A Stochastic Simulation Model for Estimating Activity Duration of Super-tall Building Project

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ABSTRACT: In super-tall building construction projects, schedule risk factors which vertically change and are not found in the low and middle-rise building construction influence duration of a project by vertical attribute; and it makes hard to estimate activity or overall duration of a construction project. However, the existing duration estimating methods, that are based on quantity and productivity assuming activities of the same work item have the same risk and duration regardless of operation space, are not able to consider the schedule risk factors which change by the altitude of operation space. Therefore, in order to advance accuracy of duration estimation of super-tall building projects, the degree of changes of these risk factors according to altitude should be analyzed and incorporated into a duration estimating method. This research proposes a simulation model using Monte Carlo method for estimating activity duration incorporating schedule risk factors by weather conditions in a super-tall building. The research process is as follows. Firstly, the schedule risk factors in super-tall building are identified through literature and expert reviews, and occurrence of non-working days at high altitude by weather condition is identified as one of the critical schedule risk factors. Secondly, a calculating method of the vertical distributions of the weather factors such as temperature and wind speed is analyzed through literature reviews. Then, a probability distribution of the weather factors is developed using the weather database of the past decade. Thirdly, a simulation model and algorithms for estimating non-working days and duration of each activity is developed using Monte-Carlo method. Finally, sensitivity analysis and a case study are carried out for the validation of the proposed model.

Keywords: Construction Management, Duration Estimation, Super-tall Building, Monte-Carlo Simulation, Weather Factor

1. INTRODUCTION

Schedule of a construction project can be considered as one of the key factors which determines project success or failure(Lee et al. 2010). Pre-conducted worldwide researches, however, represent that the majority of construction project fail to keep a target schedule and have difficulties in managing Because construction projects cannot be the perfectly same in design and construction plan, which result in construction manger's lack of experience, and is performed in dynamic and unpredictable environment, planning schedule includes fundamentally evitable risk and uncertainty, such as design change, negligent accident, and non-working day by weather condition(Schatteman et al. 2008). These kinds of risk and uncertainty sometimes bring about irrevocable problem and delay to the projects. Therefore, it is critical to analyze and manage risk and uncertainty appropriately and accurately for successful construction project schedule.

In building construction projects higher than 300 meter, referred to as a Super-tall building, some unique risk and uncertainty factors which are not appeared in the low and middle-tall building projects exist because of the unique characteristics based on its building shape, such as tasks operated at the high altitude, repetitive tasks, the application of new technologies, lack of experience on the part of managers and so on. And these factors make it more difficult to analyze and manage schedule risk and uncertainty accurately in advance.

Among the additional factors appeared in super-tall building projects, a climate condition during operating task can be considered as an unpredictable and critical factor since weather change according that the height of task space increasing. Some severe weather condition occur the non-working condition and duration delay for the reason they make the safety of workers and the quality of tasks worse. At the phase of project schedule planning, construction managers basically consider the delay by arithmetically calculating weather data which measured previously at the ground level. In the super-tall building projects, however, some of weather factors, such as, temperature and wind-speed, are vertically changed and makes it inadequate to use the weather data measured at the ground level for the super-tall building project schedule planning.

In order to deal with this kind of unforeseen risk and uncertainty, schedule managers have the tendency to usually set a unnecessary longer buffer time among the tasks, and it becomes the reason that occurs the inefficient schedule management(Park et al. 2004).

This paper is conducted to analyze effects of weather factors whose values is change along the altitude and develop the stochastic simulation model which is able to foresee the duration for structure work of super-tall building incorporating vertical distribution of weather factors.

2. LITERATURE REVIEWS

2.1 Influence of Weather Factors to the Construction Project

As mentioned above, many kinds of construction project activities, such as earth work, foundation work, structure work, and are curtain wall work, are exposed to the external environment, especially weather condition, and these works are influenced directly and inevitably with the safety of labours, the quality of outcomes and eventually duration of projects. Because tasks of construction project are performed with different materials, construction methods and equipment, they are affected dissimilar kinds of influence by different weather factors and conditions

There are three factors come about non-working days; temperature, rainfall, and wind. As shown in Table 1, the criteria of non-working day represent that task is stopped when temperature is under and over specific degree. And when the amount of rainfall is over the particular amount a day and average wind speed is stronger than certain speeds. And these criteria can be changed considering the detail of each work item. However, the criteria of non-working day are different according to institute, company, and geographical region. Much research has been undertaken to standardize nonworking days; nevertheless, all of these studies have yielded different results. Therefore, it is meaningless to standardize nonworking days. Instead, this aspect of the weather data can be better determined by managers who can take company regulations and policies, construction methods, and specific project characteristics into account.

Table 1. Suggested Criteria of Non-working Days

		Low temperature	High temperature
Temperature	KNHC/AIK/KSCE/JSCE	Concrete at daily average below 4°C	Concrete at daily average over 25°C
	KHC	Daily average below 4°C	Daily average over 35°C
	COE	Daily maximum below 0°C	
	ACI	Cold weather concrete at daily average below 4°C	
Precipitation	KNHC	Over 10 mm a day	
	RISH Act	Over 1 mm rain an hour/Over 1 cm of snow an hour	
	COE	Over 5 mm a day	
Wind	RISH Act	Daily average over 10 m/s/need equipment instant over 30 m/s	

Note: KNHC=Korea National Housing Corporation; AIK= Architectural Institute of Korea; KSCE=Korean Society of Civil Engineering; JSCE=Japan Society of Civil Engineering; KHC=Korea Highway Corporation; COE=U.S. Army Corps of Engineers; and RISH Act=Regulations for Industrial Safety and Health Act.

2.2 Vertical Distribution of Weather Factors

Among the weather factors, temperature and wind speed have simple but critical feature, which is changed with increasing of altitude. For estimating projects duration accurately, it is the best way to measure the weather values at every height for long enough time, but impracticable. So in order to analyze vertical distribution of weather values, the different ways that can utilize premeasured data at ground level should be chosen.

As the altitude rises in the troposphere, temperature decreases with a certain rate, referred to as adiabatic lapse rate. Air temperature is directly proportional with this rate, which is influenced by the air humidity. The lapse rate value changed by air humidity is tabled as follow Table 2. The average lapse rate value of actual air condition in Troposphere is similar to 6.5℃/km and this research assumes vertical distribution of temperature is following this rate.

Table 2. Adiabatic Lapse Rate

Ambient Condition	Value
Dry Adiabatic Lapse Rate	9.8 ℃/km
Saturated Adiabatic Lapse Rate	4.4 ℃/km
Average Tropospheric Lapse Rate	6.5 ℃/km

From the macroscopic point of view, the wind speed increases as the distance recedes from the surface of the earth due to the occurrence of friction between wind and surface. Surface condition is a factor which affects the vertical change of wind speed. The vertical distribution of wind speed which incorporating such a phenomenon is Exponential Law(Dyrbye and Ole Hansen, 1997). Even though two laws can explain how the wind speed is of the exponential law is as follow.

$$\mathbf{V}_{Z} = \mathbf{V}_{G}\left(\frac{Z}{Z_G}\right)^{r} \quad (1)$$

V_Z : Wind Speed at Height Z
V_G : Wind Speed at Standard Height
Z : Height
Z_G : Standard Height (Usually 10m)
r : Exponent by Surface Condition
- Rural Area : r = 7
- Suburban Area : r=4.5
- Metropolitan Area : r=3

2.3 Computational Simulation Method for Scheduling

Glenn Shafer CII (1989) defined risk and uncertainty as the probability of unforeseen event that occur an unfavorable performance to the projects. Namely, risk and uncertainty can be quantified as a the probability and influence value, and using this thinking, computational simulation method is applied as a practical way for planning schedule incorporating risk and uncertainty in various industries.

Many researchers have developed simulation models for estimating duration and planning scheduling to complement the shortcoming of CPM method which cannot incorporate the impact of risk and uncertainty. Teicholz (1963) introduced a simulation method in choosing construction equipment and Halpin (1973) build CYCLONE which is a simulation model not to require for user to learn a computational language. Subsequently, lots of simulation model have been developed and introduced, such as INSIGHT (Paulson and Koo 1987), MicroCYCLONE (Halpin 1985), RESQUE (Chang 1987), COOPS (Liu and Ioannou 1992), DISCO (Huang et al. 1994), CIPROS (Odeh et al. 1992), and STROBOSCOPE (Martinez and Ioannou 1994), SimCon (Chehayeb and AbouRizk 1998), PICCASO (Senior and Halpin 1998), ABC (Shi 1999), NETCOR (Wang and Demsetz 2000), SPSS (Lee 2005), and so on.

Even though these models have been applied to extensive projects which have many kinds of purposes under various risks and uncertainties, none of these models has been conducted for analyzing how weather conditions change at the high altitude where task is performed and identifying how weather conditions specifically influence duration of super-tall building construction projects.

3. ANALYSIS OF VERTICAL CHANGE OF WEATHER FACTORS

In this chapter, the analysis on how the value of weather factors is changed according to altitude increase and how many non-working day is influenced due to the weather change is conducted.

Using the vertical distribution represented by the average tropospheric lapse rate of temperature, and the exponential law of wind speed, the calculated values are represented by two laws, the law of large numbers and the distributed vertically in similar way, for construction project in urban area, the latter has usually used. Equation shown in Table 3. Since super-tall building is usually built in the unban space, the exponent by Surface Condition of the exponential law is set as 1/3. Because temperature decreases by minus 0.65 per 100m, temperature at high altitude where super-tall building operated decreases up to -6.5 degrees Celsius. And since the rate of wind speed is exponentially increase, when assuming that wind speed is 5 m/s at the standard height, the speed increase by 13.4m/sat 500 meter height and by 18.2 m/s at the 1000 meter height. Considering nonworking criteria by wind speed is usually over the 10 meter per second, it is critical enough to operating project.

Table 3. Vertical Change of Temperature and Wind Speed at Unban Space

Height (m)	Temperature (℃)	Increase Rate of Wind Speed	Wind Speed When Wind Speed at Standard Height is 5m/s (m/s)
100	-0.65	2.2	10.8
200	-1.30	2.7	13.6
300	-1.95	3.1	15.5
400	-2.60	3.4	17.1
500	-3.25	3.7	18.4
600	-3.90	3.9	19.6
700	-4.55	4.1	20.6
800	-5.20	4.3	21.5
900	-5.85	4.5	22.4
1000	-6.50	4.6	23.2

(Standard Height : 10m)

Using the result of weather change value, additional analysis is conducted on how much those have an influence to the construction project scheduling. Non-working criteria adapted to research is as below.

- Temperature: Daily average over 35℃ or under 4℃
- Wind speed: Daily average over 10 m/s

Using the weather data which is measured by Korea Meteorological Administration, the likelihood rate of non-working day is analyzed for three cities of Korea, Seoul, Inchon and Pusan, where the majority of super-tall building projects is performing or already done. And the result is represented as follow Table 4.

The result shows that without reference to the area and the weather factor, the occurrence rate of non-working day becomes higher as the height to increase. And the value differences of temperature appeared as almost double. Although the likelihood of non-working day is similar to zero at the ground level in all of three cities, it increases up to 62.6 at 500 meter altitude in Pusan. It means construction task which influenced by wind cannot be operated more than half of years.

Table 4. Ratio of Non-working Day

Unit: Percentage (%)

Height (m)	0	100	200	300	400	500
Temperature.						
Seoul	21.4	26.1	28.4	30.1	32.2	33.8
Inchon	23.5	25.4	27.7	29.4	31.4	33.2
Pusan	11.1	12.6	14.6	16.2	18.3	20.1
Wind Speed						
Seoul	0.0	8.4	16.5	24.6	30.5	33.5
Inchon	0.6	16.9	27.1	36.5	43.4	46.8
Pusan	1.0	28.3	42.4	53.2	59.9	62.6

As shown above, the weather condition at high altitude is severely changed comparing to that of the ground level, and it can be critical risk factors for performing construction project.

4. DEVELPOING SIMULATION MODEL

A duration estimating model was developed that considers the vertical distribution of three weather factors, temperature, wind speed, and rainfall, and the nonworking criteria influencing work duration of super-tall building. This model process consists of six phases: (1) identifying weather data and analyzing probability distribution, (2) defining the criteria of non-working condition by work item, (3) inputting construction information and schedule data, (4) creating virtual weather calendar with Monte-Carlo method, (5) discriminating occurrence of non-working day by each task, (6) estimating overall project duration and probability with iterate algorithm. The first three phases are the preparing phases which define and set the information for simulation model and the others are about the simulation running processes.

Phase 1: Identifying Weather Data and Analyzing Probability Distribution

At this Phase, it is conducted to identify the weather data which measured at a meteorological observatory and creating the discrete probability distribution of weather factor for Virtual Weather Calendar at Phase 4. Weather data should be the one which has been measured for several years long enough to make reliable estimation results.

In order to reflect a degree of climatic seasonality, one year is divided into a several number of periods and the weather data in the same period over the years is treated as the same range of analysis. The more the number of period is set, the more sensitively the seasonal climate change is reflected but the more simulation data and running time is required for the results.

According to Non-working day analysis in chapter 2.1, temperature makes task stoppage when the temperature of day is under or over the specific value. Maximum and minimum values of a day, therefore, are necessary and extract for the analysis. Wind speed which affects nonworking condition is average value for a day, so wind data measured by time is calculated as an average of day. Since the amount of rainfall for a day more than specific level occurs non-working day, Rainfall data measured at each time is summed. Then, using the values which have near measurement date in the same period, the frequency distribution and cumulative frequency distribution of each period is created.

Phase 2: Defining the Criteria of Non-working condition by Work Item.

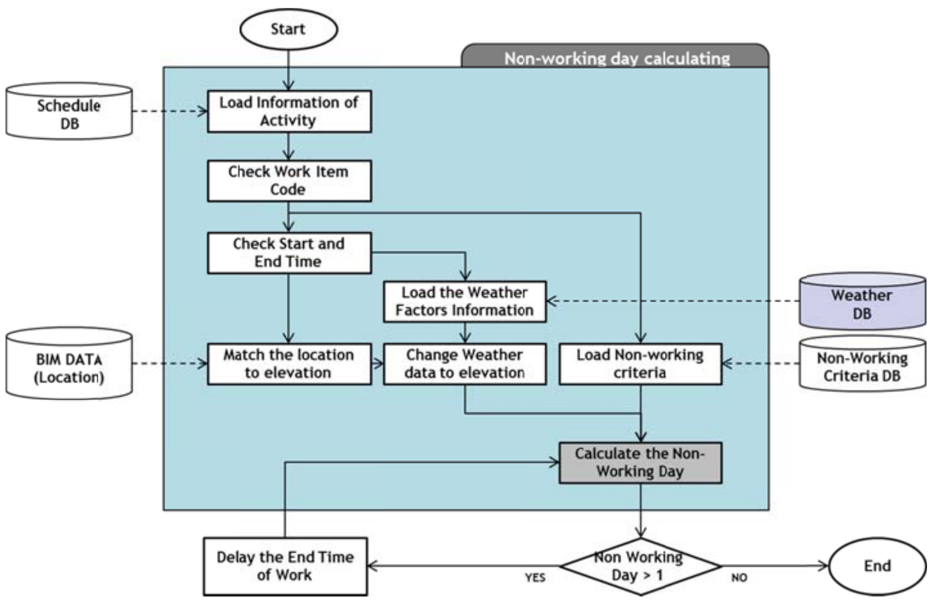

Figure 1. Algorithm for identify occurrence of non-working day and adjusting activity duration.

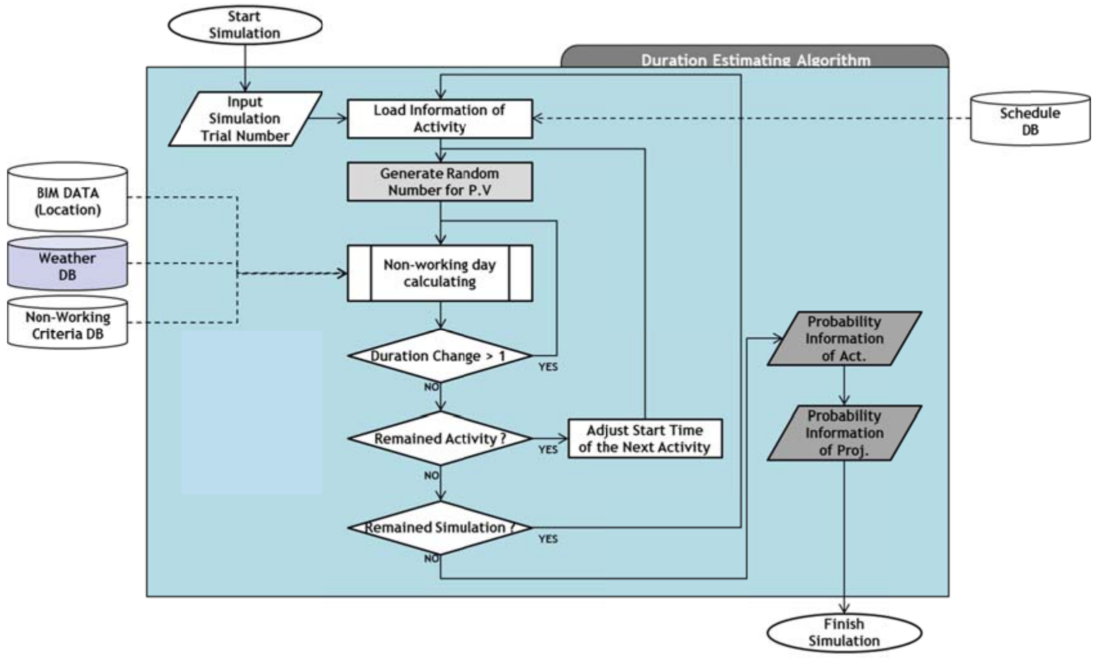

Figure 2. Iterate Algorithm for Duration Estimation of Construction Project

Because weather condition causing the non-working day is different by work time, the criteria of non-working condition should be determined to connect the analyzed weather data to task information.

Based on the WBS work time code, non-working conditions, the maximum and minimum values of temperature, average wind speed of day and the sum of day rainfalls, are input in the database for each WBS code. Non-working criteria applied to the upper-level of WBS code is applied to the lower-level of work items in the same way.

Phase 3: Inputting Construction Information and Schedule Data

This phase is to insert the activity information of a construction project which is a target of duration analysis. The data-base form of Construction information data is defined based on the general schedule data sheet which can be created and modified in Microsoft Excel or Microsoft Project, and additional data is inserted into the exist format. Construction information data consists of follow: activity code, activity name, start date, finish date, location (height), sequencing (SS/SF/FS/FF), and WBS code. WBS code is for loading the non-working data and identifying the criteria of the activity, sequencing is the set of succeeding activities code and relationship in order to adjust the start time reflecting time delay the preceding activity. Location is height where the activity operates.

Phase 4: Creating Virtual Weather Calendar with Monte Carlo Method.

Using Monte-Carlo Method, the model generate random variables and represent the value of weather condition day by day, virtual weather calendar, based on the probability data of the weather factors created at phase 1. The date range of virtual weather calendar is based on activity duration and extra date can be also examined by project delay. Virtual weather calendar includes components as follow: maximum temperature, minimum temperature, daily average wind speed and daily cumulate amount of rainfall.

Phase 5: Identifying Occurrence of Non-working day by Each Task

In order to identify the occurrence of non-working day and analyze activity duration, the Non-working day identification module is run, the process of module is shown in Figure1.

The identification module loads the activity information, and calculates weather condition values based on the height of the activity. Non-working criteria is also loaded according to the WBS code which is included in the activity information. With the start and finish time of the activity, the modified weather condition values and the non-working day criteria of the activity, the occurrence of non-working day is analyzed. If non-working day cause for the duration of the activity, extra one day is added to the duration of activity and repeat the identification operation until the non-working day does not carry out. After finishing identification operation, calculate the adjusted activity duration and save the value to the construction information data-base.

Phase 6: Estimating Overall Project Duration and Probability with Iterate Algorithm

The process of the iteration algorithm for estimating over-all duration of project is shown in Figure 2. After simulation trial number is input, virtual weather calendar is created repeatedly as many as the trial number. With these virtual weather calendars, the occurrence of nonworking day during the duration of each activity is analyzed. In the case non-working day occur and the duration of the activity is adjusted, the start and finish time and duration of succeeding activity is changed as well according to the sequence of construction project information. In this way, all activities is analyzed in order, and when the analysis of the final activity duration finish, one trial of simulation completes. Then repeat the process as many as initial input number.

After completing the all simulation trial, simulation analysis deduct the result for each activity's duration and overall project duration as a probability distribution data. Project manager can use these data to make a plan for the super-tall building project, when or what date is advantageous to start project with the quantified and detail value or how much influence by weather condition affect the duration during the implement of projects.

5. CONCLUSIONS

This Research is conducted to analysis the vertical distribution of weather factors and how to affect tasks of the construction project. And to quantify risk factors and adapt to construction schedule information, the stochastic simulation model which create virtual weather calendar using Monte Carlo Method and estimate the probability of the duration of each task and the overall project is developed as well.

At the high altitude environment where super-tall building projects operated, the wind speed at 500m height increases 3.3 times comparing to the ground level, which means only 5m/s wind speed is amplified up to 18.4 m/s enough to interrupt lifting work and it consequentially bring about task stoppage. Temperature also decreased with increasing the height of work place, -0.65℃ per 100m, and it result in more non-working day than the ground level task. Scheduling of super-tall building, therefore, is more easily influenced by weather factors and is necessary to analyze and incorporating it in advance.

For this reason, the proposed simulation model is to estimate duration by activity using stochastic construction information and iterate algorithm based on weather data measured at the ground level. Although this model is needed to fulfill the validation and verification phase with actual super-tall building project data, it can become basic information to project managers of super-tall building.

And this research has limitation and discussing point as follow.

- This research assumed that weather factors are independent variables to each other although actual weather event happens relevantly. However, adapting of dependent relation of weather into creating virtual weather calendar has at risk for enormous simulation time increase.
- Since the proposed simulation model calculate only a non-working day, temporary task stoppage and productivity change by weather condition is not considered in this algorithm.

And this limitation of the research will be conducted inthe further study.

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