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# AP$^3$ - ADVANCED PROJECT PLANNING PARADIGM FOR CONSTRUCTION

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## ABSTRACT

AP$^3$ is a simulation-based method that provides a framework for modeling large and complex systems. AP$^3$ is geared towards modeling of construction projects, however the underlying philosophy can be adopted for modeling any generic system. Hierarchical and modular modeling constructs form the basis of the modeling methodology. The focus of this paper will be to highlight the enhanced modeling features that form the basis of this method. Logical division of a large system such as a construction project into work components, development of simulation models for the identified components and their internal linkage is the key contribution of this work.

## 1 INTRODUCTION

Simulation of construction processes has been the focus of research for a number of years. Although numerous examples are available in research, where a process is simulated and the desired analysis is performed, the actual use of computer simulation in construction field has remained primarily at an experimental level (McCahill and Bernold 1993). One of the reasons for the under-use of simulation in construction is the lack of a modeling framework for large and complex systems such as construction projects. Riggs (1989) reported that current simulation methodologies do not allow simulation of large projects and that large projects could be simulated by simulating portions of the project such as sitework or concrete floor slab work. Such a fragmented simulation of the construction project would require excessive manipulation to produce an optimum solution. Furthermore, AbouRizk and Dozzi (1993) in their attempt to simulate a bridge project have reported that, they experienced that modularity of the model being developed will help in the overall simulation effort. They also reported that a single simulation model becomes too large to comprehend and work with. This clearly indicates the need to develop a modeling framework for project-level modeling.

Most of the previous simulation-based project planning models were hybrid in nature and generally involved a Monte-Carlo simulation of a project depicted by a network technique (see Ang et. al. (1975), Crandall (1976), Woolery and Crandall (1983), and Ahuja and Nandakumar (1984)). Dabbas (1981), and Dabbas and Halpin (1982) described the development of a simulation technique that provides a planning tool for construction projects coupled with a process level analysis. This technique provides a basic step towards applying simulation to construction projects. The limitation of this technique is that resource allocation is done individually for each cyclic activity. CIPROS, an object-oriented, interactive system for developing discrete-event simulation networks and simulating construction plans, was recently developed by Odeh et al. (1992). CIPROS provides a method by which modelers can divide their work into various steps, but limited hierarchical modeling is achieved. The above mentioned methods basically mimic the network techniques in one form or the other which leads to an insufficient solution.

The major problem with simulating a construction project is the size and complexity of the information to be modeled. It is essential for any proposed simulation modeling framework to allow a simple solicitation scheme of the project information and a structured representation of the large quantity of the project information. For the development of AP$^3$ the authors identified the following important characteristics (AbouRizk and Sawhney 1994):

- The modeling framework should be flexible to model project information for different types of construction and should allow quick and efficient solicitation of the information.

- It should model resources distributed at the project level and internal linkages between processes. It should provide support for modularity and reusability of model components.

In this paper we describe the $AP^3$ modeling framework that addresses these issues. The paper is organized as follows. In Section 2 we provide a general description of $AP^3$. Section 3, 4 and 5 describe the various modeling enhancements that have resulted in the development of $AP^3$. Finally in Section 6 we present our conclusions and research contributions.

## 2 GENERAL DESCRIPTION OF $AP^3$

Under the $AP^3$ scheme simulation of a large and complex systems is performed using the following five steps that are depicted in Figure 1:

1. Develop a hierarchical breakdown by identifying operations and processes.
2. Develop the project resource library by defining the resources allocated to the project.
3. Sequence the identified operations using serial, cyclic, parallel and hammock links.
4. Develop process models to define the project work tasks using CYCLONE (Halpin, 1977).
5. Analyze the project simulation models and produce output.

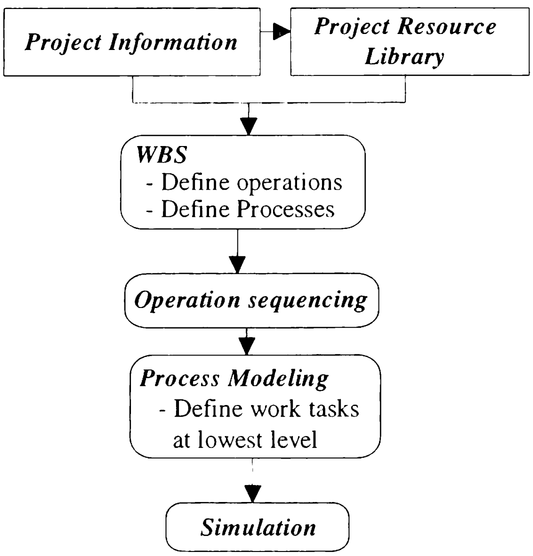


Figure 1: Development of Simulation Models using $AP^3$

## 3 SPECIFICATIONS FOR BREAKDOWN OF THE PROJECT

The breakdown of a project is achieved using the following concepts:

1. Hierarchical work breakdown structure.
2. Definition of modular project components, and
3. Resource definition.

The objective of project breakdown is to divide the project information into manageable units. This involves identification of the work to be performed on the project, identification of repetitive work components (if any) and resource requirements for the project.

### 3.1 Hierarchical work breakdown structure

$AP^3$ utilizes the concept of "hierarchy" of work on a construction project as formulated by Halpin and Woodhead (1976). Under this scheme, the work on a project is divided into the following four levels:

1. Project level is the highest level and the focus at this level is on "gross project attributes" like project cost, schedule, resources, material requirement and other management issues.
2. Operation level is the next level in the hierarchy where the focus is on construction methods and implementation strategy.
3. Process level is the third level with focus on the basic technological sequence of work.
4. Activities or work tasks form the fourth level of the hierarchy with focus on the physical work required for the project.

$AP^3$ uses three constructs namely: "project," "operation" and "process" for project breakdown. Each project contains a root element called project-element. All other elements originate from this element and are its descendants. Operations in the WBS descend from the project or other operations (terms used to describe the relationships in the WBS include parent, child and descendent and have their usual familial meanings). An operation element can have more than one child element attached to it. Children of an operation element can either be other operations or process elements provided that they are of the same category (i.e. all operations or all processes). Process elements form the lowest level of project breakdown. These elements cannot have any descendants. They have one operation element as their parent. A project must have process elements in its work breakdown.

### 3.2 Modularity concepts

$AP^3$ enhances the modeling process of a construction project using modular concepts. Many repetitive technological components can be found in construction projects. These recurring units of work (operations as well as processes) can be combined in modules and referenced in the WBS as needed. This is referred to as modular components in $AP^3$. The concept of modularity for simulation models is covered in detail by Zeigler (1987) and Luna(1991).

### 3.3 Resource Definition

$AP^3$ provides detailed resource modeling capabilities for a given project. Following the natural approach to resource assignment on a project, $AP^3$ defines resources at the project level. These resources are then allocated to various tasks as needed during the simulation experiment. In essence tasks compete for resources which are dynamically updated throughout the analysis.

## 4 SPECIFICATIONS FOR OPERATION SEQUENCING

Operation sequencing allows the modeler to specify the implementation strategy for the project being planned. This information is important to determine the implementation sequence of the underlying processes. On the basis of the construction logic, technology, strategy and resource availability various operations can be sequenced in different ways.

### 4.1 Types of links in $AP^3$

$AP^3$ provides four different types of relationships including serial, parallel, cyclic and hammock.

Serial relationship: This relationship models situations where an operation can start only after the completion of another operation.

Parallel relationship: A parallel relationship between operations basically denotes that the two operations may proceed simultaneously.

Cyclic relationship: $AP^3$ allows use of cyclic relationship for operations. Using this relationship a single operation or a group of serially connected operations can be allowed to cycle. The number of cycles is determined by a "cyclic counter" defined by the modeler.

Hammock relationship: Some operations are independent of all other operations and as such they neither have a serial nor a parallel relationship with other operations. Such operations can be included in the operation sequencing by using the hammock relationship.

### 4.2 Rules governing the use of $AP^3$ relationships

The four links described above provide the modeler with the flexibility to model different scenarios normally experienced on construction projects. However, in $AP^3$ certain rules govern the use of these links to avoid conflicts and reduce redundancies. The governing rules are as follows:

1. Operations with common parents are sequenced in one group.
2. Once an operation has been defined as hammock, no other links can be provided for that operation.
3. For connecting more than one operation by a cyclic link the modeler has to first connect them serially.

## 5 SPECIFICATIONS FOR PROCESS MODELS

Process models are used to model the work tasks in a project at the lowest level. The process models are developed using CYCLONE modeling elements. Two enhancements have been made to the CYCLONE method to allow project level simulation. These enhancements are as follows:

1. modeling of resources which are defined at the project level.
2. modeling of process interdependencies.

The modeling philosophy adopted is the CYCLONE methodology. For a detailed discussion of CYCLONE and its applications, refer to Halpin (1973), and Halpin and Riggs (1992). The CYCLONE modeling elements are shown in Figure 2 with a brief description in Table 1 (source Halpin 1990).

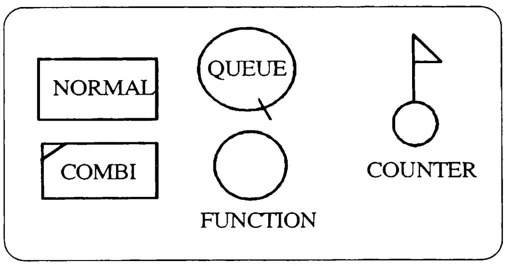


Figure 2: CYCLONE modeling elements

Table 1: Rules for developing CYCLONE models

| Element | Rule |
|---|---|
| NORMAL | This node represents a non-constraint work task. |
| COMBI | This node represents a work task constrained by the availability of more than one type of resource. |
| QUEue | A node where idle resources wait. A resource arriving at a QUEue node will stay in the node until a COMBI is ready to process it. |
| FUNction | New elements can be created at this node. |
| COUnter | A node that keeps track of the number of times a unit passes it. |

### 5.1 Modeling resources at the process level

The resources that are defined at the project level are used to perform the tasks that are identified in the process models. Resources can either be linked to one process or to a number of processes. When the resource is assigned to more than one process a priority is provided to each process which determines the allocation of the resource during simulation.

Traditionally, modeling of resources in CYCLONE is done by initializing resources at appropriate QUE nodes in the process model. Though this strategy provides a simple method of modeling resources for the individual process, it does not facilitate modeling of shared resources across processes. In order to overcome this modeling difficulty two modeling elements are defined. The first element is called an Allocate Resource element and is an extension of the QUE node. In a process model a COMBI that requires a resource defined in the resource library is preceded by the Allocate Resource element. This element acts as a special QUE, that checks the availability of the specified resource. The Free Resource element belongs to the FUNCTION base class. The allocate and free elements normally work in conjunction. A Free Resource element is used for every Allocate Resource node if the resource has to be released back to the resource library. However, it is feasible to provide an allocate node without a corresponding free node. In this case the resource will be allocated and will not be released back to the resource library. The graphical representation of both elements is provided in Figure 3.

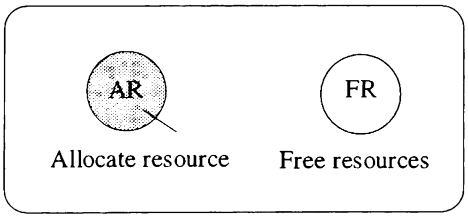


Figure 3: $AP^3$ Resource Nodes

Figure 4 shows an illustration of the use of the Allocate Resource node and Free Resource node for a process model. In the figure it can be seen that before the entity arrives at the COMBI node, the Allocate Resource node tries to allocate the designated resource. If the resource is available then the entity is processed otherwise the entity waits in the Allocate Resource node in a fashion similar to a QUE node. It should be noted that the Allocate Resource node (which is a special type of QUE) replaces the QUE node before the COMBI in this particular scenario.

### 5.2 Modeling process interdependencies

Two or more processes that have a common parent operation in a project can be linked together using the process interdependency links. In traditional planning methods, since the work tasks are defined at a common level these relationships are implicitly modeled by activity relationships. In $AP^3$ the modeler defines separate process models and links them explicitly. The process interdependency links work in conjunction with the operation sequencing defined at the operation level and ultimately provide the linkage between all processes.

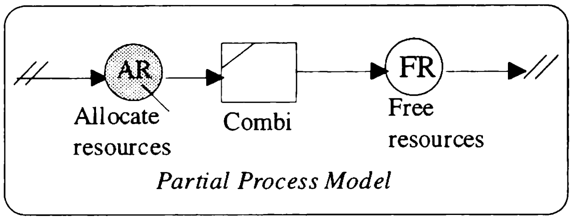


Figure 4: Illustration of Resource Nodes in a Process Model

$AP^3$ utilizes the concept of class IV control structure as defined by Halpin (Halpin and Woodhead, 1976). Figure 5(a) shows a general form of class IV control structure as depicted by Halpin (Halpin and Woodhead, 1977) and its adaptation in the proposed method.

In Figure 5(a) it is shown that process-2 can only start when a release entity is available at the control QUE that links it with process-1. In the proposed planning method a similar approach is required to link the processes. The link is achieved using two elements as shown in Figure 5(b).

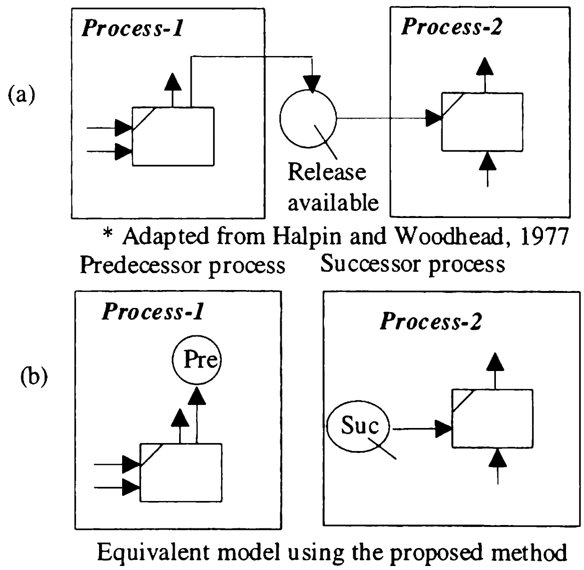


Figure 5: General Form of Class IV Control Structure

The two elements explicitly model the inter-process dependencies and are termed as Predecessor element and Successor element. Figure 6 shows a graphical representation of both elements.

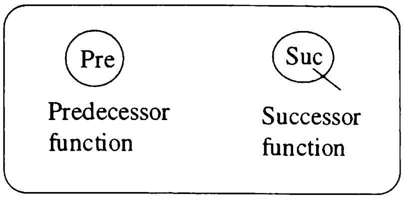


Figure 6: $AP^3$ Process Interdependency Elements

The Predecessor element belongs to the FUNCTION base class and is used in the predecessor process. It can be placed after a COMBI, NORMAL, CONSOLIDATE, FREE RESOURCE or a FUNCTION. Multiple processes can be linked from the same Predecessor element. The Predecessor element can release entities to one or more successor processes.

The Successor element belongs to the QUE base class and replaces a simple QUE that initialize control units or consumable materials or construction components in the successor process. A process can have one or more Successor elements, but these should be linked to different processes. Control to the Successor element is only released when the required quantity or cycles of the predecessor process have been completed.

## 5 CONCLUSIONS

This research has resulted in the following major contributions:

1. Development of a framework for project level information representation that will facilitate computer simulation analysis.
2. Simplification of simulation modeling through graphical user interface.

Enhancements to the work breakdown structure has been achieved to better model the project scope. Through the use of modularity this enhancement has greatly simplified the task of planning.

Through enhancement to CYCLONE process modeling method an efficient and simple environment for simulating all the processes on a project has been achieved. CYCLONE method has been enhanced to provide features like multiple process interaction and resource identification.

$AP^3$ provides an efficient and realistic approach to planning of construction projects. The authors envision that the proposed method will prove to be an efficient tool for project planning. The key factors for this efficiency are as follows:

1. the method allows demarcation of the project information into logical and manageable packages.
2. the method is driven by the dynamic allocation and utilization of resources.
3. it allows advanced facilities not afforded by traditional tools like CPM and PERT. For example $AP^3$ unlike the traditional tools allows cycling of operations and reusable modular model components.

$AP^3$ was used by the authors to plan a bridge project that was constructed in Alberta, Canada (for more details see Sawhney 1994). The modeling framework of $AP^3$ was found to be adequate for modeling a real construction project. The study demonstrated that project level simulation is feasible. The experimentation also demonstrated some potential benefits of a simulation-based project planning method.

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## REFERENCES

AbouRizk S. M. and Dozzi S.P. (1993). "Applications of Simulation in Resolving Construction Disputes" Journal of Construction Engineering and Management, ASCE, 119(2), 355-373.

AbouRizk S. M. and Sawhney A. (1994) "An information modeling methodology for simulation based project planning", Annual Conference of the Canadian Society of Civil Engineering, C.S.C.E., Winnipeg, Manitoba, June 1994, (in press).

Ahuja, N.H., and Nandakumar, V., (1984). "Simulation model to forecast project completion time." Journal of Construction Engineering and Management, ASCE, 111(4), 325-342.

Ahuja, N.H., and Nandakumar, V., (1985). "Simulation model to forecast project completion time." Journal of Construction Engineering and Management, ASCE, 111(4), 325-342.

Ang, A.H.S., Abdelnom, J. and Chaker, A.A. (1975) "Analysis of Activity Networks under Uncertainty", Journal of Engineering Mechanics Division, ASCE Vol. 101, No. EM4, pp 373-387.

Crandall K.C. (1976), "Probabilistic time scheduling", Journal of Construction Division, American Society of Civil Engineers, Vol. 102 No. CO3, pp 415- 423.

Dabbas M. (1981) "Computerized Decision making in Construction", Ph.D. thesis presented to the Georgia Institute of Technology, Atlanta, Georgia, in partial fulfillment of the requirements for the degree of

Doctor of Philosophy.

Dabbas M. and Halpin D. W. (1982). "Integrated Project and Process Management" Journal of the Construction Division, ASCE Vol. 109 No. CO1:361-373.

Halpin, D. W. (1973). "An Investigation of the Use of Simulation Networks for Modeling Construction Operations" Ph.D. thesis presented to the University of Illinois, at Urbana-Champaign, Illinois, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Halpin, D. W. (1977). "CYCLONE: Method for Modeling of Job Site Processes" Journal of the Construction Division, ASCE, 103(3):489-499

Halpin, D. W. (1990). "MicroCYCLONE User's Manual" Division of Construction Engineering and Management, Purdue University. West Lafayette, Indiana.

Halpin, D. W. and Riggs L.S. (1992) "Planning and Analysis of Construction Operations" Wiley Interscience. New York, N.Y.

Halpin, D. W. and Woodhead, R (1976) "Planning and Analysis of Construction Operations" Wiley Interscience. New York, N.Y.

Luna, J. (1991). Object Framework for Application of Multiple Analysis Paradigms. Object-Oriented Simulation 1991, Simulation Series Volume 23, Number 3, 81-86.

McCahill, D.F. and Bernold, L.E. (1993) "Resource-oriented modeling and simulation in construction", Journal of Construction Engineering and Management, ASCE, 119 (3), 590-606.

Odeh A.M., Tommelein I.D., and Carr R. I. (1992). "Knowledge-Based Simulation of Construction Plans" Proceedings of the Eighth Conference on Computing in Civil Engineering, ASCE, Dallas, Texas. 1042-1049.

Riggs, L.S. (1989). "Risk Management in CPM Network", Microcomputers in Civil Engineering, Elsevier Applied Science, Vol. 3, No 3 pp 229-235.

Sawhney, A. (1994) "Simulation-based planning method for construction". Ph.D. Dissertation, Department of Civil Engineering, University of Alberta, Edmonton, Alberta, Canada.

Woolwry J.C. and Crandall K.C. (1983), "Stochastic network model for planning scheduling", Journal of Construction Engineering and Management, American Society of Civil Engineers, Vol. 109, No. 3 pp 342 - 354.

Zeigler, B.P. (1987). "Hierarchical, Modular Discrete-Event Modeling in an Object-Oriented Environment", Simulation, November 1987, 219-230.

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