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Construction performance assessment framework by means of construction simulation for earthwork operations

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Abstract: The existing literature has witnessed the importance of productivity assessment and deducing factors affecting it. However, yet many models have shown limitations in practical applications in actual construction sites for process planning due to uncertainty and lack of data. This research presents a productivity assessment and database generation framework using simulation and compares the results with RSMeans to derive appropriate equipment combinations alternatives for earthwork operations. Data of 15 different conditions was collected from 5 different construction sites. Prediction accuracy above 90% were achieved for the simulation models with average error rate of 7.4%. The construction productivity assessment framework presented in this study is expected to be highly applicable to operation planning for earthwork operations.

Key words: Construction productivity, Database, Simulation, Construction operation plan, Deterministic method

1. INTRODUCTION

Research related to construction productivity assessment has been studied worldwide over the last few decades. The studies include productivity measurement techniques, deduction of factors affecting productivity, and methods for identifying equipment use and related technology [1]. Improving construction productivity can reduce labor costs and increase corporate profits. However, the construction industry is currently showing a lower productivity increase compared to other industries, and despite the novel results of existing studies [2][3], it is still showing low productivity advancements due to failure of implementation of uncertainty in the physical job conditions such as work size and environmental factors, and operation rate or operation efficiency [4][5]. Accordingly, there is a need for a systematic method for generating sustainable and analytical data [6][7].

As a deterministic method, the Standard Estimation in Korea provides information similar to RSMeans and it is used for calculating duration and cost for construction projects [8]. However, such deterministic methods excluses uncertainty and various parameters to be considered for appropriate productivity assessment, thus making it inaccurate [9][10]. As a result, time and manpower must be invested whenever the conditions required for planning change [11]. In order to derive reliable estimates of earthwork costs, a dynamic system through interaction analysis of numerous variables is required [12].

For this purpose, construction simulation technique is recognized as an efficient tool that can evaluate performance of construction operations in virtual environments prior to the construction stage [13][14]. However, it was studied that due to the nature of the technique, enormous amounts of data to reflect various conditions and the need for expertise for simulation modeling were presented as limitations of the technique. In addition, many failed to compare the results with actual data collected from on-going construction sites. Accordingly, this paper conducts analysis on 15 data samples collected from 5 different construction sites and compares simulation results with RSMeans values for verification of the applicability of the proposed method. The study uses web-cyclone model for the purpose of deducing optimized resources as conducted in the study of Hongjo, Kim(2019) [5]. As validation of the methodology is mandatory, the proposed method is applied to earthwork operations which is recognized to account 25% of total construction cost of road construction projects [15][16]. It is expected that the methodology can be used for establishing a reliable database that can be used for process planning for earthwork operations as more application and site data are collected. The research procedure is summarized as Figure 1.

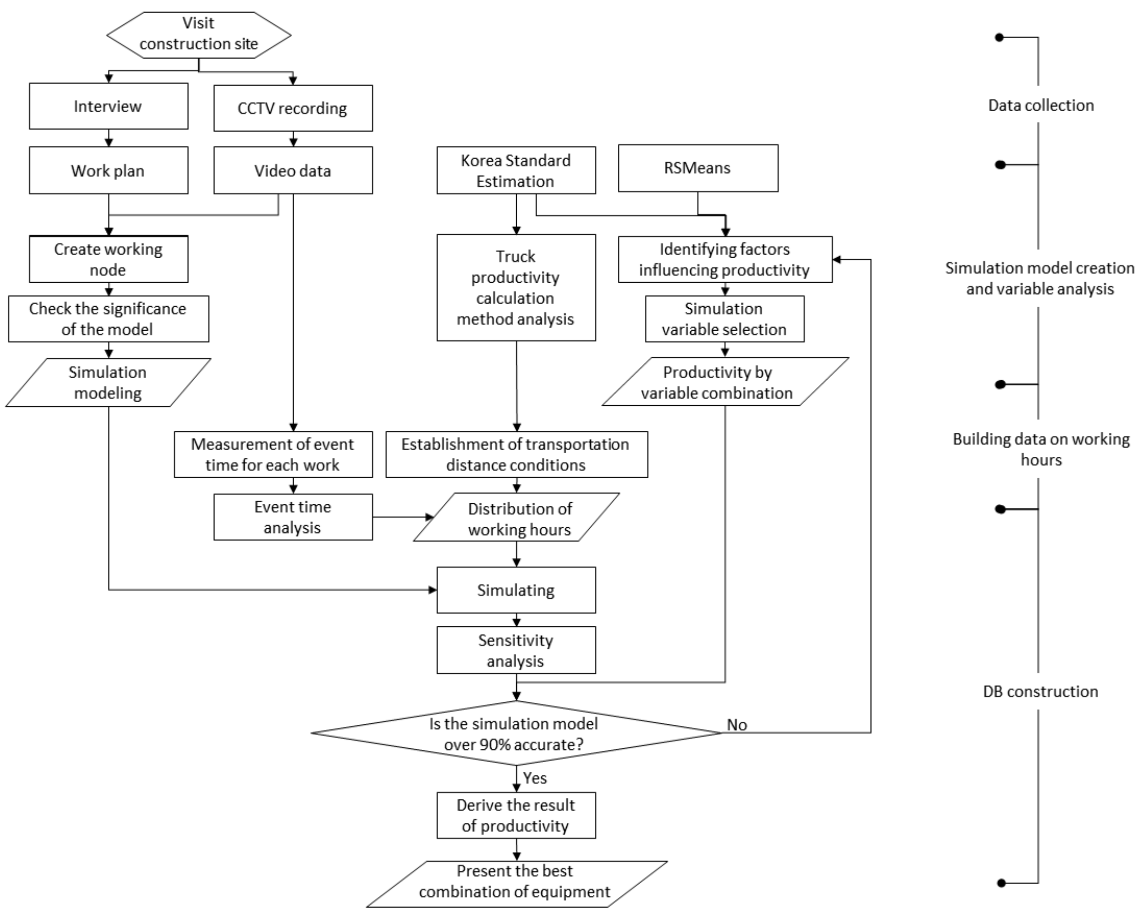

Figure 8. Framework for building a productivity DB through simulation

2. LITERATURE REVIEW

The construction simulation is a technique that can predict its performance by performing some construction activities of projects such as earthwork in a virtual environment prior to the construction stage [13]. In addition, it is a useful tool used to derive the optimal construction period and cost based on various performance data and assumptions [14].

Studies in the field of deriving earthwork operation productivity using DES(Discrete Event Simulation) were reviewed and have shown that such models can segment complex construction processes and take various scenarios of equipment into consideration [17-21]. In addition, a study using GPS sensors of construction equipment for automating the process of data collection of labor-intensive simulation input values was conducted, and process studies were previously conducted to compensate for the shortcomings of less usable simulations [22-25].

Existing studies have shown that simulation techniques provide useful information to project stakeholders and opportunities to reduce construction costs and improve productivity through virtual modeling of specific situations [14][17]. Existing studies propose the following limitations and future studies. 1) The simulation model should increase the applicability of the model by considering various field conditions as variables, and compare them with actual field data [26][27]. 2) Simulation technique demands expertise in modeling that highlights the need for developing customized analysis tool for field managers [28].

Accordingly, this study aimed to propose a productivity assessment and database generation method that overcomes the above stated limitations that is expected to be highly applicable in the field.

3. RESEARCH METHODOLOGY

3.1. Data collection

CCTV data from five road construction sites in Korea and construction activities data such as number of labors and equipment specifications were collected through site information documents. In this study, the earth cutting work vedios were analyzed as an example, and the construction photos and site information of each site are as Figure 2.

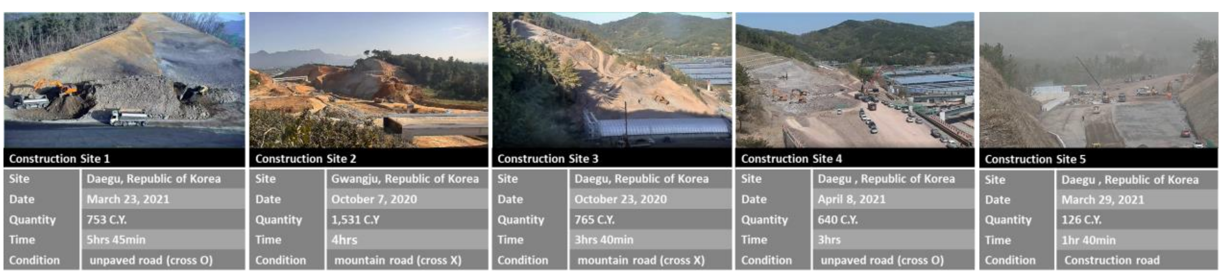

Figure 2. Conditions for each construction site

3.2. Simulation model creation and variable analysis

This study used the simulation techniques to deduce the optimal resource combination for earthwork operations. Based on the collected data explained in section 3.1, the simulation models were established using WebCYCLONE. Detailed information regarding CYCLONE and its basic modeling elements can be refer to in Halpin and Riggs (1992) [29]. Model was created based on the five site informations. The model was targetted a soil cutting operation that includes an excavator and a dump truck. Excavation, load, and transportation work can be observed through site CCTV, and each order of works are as follows. 1) Excavate is the work of excavating soil by an excavator. 2) Load is the work of filling the dump truck with soil by the excavator. 3) Travel is the work of a truck transporting soil to deposit area and returning to the earthwork site to transport soil.

Variables that affect the productivity of earthwork were selected for the most common processes and specifications of equipment by using RSMeans Building Construction Cost Data 2017 and Standard of Construction Estimate for Civil, Building and Machine Facility in Korea.

RSMeans is configured to provide a panoramic view of productivity and unit price according to equipment resources, working environment, and crew lists. In the case of dump truck transportation, it has variables as shown in Table 1 [30]. Among them, this study consisted of variables that could be considered in the operation planning stage.

Event time data corresponding to 15 conditions collected from 5 different construction sites as shown in Figure 2. The truck capacity is 12.55C.Y., the transportation speed is 10.87, 20.19, 21.75, 32.62, 37.28MPH, and the distance is 2, 4, 5.26, 6, 8, and 10 Mile. Table 2 is an example of variables analyzed through CCTV data.

Table 1. Variables of RSMeans

*VAR1, VAR2, VAR3, VAR4, and VAR4 denote variables for each type of construction activities.

No.	Earthwork Excavation and Fill		VAR1*	VAR2	VAR3	VAR4
1	Excavating		Excavator capacity (C.Y)	Deep excavation (')	Soil condition	.
2	Fill	Hauling	Truck capacity (C.Y)	The speed of transportation (MPH)	Distance (Mile)	Wait/load/unload time
3	Fill	Compacting	Types of rollers	lifts	Compaction frequency	.

Table 2. Variables of Case study

Site number	Data	Road Condition	Hauling time (km/hr)		VAR 2 (MPH)	VAR 3 (Mile)
			Load	Unload		
1	Site 1_20210323_1	unpaved road (cross possible)	15	20	11	5.26
4	Site 2_20201007_1	2 lane paved road street	25	30	17	4.00
7	Site 3_20201023_1	2 lane paved road street	25	30	17	4.00
10	Site 4_20210408_1	unpaved road (cross possible)	15	20	11	2.00
13	Site 5_20210329_1	2 lanes paved road suvurb	35	35	22	4.00

3.3. Building data on working hours

The event time of work that can be observed in the site CCTV was measured through the 3.2 criteria. An average of 50 load operations were observed in each vedios, and Table 3 is an example of the distribution of event time. The error of the result value measured through the Figure 3 and the standard deviation value was not large, so it was judged as a value that can be used as a simulation input value with data with normality.

In order to verify the accuracy of productivity of simulation data through RSMeans data, it is necessary to compare the productivity of the two under similar conditions. The construction was carried out in Korea and follows the conditions of transportation of the Standard Estimating System, which is the standard for integration in Korea. This study calculated the distance and average transportation speed by (1) through the transportation time set as the standard for the

Korean construction standard according to the transportation road conditions observed through CCTV.

$$\text{Round Trip (min)} = \frac{\text{Mile}}{\text{Average Speed(Load)}} + \frac{\text{Mile}}{\text{Average Speed(Unload)}} \tag{1}$$

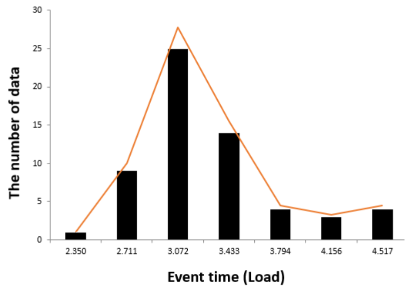

Figure 3. Distribution of load data.

Table 3. Example of Event time data

Activity	Measured duration	
	Mean	**Standard Deviation**
EXCAVATE	2.7	3.23
LOAD	3.1	0.50
TRAVEL(DUMP+RETURN)	59.2	2.23

3.4. DB constructions

In order to deal with uncertainty and compare the effect of changes in variables on work productivity [4], sensitivity analysis was performed to derive productivity estimates and optimal combinations of equipment. To verify the accuracy of productivity of simulation data through RSMeans data, it is necessary to compare the productivity of the two under similar conditions. Accordingly, the comparison was conducted under conditions similar to the conditions of RSMeans in the transport speed and distance of the site with a tolerance accuracy of 90% for the deduction of optimal equipment combination and productivity database generation.

4. CASE ANALYSIS

4.1 Simulation modeling results

Tables 4 and 5 below are the results of simulation and sensitivity analysis of Construction Site 1 data. Sensitivity analysis can be performed as Table 5 to derive productivity according to the number of dump trucks. Productivity converges to 0.365 when 15 dump trucks are put in, so it can be seen that under the conditions, the most optimal productivity can be exhibited when 15 dump trucks are put in operation plan.

4.2 Model accuracy analysis and Productivity data generation

As a result of comparing productivity in the Table 6, the following results were derived as a result of comparing productivity by 15 conditions. Since the capacity of the dump truck used in each field and the loading and unloading time of the dump truck are the same, VAR1 and VAR4 have the same values. Therefore, in this study, the values of productivity results according to changes in VAR2 and VAR3 variables were compared.

The Web cyclone productivity results ranged from 2.1% to 20.82%, showing an average error of 7.4% with RSMeans. This can be seen as a difference caused by the difference between the actual site of the variable such as the transport speed and the values of the RSMeans and the actual site.

Through comparison with RSMeans' deterministic results as follows, the created simulation model could be verified, and through simulation of other industries, it would be possible to mass-produce productivity value data that flexibly changed variables.

Table 4. Result of Web-cyclone Simulation

PRODUCTIVITY INFORMATION		
Total Sim. Time Unit	Cycle No.	Productivity (per time unit)
39992.7	1000	0.02500456

Table 5. Result of Sentivity analysis

SENSITIVITY ANALYSYS RESULT							
# of DUMP	Productivity Per Unit Time	# of DUMP	Productivity Per Unit Time	# of DUMP	Productivity Per Unit Time	# of DUMP	Productivity Per Unit Time
1	0.025	6	0.1495	11	0.2728	16	0.365
2	0.05	7	0.1744	12	0.2967	17	0.365
3	0.0749	8	0.1992	13	0.3214	18	0.365
4	0.0999	9	0.2231	14	0.3454	19	0.365
5	0.1248	10	0.2484	**15**	**0.365**	20	0.365
⁝				⁝			

Table 6. Productivity results comparison

#	Site	Productivity (C.Y./hr)		Error Rate (%)	#	Site	Productivity (C.Y./hr)		Error Rate (%)
		Simulation	RSMeans				Simulation	RSMeans	
1	Site 1_20210323_1	20.4	22.7	**10.27**	9	Site 3_20201023_3	18.4	19.6	6.04
2	Site 1_20210323_2	14.1	17.9	**20.82**	10	Site 4_20210408_1	27.5	31.3	**11.87**
3	Site 1_20210323_3	18.0	19.6	8.25	11	Site 4_20210408_2	22.5	22.7	0.79
4	Site 2_20201007_1	24.1	22.7	6.04	12	Site 4_20210408_3	18.2	20.8	**12.47**
5	Site 2_20201007_2	19.2	20.8	7.66	13	Site 5_20210329_1	26.2	27.0	3.15
6	Site 2_20201007_3	18.7	19.6	4.44	14	Site 5_20210329_2	26.1	27.0	3.32
7	Site 3_20201023_1	23.6	22.7	3.76	15	Site 5_20210329_3	23.1	25.6	9.96
8	Site 3_20201023_2	20.4	20.8	2.16					

5. CONCLUSION

Existing deterministic methods make it almost impossible to secure diversity of construction productivity data. Accordingly, this study proposed a frame work that overcomes existing limitations of deterministic methods and simulation techniques that can deduce optimal equipment combinations and generate productivity database.

The study was targeted on earthwork soil cutting work and the an average error rage of 7.4% model was achieved. Productivity information proposed through simulation in this study is composed of variables that can be grasped even in the process planning stage without the expertise of simulation modeling due to pre-generated productivity database.

However, since the simulation proposed in this study uses limited variables and data to generate productivity database 4 of 15 cases have shown error rate up to 20.8%.

Further study must be conducted to increase the accuracy of the model by reflecting additional field conditions which will facilitate users' decision-making for operational planning. Generating productivity database under various conditions is required by additional modeling so that productivity data values can be predicted according to various loading and transport conditions even in similar constructions, and research on the effective use of productivity database should be conducted additionally.

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