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Impact Analysis of Construction Delay: The Case of Defects In the Top-down Construction Method

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Abstract: Defects are the risk factors in the construction process of buildings. They cause damage, delaying the construction duration. They especially cause adverse effects on the top-down construction method. This study analyzed the degree of construction delay induced by each work type, focusing on defects in the top-down method. Then, we derived construction delay induction coefficient from different work types in order by using the severity of construction delay per defect and the occurrence probability of defect; this assessment model measures the impact of defects on construction delay for each work type. Furthermore, by comparing each work type based on the defect frequency and the construction delay induction coefficient, we found work types that need to be administered attentively. We identified that plastering work was easy to overlook, requiring caution in defect management. This study provides an efficient defect management system suitable for the buildings that are built using the top-down construction method.

Keywords: Top-down construction method, Construction delay, Defect management, Regression analysis, Occurrence probability

1. INTRODUCTION

The construction duration is defined as the period from the date of commencement of the work to the completion date of the construction contract; it is one of the most important factors to consider in construction work. Particularly, as construction delay can cause many problems, such as a loss of productivity, time extension, cost increase, and contract destruction [1], compliance with the construction duration is significantly important from various perspectives, such as preventing cost problems between various stakeholders involved in construction work [2]. A top-down construction method, one of the suitable construction methods for abiding by the organized construction duration, can construct basement levels and upper ground floors simultaneously without being affected by weather condition [3], shortening the construction duration. Hence, this method has been actively used in construction sites in South Korea for the past 30 years.

Defect generally defined as a term that interfere with the safety, function, or aesthetics of a facility can prevent following the building construction process, causing delay in a variety of ways, such as when defect remedy works are required; Thus, defect management which includes a discovering system of defects plays a crucial role in construction management [4, 5]. Particularly, as defects weaken the advantage of the top-down construction method which is about shortening the construction duration [6, 7], the damage is more remarkable in the case of defects that occurred in buildings to which the top-down method is applied. Therefore, if the top-down method is adopted as the construction method, it is necessary to manage defects effectively by studying its characteristics. However, studies on the defect occurrence have mainly focused on analyzing the frequency of defect occurrence by work types without considering the type of construction methods [8]. Specifically, there have been only a few studies on the relationship between defects and the construction delay for the top-down method.

This paper presents a model of construction delay induction coefficient for buildings. We quantitatively calculated the impact of construction delay for individual work types. Then, we identified work types with a substantially larger influence on construction delay and less frequency of defect occurrence because these work types that were not the major concerns in defect management of the past can incur serious adverse effect on construction delay [9]. This study aims to establish an efficient defect management system for the building construction process with a top-down construction method.

2. THEORETICAL BACKGROUND

2.1 Literature review

Prior studies analyzed defects in the building. In particular, studies have been conducted focusing on the causes of defects; they have used the defect frequency for work type to measure damage to a building and its construction process. Construction capacity is one of the causes of defects. Seo D et al. [10] analyzed the effect of construction capacity of construction companies on the frequency of defect occurrence by work type. They set up the contract ranking as an important indicator of construction capacity. Then, they showed that companies with higher contract rankings had less frequency. Additionally, differences in building types have a prominent effect on the the number of defect occurrences. Seo J et al. [11] showed that the number of defect occurrences in high-rise buildings composed of residential and commercial programs was higher than those in common residential buildings. Furthermore, Son S et al. [12] subdivided defects into about ten types per each work type and investigated the frequency of defect occurrence, focusing on the apartment housing. These studies focused on the frequency of defect occurrence. Yet, many studies have not analyzed the relationship between defects and construction delay.

2.2 Top-down construction method

Building with basement levels requires the installation of an underground structure. There are several ways to construct an underground structure. Its construction is commonly done using steel beams as temporary strut or earth anchor method; however, the former needs a long period of building construction and the latter provokes construction delay mostly due to safety issues of an underground structure [13]. One of the ways to solve these problems is the top-down construction method. This method which control risks caused by deep excavation can reduce construction time by excluding the construction work related to temporary struts [14]. Especially, the top-down method can shorten the period of construction work by allowing the basement levels and upper ground floors to be constructed concurrently. It can minimize construction delay by performing construction work without being affected by external environmental elements, such as precipitation.

2.3 Multiple linear regression analysis

Linear regression analysis is a technique that specifies a linear correlation between independent and dependent variables. Multiple linear regression analysis is used to study the relationships between two or more independent variables and dependent variables. One important problem to identify and solve is multicollinearity. Multicollinearity problem arises due to strong correlations among independent variables; we therefore first identified correlation coefficients among independent variables before analysis. The additional assumptions required for linear regression analysis are as follows:

1) Establishment of a linear relationship between the independent and dependent variables
2) Confirmation of independence, equal variance, and normality of residual, (i.e., the quantitative difference between the expected value calculated through the regression model and the observed value).

3. DEVELOPMENT OF CONSTRUCTION DELAY INDUCTION COEFFICIENT

3.1. Data collection

The data in this study consisted of contents collected during the construction process of twelve buildings located in South Korea. All the buildings used in the analysis had basement floors, and the top-down method was adopted as a construction approach. The buildings were built with similar levels of top-down construction technology because the same company was involved in the construction processes.

The data contained the following: frequency of defect occurrence and the number of construction delay days for each type of work. Table 1 lists a total of eleven work types which are selected based on previous study [11], excluding some work types that are not satisfied enough with the assumption of multiple linear regresstion analysis.

Table 22. List of work type

Work Type	Reinforced Concrete Work	Waterproof Work	Plastering Work	Tiling Work	Electrical Work
Classification Code	$i = 1$	$i = 2$	$i = 3$	$i = 4$	$i = 5$

Work Type	Glass Work	Interior Finishing Work	Painting Work	Metal Work	Stone Work	Plumbing Work
Classification Code	$i = 6$	$i = 7$	$i = 8$	$i = 9$	$i = 10$	$i = 11$

3.2. Severity of construction delay per defect in each work type

Multiple linear regression analysis was used to derive the severity of construction delay per defect by work type. After setting the work types (see Table 1) as independent variables and the number of construction delay days due to defects as dependent variables, the regression coefficients for each work type were calculated via multiple linear regression analysis. The calculated coefficient described in individual work types is a value indicating the duration of construction delay due to the occurrence of single defect in a certain work type. It would help identify the severity of construction delay per defect for respective work types.

3.2.1. Investigation of multicollinearity problem

Figure 1 illustrates the correlation coefficient between independent variables. In general, a correlation coefficient of more than 0.7 or less than -0.7 is considered to be an indicator of a strong correlation. Therefore, we considered that if the absolute value of a correlation coefficient was 0.7 or more, the main characteristics of the independent variable were problematic. We did not find any case where the absolute value exceeded 0.7. In other words, all independent variables were suitable for regression analysis.

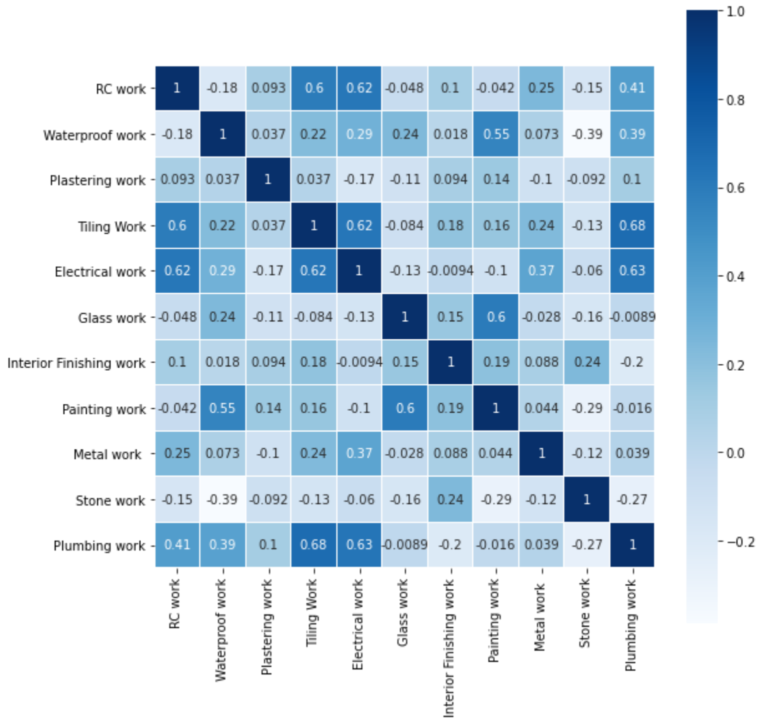

Figure 1. Correlation coefficient matrix for independent variables

3.2.2. Derivation of the regression coefficient

Table 2 contains the result of multiple linear regression analysis. Quantitative comparison between unstandardized regression coefficients was possible as the measurement scale of independent variables was consistent. R_i used in Table 2 represents the regression coefficient for

Table 2. Regression coefficient by work type

	Reinforced Concrete Work	**Waterproof Work**	**Plastering Work**	**Tiling Work**	**Electrical Work**
R_i	0.61 (i = 1)	0.89 (i = 2)	3.87 (i = 3)	0.18 (i = 4)	0.22 (i = 5)

	Glass Work	**Interior Finishing**	**Painting Work**	**Metal Work**	**Stone Work**	**Plumbing Work**

	Work					
R_i	0.48 (i = 6)	0.65 (i = 7)	0.29 (i = 8)	0.03 (i = 9)	2.34 (i = 10)	0.67 (i = 11)

each type of work. According to the Table 2, $R_{i=2}$ which implies construction delay in waterproof work is about 1.46 times larger than $R_{i=1}$ which is related to construction delay in reinforced concrete work. In other words, a defect in waterproof work needs approximately 1.46 times more time than a defect in reinforced concrete work to repair. Specifically, the higher the regression coefficient for each work type, the more severity of construction delay per defect occurrence. Table 2 shows that plastering work ($R_{i=3}$) has the highest regression coefficient value.

3.2.3. Suitability test for the regression model

The adjusted coefficient of determination (adjusted R-squared) in multiple linear regression analysis measures the degree of suitability of the estimated regression model for a given data. The estimated regression model can be trusted if the adjusted R-squared value exceeds 0.7. The value was 0.82, indicating that the implemented regression model can be trusted.

3.3. Calculating occurrennce probability of defect

The severity of construction delay per defect and the occurrence probability of defect are both considered when investigating the impact of construction delay. The occurrence probability of defect was calculated based on the percentage of the frequency of defect occurrence in each work type out of the total number of defect occurrence in eleven work types. Frequency analysis related to defect were investigated in our previous study [15]. Table 3, which reflects the previous study, shows the defect frequency by work type, the total number of defect occurrence, and the occurrence probability of defect by work type. The total number of defect occurrence was 1,224. The occurrence probability of defect in waterproof work was 22%, meaning that defects in waterproof work are most likely to occur compared to other work types.

Table 3. Frequency analysis of defect occurrence by work type

	Reinforced Concrete Work	**Waterproof Work**	**Plastering Work**	**Tiling Work**	**Electrical Work**
U_i	188 (i = 1)	269 (i = 2)	23 (i = 3)	31 (i = 4)	167 (i = 5)
$\sum_{i=1}^{11} U_i$			1224		
$U_i \div \sum_{i=1}^{11} U_i$ (%)	15.3	22.0	1.9	2.5	13.7

	Glass Work	**Interior Finishing Work**	**Painting Work**	**Metal Work**	**Stone Work**	**Plumbing Work**
U_i	14 (i = 6)	98 (i = 7)	152 (i = 8)	40 (i = 9)	10 (i = 10)	232 (i = 11)
$\sum_{i=1}^{11} U_i$			1224			

$U_i \div \sum_{i=1}^{11} U_i$ (%)	1.1	8.0	12.4	3.3	0.8	19.0

3.4. Deduction of the construction delay induction coefficient

There are two main factors constituting the construction delay induction coefficient (C_i), meaning the impact of construction delay: the severity of construction delay per defect and the occurrence probability of defect. The former was expressed by derivating the regression coefficient through multiple linear regression analysis, and the latter was calculated by dividing the number of defects occurring in individual work by the total number of defects. The values of the two factors were computed for each work type. The construction delay induction coefficient was obtained through the representative values of these two factors. It can be expressed mathematically through the average of the sum or the product. In the case of the average of the sum, unlike the average of the product, the distortion of the resulting value may arise due to the difference in the scale of the unit between factors. Therefore, it is effective to make a quantitative comparison of the construction delay impact by work type by calculating the average of the product [16]. Equation 1 demonstrates the relationship between the two factors, resulting in the construction delay induction coefficient.

$$C_i = \sqrt{R_i \times (U_i \div \sum_{i=1}^{11} U_i)} \quad (1)$$

4. Identify the characteristics of defects in each work type

Figure 2 shows the value of the construction delay induction coefficient and the defect frequency for each work type in the quarter chart. The defect frequency expressed in Figure 2 is utilized as an indicator of visual attention in defect management task. The X-axis and Y-axis represent the defect frequency and the construction delay induction coefficient, respectively. The chart is divided vertically by the arithmetic mean line of the frequency values. The arithmetic mean was 111.27. The arithmetic mean line of the coefficient values about delay separates the chart horizontally. The arithmetic mean was 2.04. These two arithmetic means divided the chart into four regions: Q1, Q2, Q3, and Q4, and work types are distributed in each region individually. For example, $Q1_i$ means work type located in the Q1 area. The work types located in each area have the following characteristics.

I = {x|x is the eleven types of construction work used in this study}

$Q1_i$ = {x∈I|x has a higher frequency of defect occurrence than average and a higher construction delay induction coefficient above average}

$Q2_i$ = {x∈I|x has a lower frequency of defect occurrence than average and a higher construction delay induction coefficient above average}

$Q3_i$ = {x∈I|x has a lower frequency of defect occurrence than average and a lower construction delay induction coefficient above average}

$Q4_i$ = {x∈I|x has a higher frequency of defect occurrence than average and a lower construction delay induction coefficient above average}

More attention to the defect management should be paid for when performing these work types located in Q1 or Q4 because those work types showed a high frequency of defect occurrence. For example, painting work is located in Q4 where its X-axis value is higher than the average. Hence, workers have to put in more effort to manage defects occurring in painting work because these defects are more noticeable than defects in other work types even though the degree of construction delay impact is lower than the average.The work types located in Q2 are the most important ones. As they show a lower frequency of defect occurrence than average, defect management tasks can be easily overlooked. However, more attention should be given to them because their Y-axis value (i.e., construction delay induction coefficient) is higher than average. Figure 2 shows that plastering work belongs to Q2.

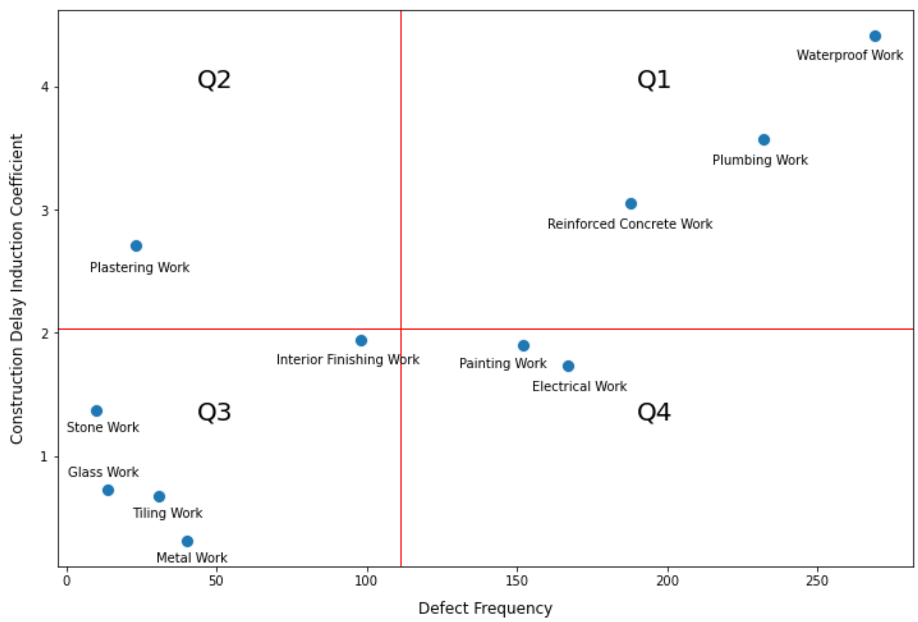

Figure 2. Defect frequency versus construction delay induction coefficient

5. CONCLUSION

We developed the construction delay induction coefficient as an assessment model of delay impact. Then, we compared it with the frequency of defect occurrence which denotes an indicator of visual attention in defect management. The relationship between these two contents was used to identify the work type that had a significant effect on construction delay with a low visual attention level in the defect management task. We found that the plastering work had a significant impact on construction delay, indicating that it requires more attention for defect management even though it is less likely to cause defects. This result is related to the feature of the top-down construction method that increases the vertical load by simultaneously implementing underground and upper ground work. The crack in the structure caused by an increment of the load during the construction process can adversely affect the plastering work.

This study is meaningful from two perspectives. First, we propose a method to quantitatively identify the damage related to construction delay due to defects. Second, our study examines the construction method conditions. Ultimately, the purpose of this study is to make defect management more efficiently by identifying work types that are easy to overlook during the building construction process related to the top-down construction method.

5.1. Limitation and future study

This study did not consider the time required for defect management, such as idle time and the time taken for repairing work. The time element is mainly affected by the location of defects and the difficulty level of repairing work that may differ based on the characteristics of work type. Eventually, the time used for defect management will induce different construction delays by work type. In a future study, the construction delay induction coefficient will be specified by applying the time element as a weight for each work type.

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