0.358
2	0.06912	0.0704	1.852
3	0.06205	0.0662	6.688
4	0.07092	0.0738	4.061
5	0.06615	0.0678	2.494
6	0.06857	0.0680	0.831
7	0.06141	0.0644	4.869
Mean			3.022
Standard deviation			2.290

Table 9. Comparison of results based on T-test pairs

Mean	Standard deviation	Standard error	t-value	df	P-value
-0.0018029	0.016557	0.0006258	-2.881	6	0.028

6. Conclusion

Construction delay factors generally applied to overall construction processes were derived through a literature review of previous research. The quantified impact of each construction delay factor on each part was presented based on multiple linear regression analysis, which is widely used not only in the social sciences but also in engineering science.

This research presented a methodology that can be applicable to similar research in the future by giving an example of statistically analyzing an explanation of a factor. In addition, from the industrial perspective, the ability to quantify the impact of construction delay factors is expected to contribute to better management of construction processes by prioritizing and eliminating the construction delay factors.

The research findings based on the multiple linear regression analysis are as follows.

First, the construction delay factors in the steel staircase system installation were analyzed, and the impact was quantified using the multiple linear regression model.

Second, based on the literature review, the construction delay factors used in the MPDM were defined, a target site was selected and then the construction delay factors were analyzed by observer group using a Likert scale. The observance group analyzed the construction delay factors of the work process (environment, equipment, labor, materials and management), and another group measured actual productivity using a site measurement technique.

Third, based on the diverse information collected, the quantified impact of individual construction delay factors was presented using a statistical method, the multiple linear regression model.

Fourth, the environment, labor and material factors of the five construction delay factors were found to be statistically significant by the multiple linear regression model, and the impact on productivity of the factors was shown as 0.593, 0.491, and 0.203, respectively, all of which are positive.

The multiple linear regression model used in this research is a data-based explanation tool, used in many studies, in which the number of input data determines the result values. Taking into account the difficulty of data collection at construction sites, a total of 28 data sets were used, but it is believed that to obtain more cohesive results values a large amount of data is needed.

The construction delay factors corresponding to each construction site and the work unit should be further studied. The scope of this research is limited to five factors applicable to general use, but various types of construction delay factors, specified or clustered, should be derived in subsequent studies.

In addition, the multiple linear regression analysis used in this research is expected to be applicable when it is composed of multiple independent variables and one variable. A new logical analysis method in which multiple independent variables and multiple dependent variables and related new variables can be set should be studied and applied in the future.

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