

S7-2**A NESTING APPROACH IN DISCRETE EVENT SIMULATION FOR INTEGRATING CONSTRUCTION OPERATION AND SCHEDULE MODELS****Chang-Yong Yi¹, Chan-Sik Park², Doo-Jin Lee³ and Dong-Eun Lee⁴**¹ Graduate student, Kyungpook National University, School of Architecture & Civil Engineering
Daegu, KOREA² Professor, ChungAng University, School of Architecture & Building Science
Seoul, KOREA³ Associate professor, Kyungwoon University, Department of Architectural Engineering
Gumi, KOREA⁴ (Corresponding) Assistant professor, Kyungpook National University, School of Architecture & Civil
Engineering, Daegu, KOREA.
Correspond to dolee@knu.ac.kr

ABSTRACT: Simulation applications for analyzing the productivity of construction operations at operation level and project schedules at project level are crucial methods in project management. The application at two different levels should be very tightly linked to each other in practice. However, appropriate integration at the levels is not achieved in that existing systems do not support to integrate operation models into a schedule model. This paper presents a new approach named to Discrete Event Simulation-Nesting modeling approach, which supports not only productivity analysis at operation level but also schedule management at a project level. The system developed by the authors allows creating operation models at the operation level, maintaining them in operation model library, executing sensitivity analysis to find the behaviors of the operation models when different combination of resources are used as existing DES systems do. On top of the conventional functions, the new system facilitates to find the optimum solution of resource combinations which satisfy the user's interest by computing the hourly productivity and the hourly cost of the operation. By drag-and-dropping an operation model kept in the operation model library, the operation models are integrated into an activity of the schedule model. When a complete schedule model is established by nesting operation models into the schedule model, stochastic simulation based scheduling is executed. A case study is presented to demonstrate the new simulation system and verify the validity of the system.

Keywords: Construction operation model; schedule model; discrete event simulation; simulation based scheduling

1. INTRODUCTION**1.1 Background Aims of Research**

The hierarchy of construction management may be broken down into 6 different levels (i.e., corporate, project, activity, operation, process, and task, etc) according to the domain at which a decision is made. A construction process is defined by linking several tasks in a specific sequence. A construction operation is formulated by combining several construction processes. An activity is defined by integrating several construction operations. Finally, a project schedule network is

modeled by establishing the relationships between activities (Halpin 1992).

At the operation level, existing Discrete Event Simulation systems (Hereafter, called by DES operation system) has been used to model a construction operation and to analyze the productivity of it. These systems model cyclic construction networks using tasks as the atomic building block and compute hourly production rate, operation completion time, utilization of input resource, and operation completion cost, etc. In addition, sensitivity analysis is used to identify the resource combination which maximizes the operation productivity and satisfies optimally the job site conditions (Halpin

1992). However, the existing DES operation systems have several deficiencies relative to the usability as follows;

First, most existing DES operation systems depend on commercial statistic software packages such as SPSS, SAS, and Crystal Ball. One should estimate the PDFs of historical task durations by manually and independently operating the software packages and should manually assign the PDFs of the task durations to the time delay functions of tasks in the operation model under study. Therefore, this inconvenience is more acute when one should deal with large network.

Second, it is always questionable if the simulation experiment is terminated when it is arrived at appropriate maturity. Existing systems use two stoppage rules to decide when to stop the experiment. One is terminating the experiment when the production unit (i.e., truck) passes a predefined numbers of cycles (i.e., 30 cycles) through a specific location (i.e., dumping site) at which production is measured. The other is terminating the experiment when the simulation time arrives at a duration (i.e., 10,000 seconds) predefined by system user. The experiment stops only if any one of the two conditions occurs. The existing systems are limited in that their very common operations are to make a single simulation run of somewhat arbitrary cycle (or length) and then treat the simulation output estimates (i.e., total operation completion time, hourly production rate, utilization efficiency of input resource, total operation completion cost, etc) as the “true” model characteristics or solutions, albeit these estimates are just particular realizations of random variables that may have large variance.

Third, sensitivity analysis, which is used to identify a set of optimal resource combination satisfying operation specific conditions (i.e., total operation time and total operation cost, etc), needs to export the output data to external applications (i.e., excel) and manually manipulate to analyze them. In this way, it is not handy to retrieve the optimal solution without delay. This inconvenience is exacerbated when the analysis method is used with a large operation networks consisting of many resource combinations.

The existing DES operation systems, which are operation research oriented, are used to model construction operation and analyze the productivity at operation level. On the other hand, scheduling systems (i.e., CPM, PERT, and stochastic simulation based scheduling, etc) are used to model schedule network and measure the project performance at the project level. These systems

These systems model non-cyclic schedule networks using activities as the atomic building block. They compute project completion time and cost, establish an optimal resource input strategy (Feng, C. W. and Liu, L. 2000), and control the schedule progress. Specifically, the stochastic simulation based scheduling method (Hereafter, called DES schedule system) are well accepted (Barraza

et al 2004, Lee and Arditi 2006), because it improves the predictability by efficiently dealing with not only the uncertainty of activity durations and costs, but also the variability of project completion times (PCTs). However, the existing DES schedule systems, also, have several deficiencies involved in the usability as follows;

First, most DES schedule systems depend on commercial statistic software packages such as SPSS, SAS, and Crystal Ball. One should estimate the PDFs of historical activities’ durations by manually and independently operating the software packages and should manually assign the PDFs of the activity durations to the activity durations in the schedule model under study. Therefore, this inconvenience is more acute when one should deal with large network.

Second, the two systems, DES operation system and DES schedule system, are independently used to model stochastic construction operation network at the operation level and stochastic project schedule network at the project level, respectively.

That is why; the simulation output obtained at lower level (i.e., operation level) is neither effectively used by schedule model at higher level (i.e., project level) nor used to support a decision making at project level. Sure, there are existing systems which link operation models each other at a same level (i.e., CIPROS, Tommelein et al 1994; Sim-Con, Chehayeb and AbouRizk 1998). However, they are neither capable of integrating the network models of different levels in the construction hierarchy nor of supporting desirable analysis obtainable by integrating them. This lack of method prevents the information obtained from the different levels (i.e., corporate, project, activity, operation, process, and task, etc) in the construction hierarchy from being effectively used in practice.

1.2 Aims of Research

This study aims to develop a new system called ‘Integrated Construction Operation and Schedule siMulatiOn System (Hereafter, COSMOS)’ which not only complements the discrepancies of the existing DES operation systems and DES schedule systems, but also integrates the network models of different levels in the construction hierarchy. COSMOS is developed as automated software which integrates information generated from micro to macro levels in project delivery. The research activities were conducted in four steps. First, a strategy was set to eliminate the discrepancies of existing DES operation systems and DES schedule systems. Second, a strategy was set to eliminate the discrepancies of existing systems. Third, a detailed illustration of the new system was demonstrated using a small operation model and a schedule model. Fourth, the capability of the system to integrate network models of different levels and to handle a large schedule network was verified. The contents in this paper are organized in the same order.

2. CURRENT STATE OF EXISTING OPERATION AND SCHEDULING SIMULATION SYSTEM

DES operation systems and DES schedule systems, which are independent systems for different purpose at different levels in construction hierarchy, are used for improving operation productivity and project performance, respectively. These systems have cumulated wide ranges of applications in practices and are well accepted.

2.1 DES operation systems in construction

After Halpin(1973) introduced CYCLONE which are specialized in construction, various DES operation systems were developed by many researchers to model construction operations and to predict and improve the productivity of them. Examples of the systems includes UM-CYCLONE (Ioannou 1990) which uses Loop; CRIPROS (Tommelein et al 1994) which defines resource properties; design component properties, and the relationships between tasks effectively; STROBOSCOPE(Martinez 1996) which handy to implement complex operation models; SIMPHONY (AbouRizk and Mohamed 2000) which models various construction resources and their flows using icons; DISCO(Huang and Halpin 1994) and COOPS(Liu 1995) which improve CYCLONE by converting it into a computer graphic environment; ABC(Shi1999) which simplifies modeling environment by reducing the number of design components (i.e., COMBI, NORMAL, QUEUE, ARROW, etc) to CPM like design components(TASK and ARROW), Extended version of ABC(Hong et al 2002) which improves the usability of ABC(Shi1999) by incorporating 2 dimensional animation function, Case-Based Reasoning (Graham et al. 2004) and Fuzzy based system (Cheng and Wu 2006) which improve the practicality of modeling task durations. These systems were applied to model various construction operations such as earth moving(CYCLONE, Halpin 1977), constructing concrete structure(CIPROS, Tommelein et al 1994), building airport service center(STROBOSCOPE, Martinez 1994), installing precast concrete(COOPS, Liu 1995), placing concrete(Micro CYCLONE, Ediz and Fuat 1997), constructing floating caissons(PROSIDYC, Halpin and Martinez 1999), driving pile(Micro CYCLONE, Zayed and Halpin 2001), re-decking bridge(Cell-DEVS, Micro CYCLONE, Hong et al 2006), etc, naming a few. The existing DES operation systems have the discrepancies mentioned earlier, albeit they were widely and well accepted.

2.2 DES schedule systems in construction

DES schedule systems (i.e., CYCLONE-CPM, Halpin 1990; Stroboscope's CPM Add-On, Martinez and Ioannou 1997; Sim-Con, Chehayeb and AbouRizk 1998; ABC-CPM, Shi 1999), which are extended from the existing

DES operation systems, are introduced to construction scheduling filed. However, these systems inherit the discrepancies from their progenitor software, namely the existing DES operation systems.

3. INTEGRATED CONSTRUCTION OPERATION AND SCHEDULE SIMULATION SYSTEM (COSMOS)

The system automatically estimates the best-fit-PDFs of historical task durations and costs, runs construction operation model for a predefined number of cycle or simulation length, estimates the PDFs of many operation models' completion times and costs, allows establishing construction operation model using tasks as atomic building blocks, assigns the PDFs of many operation models' completion times and costs to respective activities of a project schedule network using nesting method, generates random variates based on the individual PDFs assigned to each activity, run CPM for a predefined number of iterations, estimates the PDF of Project completion times(PCTs) and Project completion costs(PCCs), and make a prediction relative to project completion time and cost.

COSMOS integrates information which is generated at lower level (i.e., operation) into project performance analysis at higher level. Therefore, it is capable of synthesizing the productivity information obtained from DES operation model and the performance information obtained from DES schedule model. In addition, it provides an automated tool to search optimal input resource combination which allows delivering a project within a specific deadline and minimum cost. The method described below was developed into an automated system by using MATLAB and SimEvent for programming and simulation engine, respectively. The detail explanations of the two modules consisting of the system are provided as follows;

3.1 DES operation module

This module, which models a construction operation model and analyzes the productivity of it, is consisted of four modes. They include operation modeling, resource initialization, simulation execution, and simulation output data analysis modes as shown in Figure 1. The model building blocks (or design components) of the module are presented in Table 1. The algorithm of the module is presented in Figure 1. Detailed descriptions are delayed due to lack of space.

3.1.1 Operation modeling mode

A construction operation model is established by using the design components available in a computer graphic user interface as shown in Table 1. The historical task duration data stored in spreadsheet format (Section A in Table 2) are read by COSMOS. Then, the best-fit-PDFs and their parameters are computed using the automated

best fitting algorithm developed by the authors (Lee et al, 2009). The best-fit-PDFs and their parameters for each task are stored in section B in Table 2.

3.1. 2 Resource initialization mode

Sensitivity analysis is carried out to investigate how system productivity is affected when the numbers of input resource entities are changed. Then, the priorities of each resource combination alternatives are identified using project specific limitations such as project completion time and budget committed.

Table 1. DES operation model components.

Model Component		Description
NORMAL		The component is unconstrained by resource entity so that it can be activated as soon as a preceding task is completed.
COMBI		The component is constrained by resource entity be activated only when preceding entities are satisfied.
QUEUE		The component provides a waiting space for idle or queuing resource entities.
FUNCTION		The component splits a resource entity into a specified number.
		The component consolidates resource entities into a specified number.
COUNTER		The component counts resource entities which passed through a specific point. It can suspend a system when the frequency is equal to a defined number.
ARC		The component defines a logical relationship between nodes and the direction of a flow entity.
Probabilistic ARC		The component controls the direction of an flow entity along to the assigned probability.

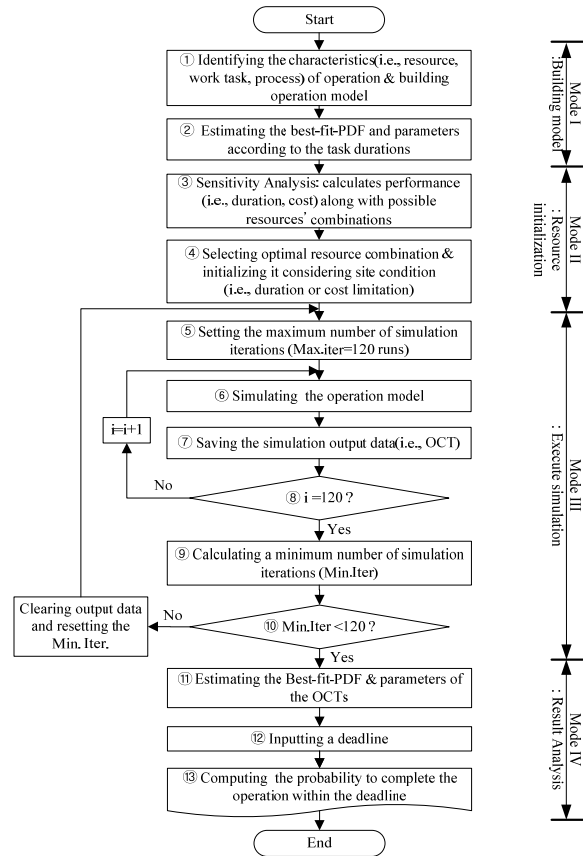


Figure 1. Operation modeling and productivity analysis flowchart.

Table 2. Historical task duration table.

3.1. 3 Simulation execution mode

Task durations are generated using the random number generator which produce random variates following the best-fit-PDFs and their parameter (refer to Section B in Table 2). The simulation output data (i.e., OCTs, OCCs, and hourly production, etc) obtained in step 6 is saved in a matrix. When 120 simulation iterations are completed, 120 sets of OCTs, OCCs, and hourly production, etc are obtained and saved in respective matrix. The system checks whether the simulation experiment passes the maturity test (Crandall 1997, Bennett 2001, Lee and Arditi 2006). The maximum number of simulation iterations is set to the value calculated in step 9. Then, steps 5 to 9 are repeated using the “for repetition structure”.

3.1. 4 Simulation output data analysis mode

When the simulation experiments reach maturity, the best-fit-PDF and its parameters describing the simulation

output data (i.e., OCTs, OCCs, and hourly production, etc) saved in a matrix at step ⑦ are identified by using the automated distribution fitting tools implemented in MATLAB. The user may query the probability to complete the construction operation within a specific deadline using the dialogue box prompted by the system.

3.2 DES schedule module

This module, which models a project schedule network and analyzes the performance of it, is consisted of three modes. They include schedule network modeling, simulation execution, and simulation output data analysis modes as shown in Figure 2. A schedule network would be readily modeled and analyzed only if operation models are well established and maintained in the operation model library. The network model building blocks (or design components) of the module are presented in Table 2. The algorithm of the module is presented in Figure 2 with detailed descriptions as follows;

Table 2. DES schedule modeling components

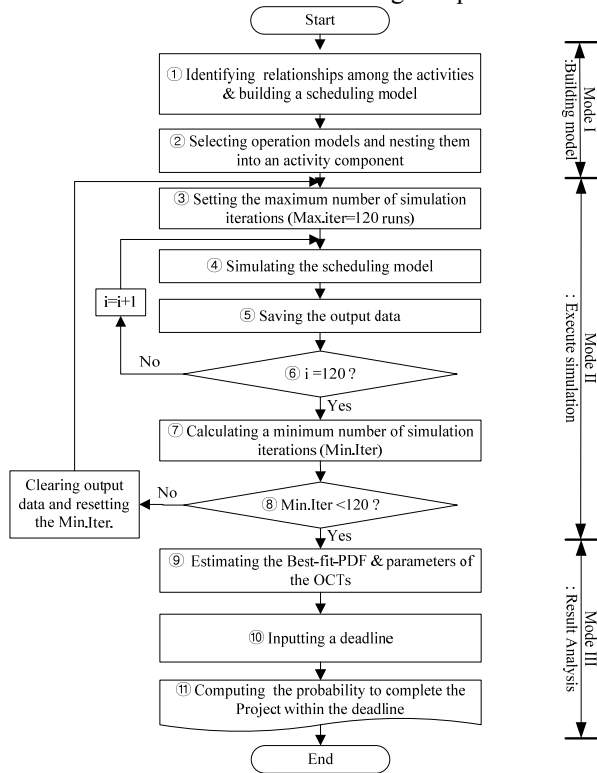


Figure 2 Schedule modeling and performance analysis flowchart

3.2.1 Schedule modeling mode

A schedule network, which defines the relationships between activities, is modeled by using the design components of schedule modeling that are available in a computer graphic user interface as shown in Figure 3. The construction operation models, which are stored and maintained in the operation model library, are nested into

activities of a schedule network by dragging-and-dropping the operation models into nesting components. This nesting method reduces the time and effort spent for data processing relative to estimating the best-fit-PDFs of the many activities in a network.

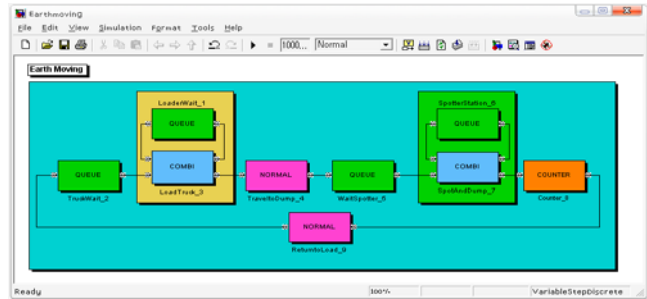


Figure 3 The Earthmoving model of COSMOS

3.2.2 Schedule network simulation execution and

Model Component		description
Project Start		·The component initializes system in order to commence a project.
Project End		·The component finalizes a system.
ACTIVITY		·The component represents an activity in a scheduling model.
NESTING		· The component is nesting the developed operation models.
Arc		·This component defines the logical relationship of each activity.

simulation output data analysis modes

The algorithm of these steps is identical with the steps 5 to 13 of DES operation module discussed previously. The detail explanations of these steps are delayed. Project completion times (PCTs) are obtained as the simulation output data after simulating the schedule network by incorporating the PDFs of OCTs as activities' durations. Since the random variates, activities' durations, are different in every simulation runs, it contributes to the variability of PCT.

4. CASE STUDIES

4.1 Case I

4.1.1 Modeling construction operation

The equivalent operation model developed by COSMOS (refer to Figure 2) was reproduced from Halpin's (1992) work to demonstrate the procedure described in the preceding section. The small operation model is reused in this case study in order to illustrate the potential of COSMOS in the context of a small network that endure rigorous testing in earlier research and verify the validity of the DES operation module by comparing

the simulation output obtained from the respective Web-CYCLONE model.

4.1.2 Initializing resource entities

The resource entities are initialized in the operation model by defining the numbers of resource entities in a certain range (i.e., maximum and minimum values). Then, many simulation experiments are enumeratively executed for all possible resource combination alternatives to carry out sensitivity analysis. The sensitivity analysis output, the minimum and maximum ranges of OCTs and those of OCCs, are presented on the pane named “Constraints Setting” in the Figure 4. The project specific limitations involved in OCT and OCC are inputted into the cells under ‘Set’ field in the pane named “Constraints Setting” by the system user. Then, a set of resource combination alternatives which results in least OCT and least OCC are rapidly retrieved out of all possible resource combination alternatives depending on the system user’s preference.

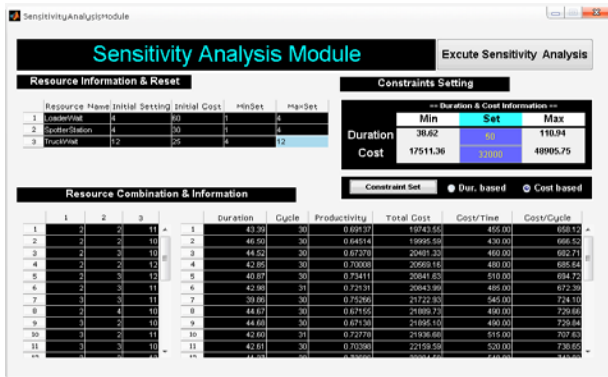


Figure 4. Sensitivity analysis module

4.1.3 Executing simulation

Using the optimal resource combination alternatives identified by sensitivity analysis in resource initialization mode, simulation is executed as shown in Figure 5. The optimal OCT and OCC are obtainable by minutely calibrating the resource combination into optimal solution. And the probability to complete the operation within a deadline queried by system user as shown in the PDF graph in Figure 5.

4.1.4 Analyzing simulation output data

Table 3 presents the simulation input data used to model earthmoving operation and the simulation output data obtained from simulation experiments using COSMOS and Web-Cyclone systems. In order to compare the simulation results obtained from the two systems, identical simulation input conditions are used.

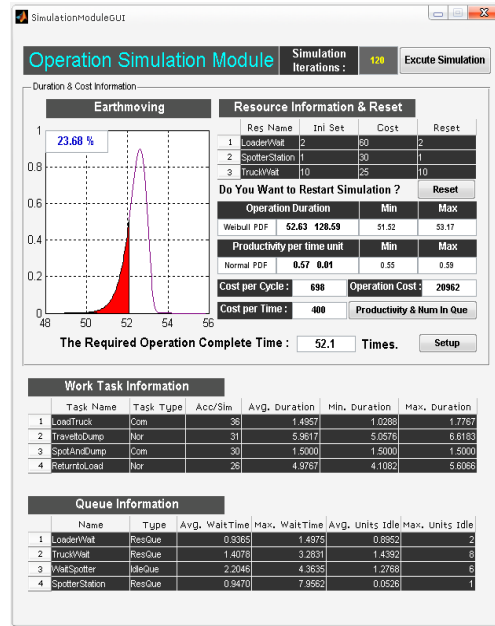


Figure 5. Operation simulation module

Table 3. Simulation result comparison

Simulation input and output data		COSMOS			Web CYCLONE		
Simulation input data	Task Description	mini mum	Most - likely	Maxi mum	mini mum	Most - likely	Maxi mum
	Load Truck	1	1.5	2	1	1.5	2
	Travel to Dump	5	6	7	5	6	7
	Spot & Dump	1	1.5	2	1	1.5	2
Input resources	Travel to Load	4	5	6	4	5	6
		Loader	Truck	Spotter	Loader	Truck	Spotter
Simulation output data		2	10	1	2	10	1
	OCT to complete 30 Cycle	Weibull PDF $\alpha = 52.63$ $\beta = 128.59$			52.1		
	Productivity per time unit	Normal PDF $\mu = 0.57$ $\sigma = 0.01$			0.585		

As shown in Table 3, COSMOS computes a total operation completion time (OCT) of normal distribution

($\alpha = 52.63, \beta = 128.59$) after automatically executing the

DES operation module. On the other hand, Web-Cyclone computes a deterministic OCT of 52.1 after a single simulation experiment as shown in Figure 1 and declares

it with 100% confidence, albeit Web-Cyclone computes the probability to complete the operation within the benchmark, 52.1, as 23.68% confidence. It shows that COSMOS is more conservative than Web-Cyclone. This is because Web-Cyclone accepts the simulation output data obtained from a single simulation run of somewhat arbitrary length and treats the resulting simulation estimates as the “true” operation model characteristics.

Table 4. Operation and activities in schedule model

Activity Name	Nesting Operations
Ground	Earth Moving
Pile	Pile Install
	Pile Cutting
Pipe	Pipe Install
Foundation	Foundation Excavation
	Foundation CON'C Placement
Slab	Slab Form Install
	Slab CON'C Placement

4.2 Case II

4.2.1 Modeling schedule network

As shown in Figure 6, a schedule network, which defines the precedence relationships between activities, was modeled by the DES schedule module of COSMOS. It shows that “Earth moving” operation model is nested into “Ground” activity. Since operation models are nested into a schedule model, a set of OCTs is generated from each operation model after simulation experiment, the best-fit-PDFs of OCTs are automatically estimated, and the best-fit-PDFs estimated are assigned to activities of a schedule model. Finally, the best-fit-PDFs of PCTs are automatically estimated by simulating schedule model. The system user does not have to define the PDFs of activities’ durations of a schedule model, because OCTs automatically generated by operation models nested into activities. In addition, a successor starts when a predefined number of cycles of predecessor are achieved. The actual start of successor is tied to the actual production amount of operation model nested into predecessor, not the predefined completion time. It provides more realistic modeling method other than existing scheduling systems (Tommelein 1996).

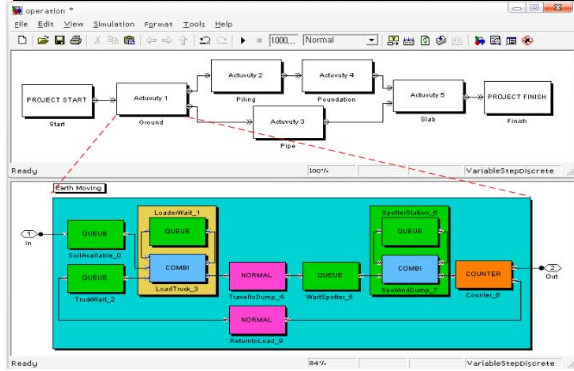


Figure 6. Operation model nesting

4.2.2 Executing schedule simulation and Analyzing simulation output data

After modeling a schedule network, DES schedule module is executed as shown in Figure 8. The simulation out data obtained from the module includes as follows; (1) project information (i.e., the best-fit-PDFs of PCTs and PCCs), (2) network information (i.e., Earliest Start, Earliest Finish, Latest Start, Latest Finish, Total Float, etc), (3) operation information (i.e., the best-fit-PDF of OCTs and OCCs), and (4) resource information inputted to project. In addition, the user may query the probability to complete the project within a specific deadline or budget using query dialogue box provided to user.

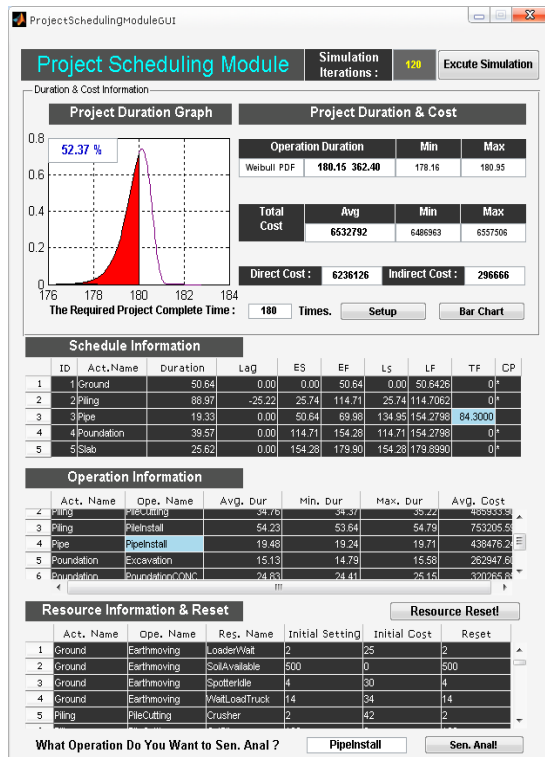


Figure 8. Project schedule module

5. BENEFITS AND LIMITATIONS

The benefits of using COSMOS can be summarized as follows:

The DES operation module of COSMOS improves the existing DES operation systems. First, the system does away with the existing DES operation systems' cumbersome and time consuming process that requires the manual and individual operation of commercial statistics packages to estimate the best-fit-PDFs of many historical task durations. Second, the system automatically executes the sensitivity analysis mode and provides the optimal resource combination alternative which meets the job site specific constraints relative to limited operation duration and/or cost. Third, the DES operation module of COSMOS automatically generates the operation completion times (OCTs), estimate the best-fit-PDF of OCTs, and compute the probability of completing an operation by a deadline.

The DES schedule module of COSMOS improves the existing DES schedule systems. First, the system directly makes use of the simulation output data obtained from DES operation module of it. Second, the system provides an automated tool which integrates production models at different levels of construction hierarchy by conveniently dragging-and-dropping operation models stored in a model library into a schedule model. Third, It automatically generates the project completion times (PCTs), estimate the best-fit-PDF of PCTs, and compute

the probability of completing a project by a deadline without supplying historical activity duration data. Since COSMOS integrates the two modules into one system, it provides more accurate and effective modeling and analysis method.

The limitations of using COSMOS are related to testing and development issues. First, fictitious data are used in the case studies for historical task durations rather than actual data collected from job site using video time lapse analysis techniques and MPDM, etc. it would be good, if field tests on actual job site are carried out to verify the usability or to identify potential issues uncovered in practice. In addition, the DES schedule module may takes considerable amount of computer memory and computation time due to using graphical user interface. It would be desirable, if the system is improved to handle the large networks frequently encountered in practice.

6. FINDINGS AND CONCLUSIONS

COSMOS entirely automates the processes relative to using DES operation system and DES schedule system and integrates them into one system. It automates estimating the best-fit-PDFs and parameters of the many tasks' durations (simulation input data), making use of the best-fit-PDFs and parameters of OCTs computed by DES operation module as the simulation input of DES schedule module, searching the optimal resource combination alternative which meets job site specific constraints using sensitivity analysis, executing the two modules using the optimal resource combination all at once and generating PCTS and PCCs, estimating the best-fit-PDFs and parameters of the PCTS and PCCs, and providing the system user information relative to resource and cost required to each activity and network to make informed decision. The previously mentioned steps were carried out using several and individual software runs. However, COSMOS automates and integrates all the steps into one system. It contributes to reduce system user's involvements and simplifies the use of several and individual software runs.

COSMOS allows handling of a large schedule network and facilitates to easily model a DES operation model that reproduces the patterns embedded in historical task duration data and to supply the simulation output obtained from the model to DES schedule model as simulation input. The main contribution of this study is the development of an easy-to-use computerized tool named COSMOS that integrate the two systems dealing with different models located in different levels in construction hierarchy.

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