ANALYSIS OF THE INFLUENCE OF WEATHER ON CONSTRUCTION PRODUCTIVITY RATE FOR SUPER-HIGHRISE BUILDING CONSTRUCTION FRAMEWORK

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ABSTRACT : The duration of a construction project is not only a key element for taking a new order, but also a strict yardstick to determine certain project successful or not. However, since construction project is basically outdoor job and most of the activities are proceeded out-air, no matter how the schedule plan has been established accurately, actual project proceeds due to the weather condition, beyond anyone's control. In this paper, the functional relationship between work productivity rate and weather elements is suggested by regression analysis. Difference of the relationship and influence of weather due to the seasonal group are also revealed. With these results, by simulating actual weather data and generating weather forecast through historical data, more accurate schedule would be obtained.

Key words : Work Productivity rate, Weather Elements, Regression Analysis

1. INTRODUCTION

1.1 Background and Purpose

The duration of a construction project is not only a key element for taking a new order, but also a strict yardstick to determine certain project successful or not. Project managers concerns about this duration, and this concern let them establish more accurate schedule plan and check the plan continuously, and recent schedule planning software helps them work efficiently. However, construction project is basically outdoor job and most of the activities are proceeded out-air, except for interior finishing work, and that means no matter how the schedule plan has been established accurately, actual project proceeds due to the weather condition, beyond anyone's control. At the actual work field only rainfall is considered among all the weather elements. Moreover, it is not about the precipitation and its influence, but just an estimate of unworkable days. From experience, average of annual rainy days are scattered all through a year.

Therefore, to establish more accurate schedule plan, definite research on the effects of weather on construction work productivity rate and practical way of applying this relationship to construction project schedule planning are needed. In this paper, regression analysis is conducted to find out the relationships between weather elements and construction work productivity rate, and the way of applying those relationships in construction project schedule planning process is suggested. If the suggested way can be applied to actual work field, more accurate schedule can be obtained.

1.2 Scope and Method

Generally, construction project has four main phases; Site preparation – Excavation – Framework (underground /aboveground) – Finishing work and these four main phases are all critical to total work duration. All of these phases are affected from weather condition, but except for framework, there are some other factors that can influence more than weather elements. Site preparation is controlled by site condition and excavation is swayed by earth condition. Specific finishing works such as curtain wall operation are also influenced from weather, but most of the works in finishing work phase are indoor jobs. Therefore, this paper is focused on the framework phase of a construction project on which weather elements influence the most.

Regression analysis is used to find out the relationships between the weather elements and work productivity rate. Actual weather data are collected from the homepage of Korea Meteorological Administration. This paper progresses as follow:

(1) Analyze historical data from two similar construction projects

(2) Calculate the work productivity rate of the projects for each day.

(3) Only actual weather data for the days that productivity rate loss has occurred are collected.

(4) Conduct regression analysis putting work productivity rate as dependent variable and weather elements as independent variables.

(5) Suggest the way of applying the result.

2. LITERATURE REVIEW

Several researches have been executed to apply weather elements to the schedule plan of construction project by making a simulation system.

AbouRizk[1] used general regression neural network to suggest the relationship between weather elements and earthwork productivity. He investigated three weather elements – precipitation, daily maximum temperature, and daily minimum temperature. He assumed the productivity factor as the ratio of achieved productivity and estimated productivity. He showed the impact of weather elements on project schedule by calculating the same project assuming different start date that finishes with maximum 93days of difference.

Carr[2] suggested a simulation method, model of uncertainty determination (MUD). This model uses two groups of variables that can affect work productivity. Variables independent of calendar date (INCAD) such as excavation equipment productivity, instrument crew skill, etc., and variables dependent of calendar date (DECAD) such as daily maximum dry bulb temperature in degree Fahrenheit, daily precipitation in inches over a 3-day, 7-day, etc..

Also, many papers studied about the relationship between weather elements and work productivity. Lee[3] connected unworkable days due to the weather elements and estimated schedule plan, and suggested the way to decide the best starting date for a project. Koo[4] focused on, among all the factors that can affect schedule planning, weather elements, their influence on the total duration of construction project, and the way to calculate the total duration of a project based on weather elements. Kim[5] analyzed the relationship between work productivity and weather elements in reinforced concrete structure of Korean High-rise apartment house through regression analysis.

3. WEATHER ELEMENTS AND WORK PRODUCTIVITY RATE

3.1 Matching Weather Elements and Productivity Rate

Target project of this paper is a residential-commercial building construction project located in Seoul. This building is 40 story's high, and the framework which used reinforced concrete, was from September 2002 to August 2003. From the actual framework data of the project, productivity rate was calculated by divide the estimated duration by achieved duration. If the productivity rate is same or over 1, the activity is going well, but the productivity rate is under 1, the activity is proceeding slower than expected.

From the data, only the days that the productivity rate is under 1 are chosen for further research and for each day, actual data of daily weather elements for region Seoul are matched. The daily weather elements are; average temperature, maximum temperature, minimum temperature, relative humidity, precipitation, duration of sunshine, and average wind velocity. The actual weather data for each day in Seoul were obtained from Korea Meteorological Administration (KMA; http://www.kma.go.kr)

3.2 Data Generation

Most of the previous researches regarding on weather elements were dealing with the whole construction project, and some researches deal with specific project process were treating the weather elements as a whole. However, it is obvious that as season changes, some prior affecting weather elements would be changing. For example, it can be assumed by intuition that while precipitation would affect through a year without significant difference, daily minimum temperature would not be as decisive factor in summer as it would be in winter. Therefore, in this paper, the data were divided into four groups; March to May, June to August, September to November, December to next February as spring, summer, autumn, and winter, respectively. Even though there is no definite time division for season, but this four groups are generally accepted for weather condition in Seoul.

4. REGRESSION ANALYSIS

4.1 General Information

Regression analysis is statistic method to analyze functional relationships between variables. This method is used basically for three purposes; to estimate a functional relationship between dependent variable and independent variables, to estimate and verify the influence of prior independent variables on dependent variable, and to estimate and forecast the change of dependent variable by functional relationship as the independent variables change.

In this paper, regression analysis was conducted to find out the functional relationship between work productivity rate and weather elements. Regression analysis of the four groups of data proceeded separately.

4.2 Assumption and Procedure

Analyzing the relationship between weather elements and work productivity rate, two assumptions have been made. One is about precipitation; this element had been categorized into three classes. 0, 1, 2 for 0 to 0.2mm, 0.2mm to 4.9mm, and 5mm to 10mm respectively; the data of over 10mm's of precipitation are deleted because that amount of precipitation is regarded to unworkable day. The other is about work productivity rate; estimated duration of each floor divided by achieved duration of each floor is regarded to work productivity rate, and data of the dates the work productivity rate is under 1 are analyzed.

Schedule data of actual work performed were executed by following analysis procedure.

(1) Actual work dates and planned work dates were extracted from actual data.

(2) Work productivity rates for each day were calculated.

(3) Actual weather elements for each day were matched.

(4) Data of non-working days and the days whose work productivity rate is over 1 were deleted.

(5) Regression analysis with all independent variables, and reduced the independent variables one by one.

(6) Regression analysis was performed repeatedly until trustful results have been made.

4.3 Outcomes

All four of seasonal groups have followed the same analysis process repeatedly. Therefore, precise explanation for Spring group is made as representative.

To sort out meaningful variables from many independent variables - average temperature, maximum temperature, minimum temperature, relative humidity, duration of sunshine, average wind velocity, squares of all these variables, and precipitation category – for better regression function, the independent variables which is lack of reliability are subtracted from the data list.

Table 1. Model Summary (phase 1)

R	R ^2	Modified R^2	Standard Error of Estimate
.646(a)	.418	.285	.06407

Table 1 shows that the coefficient of determination of the regression is 0.418 and modified coefficient of determination is 0.285. Generally, high value of R square means meaningful result, but even though the variables are meaningless, if the number of variables is big, the R square gets higher. Therefore we use modified R square; if meaningless variable is added to the regression, the value gets smaller. The difference between R square and modified R square shows how meaningless many variables are included.

Table 2. Analysis of Variance (phase 1)

	Degree of Freedom	Mean Square	F	Significance Probability
Regression	13	.013	3.146	.001(a)
Residual	57	.004		
Total	70			

Table 3. Coefficient (phase 1)

	Unstandardized		Standardized	t	Significance Probability
	B	Standard Error	Beta		
Constan	.415	.197		2.104	.040
Ave. Tem.	-.001	.044	-.093	-.025	.980
Max. Tem.	-.004	.029	-.375	-.133	.894
Min. Tem.	.005	.018	.355	.251	.803
Prec. Cate.	-.020	.020	-.150	-1.008	.318
Res. Hum.	.014	.004	2.527	3.319	.002
Dur. Sun.	-.021	.014	-.899	-1.587	.118
Ave. Wind	-.048	.091	-.401	-.531	.598
S. Ave. Tem.	.001	.001	2.053	.609	.545
S.Max. Tem.	.000	.001	-1.141	-.445	.658
S. Min. Tem.	-.001	.001	-.985	-.868	.389
S.Res. Hum.	.000	.000	-2.298	-2.840	.006
S. Dur. Sun.	.003	.001	1.200	2.477	.016
S. Ave. Wind	.005	.017	.198	.272	.787

As shown in table 2, the F value of this regression is 3.146, and significance probability is 0.001(0.001380122657775). From this result, this regression seems to be acceptable. However, as can be seen in table 3, the t values of most of the variables are not high enough to be accepted as independent variable of this regression. The t value of independent variable should higher than 1.96 in 95% of reliability, or 1.645 in 90% of reliability. As a result, the regression function is not reliable due to the unreliable variables at this phase.

Table 4. Model Summary (phase 6)

R	R ^2	Modified R^2	Standard Error of Estimate
.637(a)	.406	.330	.06204

Table 4 shows the result of sixth phase of the procedure; that means 5 variables – average temperature, maximum temperature, minimum temperature, precipitation category, and square of wind velocity - have been deleted from the regression. The R square has been reduced to 406, on the contrary, Modified R square has been increased to 330; the gap of the two has reduced from 133 to 76. This reduction means fewer meaningless variables in the regression. Table 5 shows that the F value has been increased and significance probability has been reduced, and says that this regression is getting even more meaningful.

Table 5. Analysis of Variance (phase 6)

	Degree of Freedom	Mean Square	F	Significance Probability
Regression	8	.020	5.301	.000(a)
Residual	62	.004		
Total	70			

Table 6. Coefficient (phase 6)

	Unstandardized		Standardized	t	Significance Probability
	B	Standard Error	Beta		
Constant	.341	.121		2.811	.007
Res. Hum.	.014	.004	2.570	3.781	.000
Dur. Sun.	-.018	.011	-.775	-1.640	.106
Ave. Wind	-.024	.015	-.197	-1.612	.112
S. Ave. Tem.	.001	.001	2.366	1.743	.086
S.Max. Tem.	.000	.000	-1.591	-1.749	.085
S. Min. Tem.	-.001	.000	-.918	-1.585	.118
S.Res. Hum.	.000	.000	-2.351	-3.367	.001
S. Dur. Sun.	.003	.001	1.093	2.611	.011

However, there are still many unreliable variables with unsufficient t values. This iteration continues until satisfactory result has been made; and this is a problem of decision.

Table 7 is about coefficient at ninth phase of this regression. As can be seen, phase 9 can be the last iteration of this regression, if 90% of reliability has been chosen; no variable has t value less than 1.654. Table 8 is summary of ninth phase model.

Table 7. Coefficient (phase 9)

	Unstandardized		Standardized	t	Significance Probability
	B	Standard Error	Beta		
Constant	.311	.119		2.609	.011
Res. Hum.	.014	.004	2.525	3.703	.000
Dur. Sun.	-.018	.010	-.750	-1.702	.094
Ave. Wind	-.022	.013	-.179	-1.708	.092
S.Res. Hum.	.000	.000	-2.259	-3.231	.002
S. Dur. Sun.	.003	.001	1.072	2.651	.010

Table 8. Model Summary (phase 9)

R	R ^2	Modified R^2	Standard Error of Estimate
.610(a)	.372	.324	.06229

If not stopped at phase 9, following is the final phase of this regression. Even though the modified coefficient of determination is reduced compared to ninth phase, the gap between R square and modified R square also reduced from 48 to 39 and all the variables have t value greater than 1.96; satisfies 95% of reliability.

Table 9. Model Summary (phase 10)

R	R ^2	Modified R^2	Standard Error of Estimate
.587(a)	.344	.305	.06318

Table 10. Coefficient (phase 10)

	Unstandardized		Standardized	t	Significance Probability
	B	Standard Error	Beta		
Constant	.304	.121		2.517	.014
Res. Hum.	.013	.004	2.318	3.406	.001
Ave. Wind	-.025	.013	-.206	-1.965	.054
S.Res. Hum.	-9.411 E-05	.000	-1.942	-2.842	.006
S. Dur. Sun.	.001	.000	.416	3.366	.001

As same procedure had performed for all four groups, following is the results of model summary and coefficient of other three groups.

Table 11. Model Summary (summer)

R	R ^2	Modified R^2	Standard Error of Estimate
.611(a)	.373	.341	.07666

Table 12. Coefficient (summer)

	Unstandardized		Standardized	t	Significance Probability
	B	Standard Error	Beta		
Constant	1.431	.209		6.858	.000
Min. Tem.	-.017	.004	-.479	-4.319	.000
Res. Hum.	-.013	.007	-1.506	-1.875	.066
S.Res. Hum.	9.036 E-05	.000	1.350	1.695	.096

Table 13. Model Summary (autumn)

R	R ^2	Modified R^2	Standard Error of Estimate
.721(a)	.520	.473	.02653

Table 14. Coefficient (autumn)

	Unstandardized		Standardized	t	Significance Probability
	B	Standard Error	Beta		
Constant	1.122	.111		10.086	.000
Res. Hum.	-.010	.003	-3.413	-3.103	.003
S. Ave. Tem.	.000	.000	-2.699	-5.065	.000
S. Min. Tem.	.000	.000	2.258	4.259	.000
S.Res. Hum.	7.810 E-05	.000	3.435	3.110	.003

Table 15. Model Summary (winter)

R	R ^2	Modified R^2	Standard Error of Estimate
.579(a)	.335	.311	.07076

Table 16. Coefficient (winter)

	Unstandardized		Standardized	t	Significance Probability
	B	Standard Error	Beta		
Constant	.696	.015		47.913	.000
Min. Tem.	.011	.002	.649	5.067	.000
Dur. Sun.	.016	.004	.493	3.846	.000

5. RESULT

The relationship between weather elements and work productivity rate was obtained. Putting X1 to X8 on weather elements, minimum temperature, respective humidity, duration of sunshine, average wind velocity, square of average temperature, square of minimum temperature, square of respective humidity, square of duration of sunshine, respectively, following four equations could be obtained.

Spring
$$Y = 0.3036 + 0.0130X2 - 0.0249X4 - 9.41E\text{-}05X7 + 0.0109X8$$

Summer
$$Y = 1.4309 - 0.0174X1 - 0.0129X2 + 9.036E\text{-}05X7$$

Autumn
$$Y = 1.1216 - 0.0105X2 - 0.0004X5 + 0.0005X6 + 7.810E\text{-}05X7$$

Winter
$$Y = 0.6958 + 0.0109X1 + 0.0159X3$$

All four of equations have different constant; 0.3036, 1.4309, 1.1216, and 0.6958 for spring, summer, autumn, and winter, respectively. Due to these different constants for each equation, one variable has two coefficients with similar absolute value with opposite sign at two different equations. For instance, minimum temperature and square of respective humidity have opposite influence on work productivity rate in spring and summer.

Besides, all four groups obtained modified coefficient of determination. 0.305 for spring, 0.341 for summer, 0.473 for autumn, and 0.311 for winter. They indicate how the 4 equations can explain certain loss of productivity rate; if work productivity rate reached 0.8000 on one day in summer, weather of the day (minimum temperature, respective humidity, and square of respective humidity) can explain 0.0946 (0.2000 * 0.473) of productivity rate loss

Now it is obvious that different weather elements affect differently in different season; some elements influenced work productivity rate positively in one season even affected negatively in another. In addition, weather as a whole has different influence on work productivity rate in each season. In spring, weather takes 30.5% of responsibility for work productivity rate loss, while in autumn, weather takes 47.3% of responsibility.

6. CONCLUSION

This paper suggested the influence of weather on construction framework productivity rate through regression analysis. Unlike with previous studies, in this paper, one year was divided into four seasonal groups. In-depth research has been made separately for these four groups and four regression functions and four modified coefficients of determination are extracted. As assumed earlier in this study, different equation for each season proves that certain weather element affects work productivity rate differently as season changes, and weather as a whole has different influence on work productivity rate for a different season.

After simulating past weather data and forecasting weather data for estimated work days, the result of this paper can be used to generate work productivity rate for each work days. Applying this method and result of work productivity rate to actual schedule planning process, more accurate and reliable schedule plan can be obtained.

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