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CLUSTERED SIMULATION FOR THE SIMULATION OF LARGE REPETITVE CONSTRUCTION PROJECTS

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ABSTRACT

Construction planning methods have been in continuous evolution due to the increasing complexity of construction projects. Construction simulation modeling is one of the later stages of this evolution that has received much attention in research. Many simulation based construction planning methods developed modeling methods that attempt to cluster project activities into smaller sub-models that enhance model reusability. Many of these modeling methods, however, create new modeling elements that are not familiar to traditional construction simulation modelers. Therefore, the objective of this paper is to develop a method for clustering activities of large and repetitive construction projects for enhancing the reusability of those simulation models. The developed method does not create any new modeling elements and is called Clustered Simulation Modeling (CSM). CSM was evaluated in modeling an actual large-scale repetitive construction projects, and the results have illustrated the effectiveness of the method and the proposed clustering scheme.

1 INTRODUCTION

Methods of construction planning have been in continuous evolution due to the increasing complexity of construction projects. The first step of this evolution was the advent of the critical path method (CPM), which was developed on several stages, each introducing a new method of data presentation. The earliest of these methods of presentation was the Gantt chart developed by Henry Gantt during World War I (Callahan et al. 1992). A lot of criticism has been directed to CPM, since it was not initially developed for planning construction projects and for its inefficiency in planning projects of a repetitive nature (Jaafari 1984). Another important step in the evolution of construction planning method that was developed in the 1960's was Project Evaluation and Review Technique (PERT). This method was initially developed for planning a missile development project, but unlike CPM, PERT is capable of probabilistically analyzing project durations. The main drawback of PERT is that it involves a large amount of calculations since it requires the use of three estimates for the durations for each activity. Another shortcoming of PERT is that it assumes the presence of a single critical path in the project. If more than one critical paths exist, the accuracy of the results obtained from the PERT calculations is doubted (Callahan et al. 1992). The following step in the evolution of methods of planning utilized computers, which enabled modelers to analyze project durations probabilistically without concern for the computational requirements for these analyses. Among these early attempts to use computers in planning were Monte-Carlo Simulations (Vose 1996), Model for Uncertainty Determination (MUD) (Carr 1979) and GPSS (Chisman 1992). CYCLONE was also developed at an early stage of computer development, but CYCLONE was widely accepted and continues to be researched until this moment (McCahill and Bernold 1993). The concepts of CYCLONE were also used to develop other computer based planning tools, such as INSIGHT and RESQUE (McCahill and Bernold 1993), and the very prominent STROBOSCOPE (Martinez and Ioannou 1994, 1996, 1999; Martinez 1996) . CYCLONE utilizes a number of modeling elements that are linked to each other to form networks that simulate construction projects (Halpin and Riggs 1992).

More recent research in the field of computer based construction planning focused on facilitating the planning process. These researches sought this goal by developing methods breaking projects into subparts that can be reused in more than one project with a few minor changes. A number of methods of planning were developed in which project activities were clustered to enable model reusability. The first of these methods was Resource Based Modeling (RBM), which grouped project activities according to the resources they are associated with. The grouped project activities form special types of process models called "r-processes", which can be reused in any project with minor changes (Shi and Abourizk 1997). Another method that utilizes the concept of clustering is Hierarchical Simulation Modeling (HSM), which groups activities according to their level in the project hierarchy or WBS, by grouping activities of the same processes together. Then these different process models are linked to each other using special links developed in HSM (Sawhney and AbouRizk). A third method of clustering was Simulation-based Project Control (SimCon), which developed a new method of breaking down project information called Production Breakdown Structure (PBS). This breakdown structure divides project information into three levels: (1) Cost Breakdown Centers, which are composed of the project's cost control centers; (2) Location Breakdown Centers, which are used to associate cost control centers to specific locations of the project; and (3) Simulation Process Centers, which is used to define processes that will be simulated and sequenced (Chehayeb 1995, Chehayeb and AbouRizk 1998). SimCon has a number of new modeling elements that are used to link and control the simulated processes.

The aforementioned simulation based construction planning methods have offered many advantages in handling large and repetitive projects probabilistically. These studies, however, did not investigate the practical methods for creating reusable clusters for large highly repetitive projects. Further, the aforementioned studies have developed new simulation constructs that enable the clustering process. This paper will demonstrate a method of planning that will use traditional simulation modeling for the probabilistic analysis of large repetitive project, and will also facilitate the clustering or grouping of project activities to enhance model reusability. The developed method of planning will only use the well-established concepts of CYCLONE that most construction simulation modelers are familiar with, and will be called Clustered Simulation Modeling (CSM).

2 METHODS OF CLUSTERING

The method of planning described in this research aims at simplifying the process of simulation modeling of large projects, and allowing for better model reusability. The simplification process is performed by systematically breaking down and grouping project activities into clusters that are simulated by separate simulation models. These clustering methods will not introduce new concepts to a traditional method of construction simulation, which is CYCLONE. This approach creates a number of restrictions and criteria for selecting the method of clustering selected to group project activities to be simulated. The first of these restrictions is that CYCLONE doesn't allow the sharing of resources between separate simulation models, which requires each cluster to aggregate activities sharing the same resources. Secondly, there is no method of directly linking clusters created in separate simulation models to each other. A method of linking models in separate files will be describe later in this paper, however, it is still preferred to minimize the number of links as much as possible to reduce the amount of work to be performed by the modeler. The third restriction on the method of clustering selected is that no cluster should contain activities present in another cluster, since the presence of an activity in more than one cluster can cause great confusion since overlaps between clusters are not easily quantifiable (Kandil 2000).

A number of methods of clustering were analyzed and compared to determine the most suitable method among those investigated. The following is a description of the different methods of clustering investigated:

1. Clustering by Unit of Work: Activities leading to the completion of a single unit of work are grouped to form a project cluster. Unit of Work clustering would be best applied to projects of a repetitive nature, since it would capitalize on the cyclic nature of CYCLONE. Unit of Work clustering, however, conflicts with a number of criteria of cluster selection, since it requires resources to be shared between different project clusters, and also since there would be a large number of cluster to cluster links, which is not desirable in the proposed clustering method.
2. Clustering by Resource: Activities sharing the same resources are grouped with each other. Although this method of clustering satisfies one of the criteria for cluster selection, which is the resource sharing criterion, it conflicts with two other criteria. Resource clustering conflicts with the cluster exclusivity criterion, since some activities may require more than one resource to be performed. The method also conflicts with the restriction on the number of cluster to cluster relations, since this method of clustering would lead to the creation of numerous cluster to cluster relations.
3. Clustering by Path: CPM links project activities to form networks having different paths. This method of clustering would group activities on the same path together to form a project cluster. This method of clustering has a large number of shortcomings, since it makes the clustering process both complicated and time consuming. This method of clustering also conflicts with a number of cluster selection criteria, because the CPM paths are not exclusive as project clusters should be, and also since a large number of relations exist between paths of the same project, and finally because activities in different paths can have shared resources.
4. Clustering by Process: This method of clustering groups activities according to their Trade or Process, which is the third level of the hierarchy of the project Work Breakdown Structure (WBS). The shape of the structure of a project WBS is shown in Figure 1 (Kandil 2000).

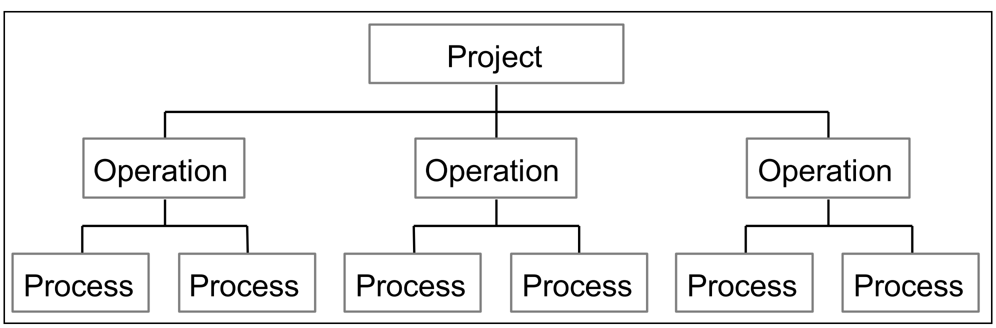

Figure 1: Project WBS (Kandil 2000).

This method of clustering conforms with most of the cluster selection criteria, since it groups activities by trade leading to almost no resource sharing between clusters, and also since the clusters created are exclusive. This method of clustering however conflicts with of one of the cluster selection criteria, since there would be a large number of cluster to cluster relations between the different trades.

5. Clustering by Operation: The final method of clustering also uses project WBS. This method of clustering groups activities of the same Operation or Type of work. This method satisfies all the cluster selection criteria, since it avoids the only conflict the previous method has, which is its

numerous cluster to cluster relations (Kandil 2000). This method of clustering proved to be the most suitable among those tested and hence it was used in the developed method of planning.

3 PROJECT CLUSTERS

The method of clustering identified in the previous section includes a number of possible types of clusters that can be classified according to their relations to other clusters in the project, including (Kandil 2000):

1. Independent Cluster: This type of cluster represents an operation that does not depend on any preceding operations. An example of such an operation represented by an Independent cluster is earthmoving operations in a building project, since it doesn't depend on the completion of any construction works.
2. Intermediate Cluster: These clusters represents operations that depend on the completion of other operations and also have operations that depend on their completion. An example of this type of operation is the concrete structure operation, which depends on the completion of the earthmoving works, and at the same time precedes the Finishes operation.
3. Dependent Cluster: This type of cluster represents operations that depend on preceding operations and that do not have any operations depending on them. An example of an operation represented by this type of cluster is the Landscaping operations in building project.
4. Hammock Cluster: These clusters represent operations that neither have preceding nor succeeding operations. The kind of operations represented by this type of cluster is not very common in construction.

Cluster to cluster relations can also be classified according to which parts of the cluster do they link. These relation types include:

1. Operation to Operation relation: The last activity of an Operation triggers the work of another Operation.
2. Process to Operation relation: One of the activities of one of the Processes in an Operation triggers the work of another Operation.
3. Operation to Process relation: The last activity in an operation triggers the work of a Process within another Operation.
4. Process to Process relation: One of the activities of a Processes in an Operation triggers the work of another Process in another Operation.

The different types of Cluster to Cluster relations are represented in Figure 2 (Kandil 2000).

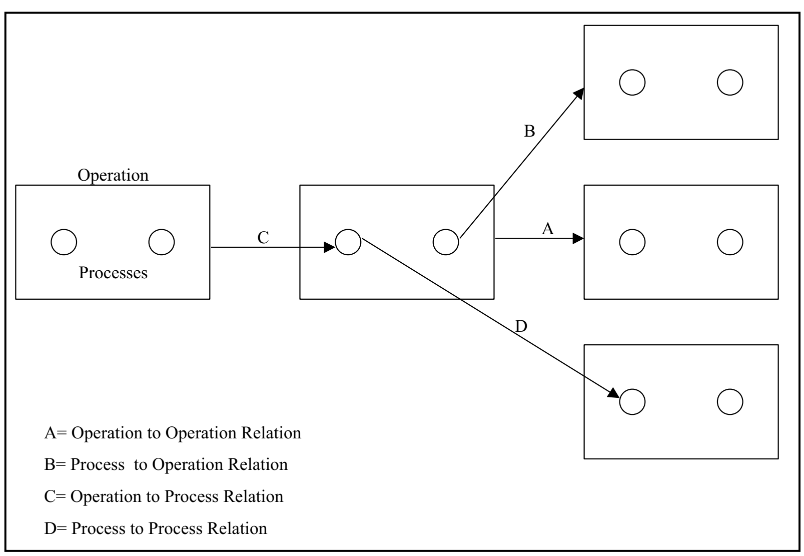

Figure 2: Cluster to Cluster Relations (Kandil 2000).

4 CLUSTER LINKING TOOLS

CSM was developed to simplify the process of modeling large and complex construction project and enhancing the reusability of these models, and this is why the process of linking the different clusters of a project needs to be executed without adding any new modeling elements. The method of linking of project clusters in CSM was therefore developed using only the current modeling elements of CYCLONE. The linking of clusters in CSM involves the development of two tools using CYCLONE modeling elements. The first of these modeling elements is the Marked Dummy, which is an activity that doesn't model any physical work. The purpose of this activity is to record the times at which signals need to be transmitted from one cluster to another. These event times are recorded in the CYCLONE's CHRONOLOGICAL list (Kandil 2000). The second tool developed in CSM is the Simulation Trigger Timer (STT). The purpose of this tool is to relay the signals from another cluster to the cluster in which the STT is placed. Each Marked Dummy has a corresponding STT in the succeeding cluster. The STT is composed of a number of trigger activities equal to the number of occurrences of the Marked Dummy and having durations that correspond to the times at which signals are emitted from the Marked Dummy. STT's are also composed of a number of Timer Starter QUEUE's that varies according to the configuration of the STT. The function of these is to start the work of the STT. The final component of STT's is the Collector Activity. The purpose of this activity is to channel the signals emitted by Trigger activities to the succeeding activities (Kandil 2000). There are two configurations of STT's in CSM. The conventional STT was developed for use in projects that are going to be simulated using deterministic durations. In this STT configuration there is only one Timer Starter QUEUE and Trigger activities are connected to each other and their durations are calculated by subtracting the subsequent event times of the occurrences of the Marked Dummy from each other (Kandil 2000). An example of this configuration of STT's is shown in Figure 3.

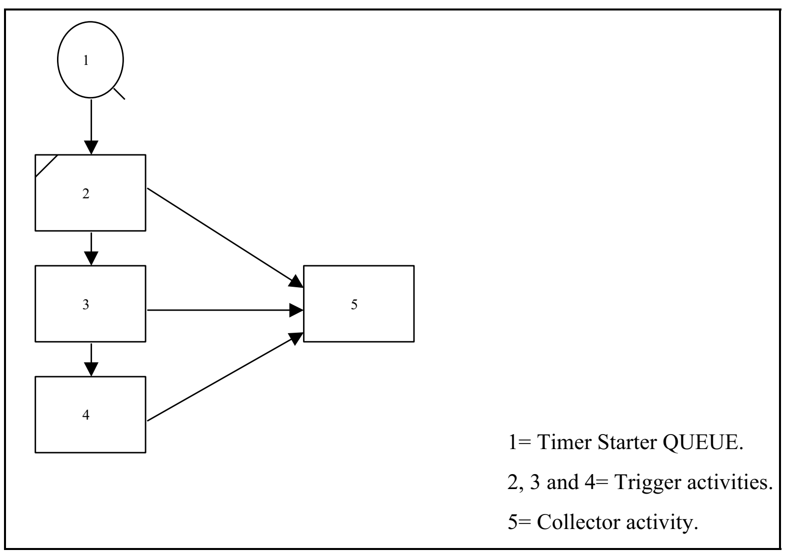

Figure 3: Sample Conventional Simulation Trigger Timer (Kandil 2000).

The second configuration of STT's is the modified STT which was developed for use in project models with probabilistic durations. In this configuration of STT each Trigger activity has a Timer Starter QUEUE. The Trigger activities are not connected to each other, and their durations are equal to the event times of the corresponding occurrences of the Marked Dummy. The reason this configuration of STT was developed was because of the nature of the probabilistic durations and event times. There is no accurate way of subtracting two probability distributions from each other, and this is why the configuration avoids the subtraction Marked Dummy occurrences' event times from each other, and uses these event times directly as probabilistic durations of the Trigger activities (Kandil 2000). An example of this configuration of STT is shown in Figure 4.

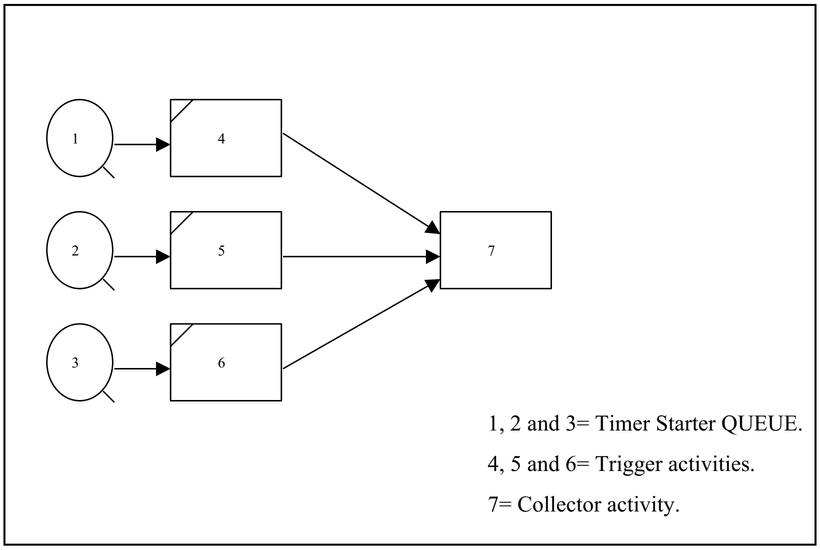

Figure 4: Sample Modified Simulation Trigger Timer (Kandil 2000).

5 CSM APPLICATION

The method in which the above discussed tools are used to formulate cluster to cluster links is undertaken in a number of steps. The first of these steps involves the positioning of these tools to form the type of relation desired between clusters. These relations were previously categorized in this text into Operation to Operation, Operation to Process, Process to Operation, or Process to Process relations (Kandil 2000). The way cluster linking tools are positioned to produce each of these categories of relations is shown in Figure 5.

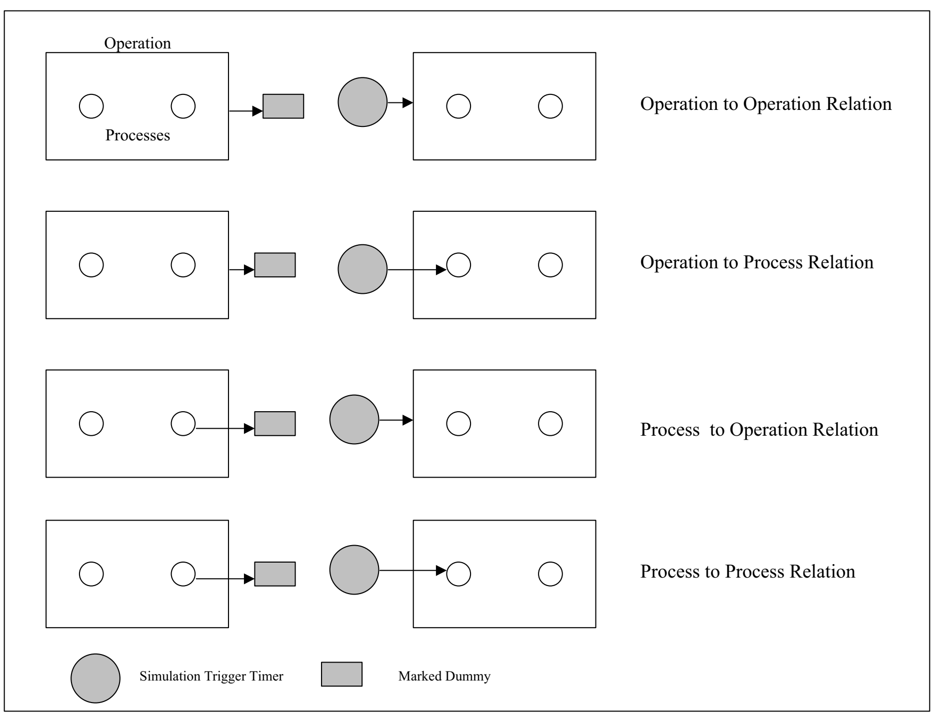

Figure 5: Method of formulation of Cluster to Cluster Relations (Kandil 2000).

The second step of the implementation of the method of linking is the step in which the different clusters of the project are executed. The order in which clusters are executed depends on their type and relation with other clusters. The first clusters to be executed are the Independent clusters, followed by the Intermediate clusters. Intermediate clusters are executed according to their relations with other clusters in their order of precedence. Then finally the Dependent clusters are executed. The sequence of execution of Intermediate clusters in some cases needs to be iterative. This is the case when multiple relations exist between two intermediate clusters, such that some resource sharing processes are executed in order to execute a process in another cluster, while the processes they share resources with are not being executed. In this case the event times of the Marked Dummy are not accurate since there was no competition for the resource. To avoid this inaccuracy intermediate clusters with multiple relations are executed several times until the event times of the different Marked Dummies become constant (Kandil 2000). The following Flow Chart shown in Figure 6 explains the method of implementation of project clusters.

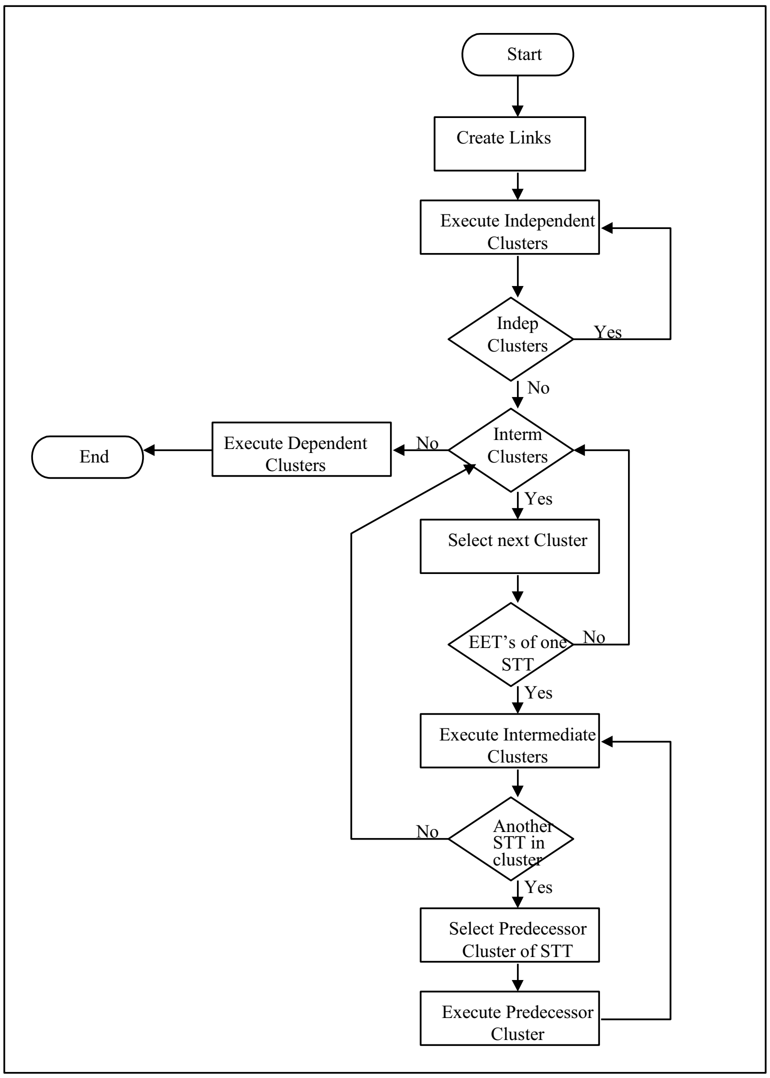

Figure 6: The cluster linking process (Kandil 2000).

The application of this method of linking is affected by whether the model is deterministic or probabilistic. The application of this method is slightly different for projects with probabilistic durations. The main difference in the application of the method for probabilistic and deterministic models is in the number of times each cluster is run. Marked Dummy occurrences' event times are obtained as probability distributions which are represented by the mean and standard distribution of a sample of runs. In order for this sample to represent the population the sample size needs to be greater than or equal to thirty. Therefore each cluster is executed at least thirty times. The implementation of the method of linking would be very tedious this way if the clusters being executed are Intermediate clusters with multiple cluster to cluster relations, since they will be executed iteratively and for each iteration the clusters are going to be executed at least thirty times. To avoid this large amount of work, Intermediate clusters with multiple cluster to cluster relations are executed first using deterministic durations in the STT Trigger activities, and as soon as the durations of these activities start to stabilize the clusters are executed thirty times to obtain the probability distributions of the durations of the Trigger activities (Kandil 2000).

CSM also developed a method of utilizing probabilistic information obtained from probabilistic models. The method developed is capable of calculating the probability of cluster and/or cluster completion at a certain time. This probability can be obtained by sampling the event time of the event understudy and obtaining at least thirty event times. This sample is then used to obtain the mean and standard deviation of the event, which can be safely assumed to be equal to the mean and standard deviation of the population. These values are then used to calculate the standard deviation of a normally distributed population or the (Z) value. This value is calculated by subtracting the mean event time from the time for which the probability is being calculated and dividing the result by the event standard deviation. The (Z) value can then be used to obtain the desired probability.

6 CASE STUDY

The concepts introduced in the previous sections needed to be tested. Therefore simulation models were developed for an actual project that was constructed in downtown Cairo, Egypt. The project was for the construction of a hotel and residential complex, and it is being constructed by a number of multinational firms. The models developed for the testing and validation of the concepts of Clustered Simulation Modeling were for the construction and finishes of the hotel floors 7 to 11. The models developed included operations for Structural works, Finishing works, Electro-mechanical works, and HVAC works. The Structure of this part of the project was made of concrete slabs and rectangular columns, and was constructed using wooden formwork supported on steel props. After a slab's concrete sets the formwork is removed, but some steel props are not removed for structural reasons until the construction of the following two floors is complete. Finishes works can commence in a floor only after the removal of steel props. Finishes works start by the Blockwork and the 1st fix of gypsum board partitions which works in parallel with the fixing of the ceiling frame. After this stage the embedded electrical, plumbing, fire fighting and HVAC works can be installed in the walls and ceilings, and then the second fix of the ceiling and wall works can be complete. The second fix of the ceiling and gypsum board works also precedes the stone and ceramic works, which precedes the finish carpentry works. The plastering works are then executed, followed by the painting works, which is also preceded by the finish carpentry works.

The segment of the CPM schedule representing this part of the project showed that this segment of the project is going to be constructed in 340 days. Figure 7 shows a summary level schedule of this part of the project.

This case study was then modeled using CYCLONE. There were two models developed. The first model simulated the case study as a whole, the second model simulated the project in cluster form. Each of these models was modeled using probabilistic and deterministic durations, and for this reason the clustered model was developed using the Modified STT. There were four operations modeled in this case study. The first operation is the structural operation modeling the construction process of the concrete structure. The second operation is the finishes cluster which represents all the finishes works in the project. The third operation is the electromechanical cluster, which contains the Electrical and Plumbing works. The fourth and final operation is the HVAC operation, which represents both the HVAC and Fire Fighting works of the project. Each of these operations was modeled in a separate cluster. The sequence in which these operations were executed is shown in the Figure 8.

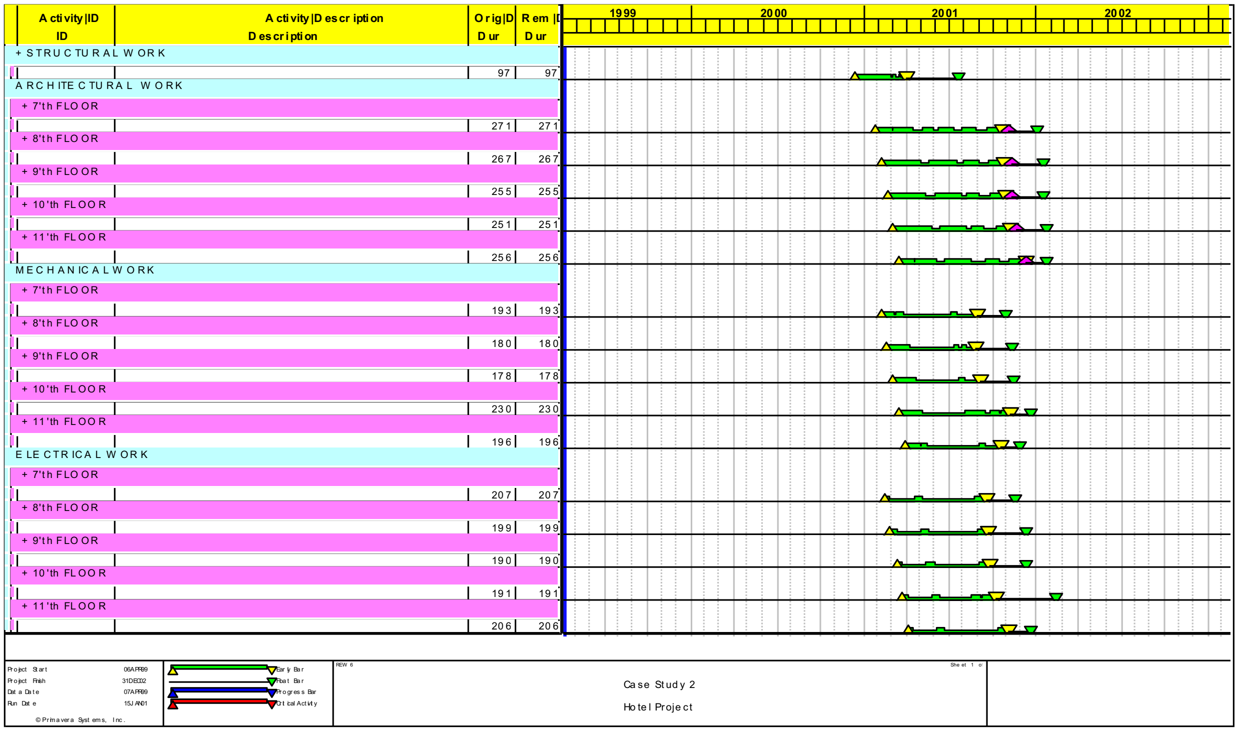

Figure 7: Summary level schedule.

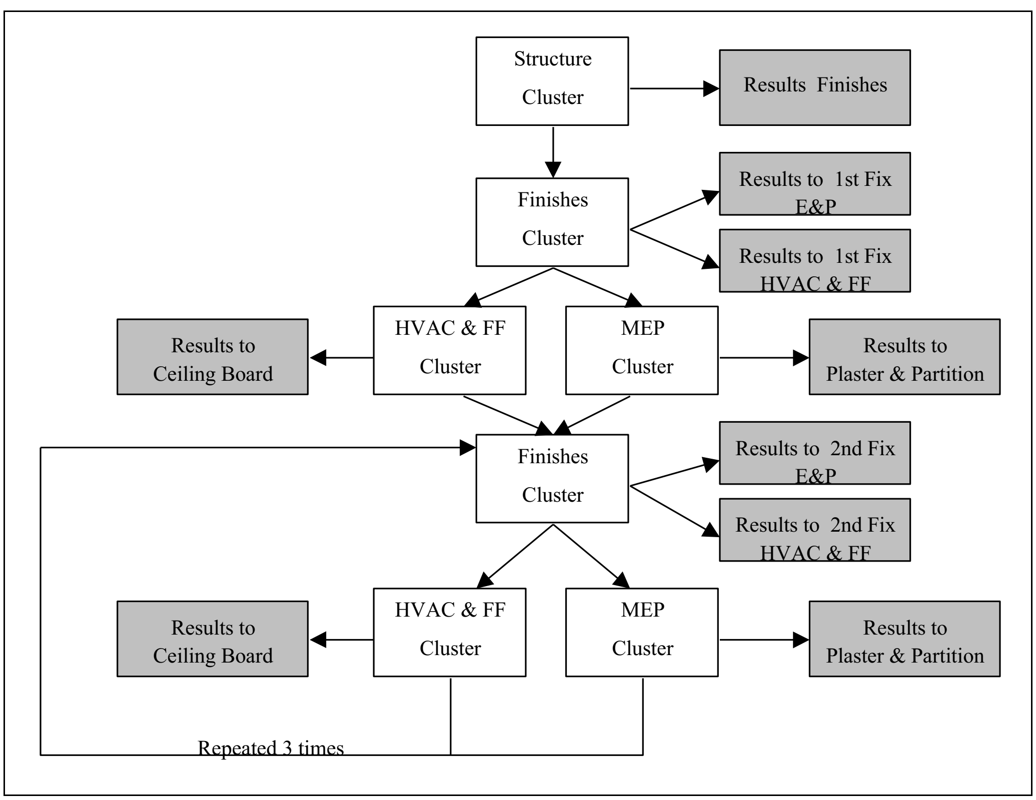

Figure 8: Sequence of cluster execution (Kandil 2000).

The results of the both models in the probabilistic and deterministic application were compared. Table 1 shows the results of the deterministic application of both models.

Table 1: Comparison of Models with deterministic durations.

Operation	Clustered Model			Overall Model		
	Duration	Start Time	End Time	Duration	Start Time	End Time
Structure	108	0	108	108	0	108
Finishes	168	52	220	168	52	220
HVAC	151	78	229	151	78	229
MEP	172	63	235	172	63	235

The results of the probabilistic application of both models were also compared. The comparison of these results is shown in Table 2.

Table 2: Comparison of Cluster completion probabilities.

Method	Operation	Mean	SD	Z	Probability
Deterministic Clustered	Structure	108			
	Finishes	220			
	HVAC	229			
	MEP	235			
Modified STT	Structure	107.51	2.007902	0.244036	0.5948
	Finishes	212.064	5.4832	1.447311	0.9251
	HVAC	219.6003	5.199074	1.80795	0.9649
	MEP	227.475	4.590074	1.639407	0.9495
Overall Model	Structure	108.5143	1.714632	-0.29997	0.3821
	Finishes	210.18	5.299576	1.852978	0.9678
	HVAC	219.43	5.328897	1.795869	0.9706
	MEP	225.3773	5.340077	1.801972	0.9706

7 ANALYSIS AND CONCLUSION

As shown in the results displayed above the results of the clustered model were identical to those of the overall in the deterministic application of the model. The results of the probabilistic application of both models also showed that the probabilities of cluster completion in both models were very close. The comparison of the results of both applications of the two models showed that clustered models are capable of yielding results similar to overall models. Clustered Simulation Modeling, hence, showed that it is capable of enhancing the current features of CYCLONE. CSM provided a method of probabilistically analyzing large projects and obtaining the same information that PERT is only capable of providing for small project networks. The second very important feature of CSM is the reusability of project clusters. Clusters developed for one project can be reused for other projects with a few simple modifications. This feature of CSM would decrease the time planners use in developing project models. CSM however also includes a number of steps in its application in which the modeler has to transfer manually the results of the application of one cluster to another, which leads to the presence of some human errors in the results. The probabilistic calculations of CSM are also performed manually which also may lead to some errors in calculation. For this reason further work should be done on CSM to eliminate any human intervention in the calculations, and to develop the modeling capabilities of CSM beyond the modeling capabilities of CYCLONE.

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