A SINGLE ELEMENT BASED MODELING APPROACH FOR SIMULATING CONSTRUCTION OPERATIONS

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Construction simulation has been around for over 50 years, yet it remains largely constrained in academia instead of being widely adopted in industry. To remedy the incapability of network-based modeling and simulation tools to address complex model associations and interactions that are beyond causal relations, a new modeling method that replaces network with programming statements is proposed in this dissertation.

This proposed method uses only one type of model element. The single type of model has an explicit four-state pattern, which represents a simplest repeated process, namely atomic process. Construction operation is broken down into such details that can be represented by multiple atomic process models.

Model relations are represented by "Prerequisites" and "Functions" that enable logic programming. Modeling of complex model relations and interactions are achieved with: 1) uniformly designed model structure, 2) specifically suited programming statements, and 3) embedded model data that enhances model transferability and exchangeability.

Two model templates for Activity Process and Resource Process are drafted for quick construction operation modeling task.

The proposed modeling and simulation methods are implemented with a computer program using Object-Oriented language (C#) and this program is validated by comparing the equivalent simulation results from ABC-SIM.

Example shows using uniformly designed model structure and programming statements instead of network enhances modeling flexibility and sophistication. Some logics like queuing priority can be modeled with ease using the proposed modeling method, which is not possible for pure network-based methods.

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CHAPTER 1. INTRODUCTION

1.1. BACKGROUND

1.1.1. LEVELS IN CONSTRUCTION MANAGEMENT

A construction process utilizes numerous resources to realize a designed facility – building, highway, airport, tunnel, bridge, etc. The organization and application of these resources can be viewed from the level where decisions are made. A hierarchical structure is commonly used in construction describe the level of decisions on resource utilizations (Halpin 1992), i.e., organization, project, operation, process, and task levels.

The organizational level is concerned with a firm's legal and business structure, various business functions, and interactions between the main offices and field offices. Project level is related to project scope, contract specifications, product definition, breakdown of the project objectives, and also, cost, time and resource control, etc. Operational level focuses on construction methods. It involves applications to achieve construction objectives, and synthesis of construction processes. Process level is activity focused and consists of collections of tasks. It is the recognizable portion of a construction operation. Task level is about fundamental field action and work units. Work is assigned to specific personnel at task level.

1.1.2. OVERVIEW OF A CONSTRUCTION PROJECT

A construction project could be considered a multi-stage and dynamic system in which designed infrastructure or facility is assembled through concurrent or sequential activities under management supervision. Construction materials needed for the project are acquired through procurement, and specialized labor forces and equipment are

employed. Usually a construction project is under a tight schedule with limited budget. The end result of the project - building or other facilities - is set at specific location where construction activities are geologically, legally and environmentally feasible. After delivery and acceptance of the final product, the contractor gets a full reimbursement to cover profits, salaries, fees, payments to subcontractors, overhead, depreciation, tax, etc. Each construction project is temporary, unique and location specific in nature.

1.1.3. REPETITIVE CONSTRUCTION PROCESSES

A construction process is defined as a unique collection of tasks, which are related to each other in certain sequential or structural order. A construction process represents a readily identifiable segment of a construction operation.

Many construction processes are highly repetitive by executing identical sequences of tasks. The repetitive process results in the completion of a definable piece of construction.

1.1.4. DETERMINISTIC METHODS FOR CONSTRUCTION PROJECT PLANNING

Deterministic planning and scheduling tools have been widely used for construction project planning. The Critical Path Method (CPM) is a planning and control technique that provides an easily understood picture of the project. One of the most important features of the CPM is the logic diagram. The logic diagram graphically portrays the relationships between project activities. Gantt chart (bar chart) is a visual tool for scheduling and planning tasks and is widely used for its simplicity, ease of preparation, and graphical format. Normally the activities are listed in chronological orders according to their starting date. Though widely accepted in the industry, CPM and

Gantt chart do not take into consideration the dynamic and random nature of activity duration in a construction operation. Instead, a deterministic estimate is commonly used.

1.1.5. STOCHASTIC METHODS FOR CONSTRUCTION PROJECT PLANNING

Time, cost and quality are important factors to measure the performance of a construction project. Before a construction project starts, a carefully designed construction process and system simulation can be used to illustrate the whole construction project, to assist in estimating the project cost and time, to provide a more practical schedule, and to detect potential problems to assure the project to be completed on time, cost and designed quality.

For its advantage of addressing random and stochastic factors, such as operating status of equipment and weather conditions, simulation was introduced as a planning tool. Computer simulation is the process of designing a mathematical-logic model of a real system and experimenting with this model on a computer (Pritsker et al. 1997). Discrete event simulation was introduced to benefit construction project planning and resource management from stochastic perspective.

General-purpose simulation systems (or languages) can be used to model and simulate almost any time-related processes. Numerous researchers have reported their applications in construction. (e.g., Teicholz 1963, Moavenzadeh and Markow 1976, Carr 1979, Ioannou 1984, and etc.) However, building a model for a given construction operation or process from the scratch with a general-purpose simulation tool takes a tremendous amount of time and effort. Considering the temporary nature of a

construction project and the uniqueness of each product, it is usually too costly to use in most construction projects.

The construction industry is rather reluctant to adopt simulation. Research has showed a great potential of tools in aiding construction project planning and scheduling, by allowing the user to experiment with various resource allocation strategies and different construction methods. One reason for a slow adoption of simulation in construction could be the high requirements for the user to be proficient in both simulation technology and field knowledge, which requires years of work experience and technical training.

1.1.6. GRAPHICAL REPRESENTATION METHODS FOR CONSTRUCTION SIMULATION

Since Activity Cycle Diagram (ACD) was introduced for modeling a dynamic process (Tocher 1963), graphical representation approach is used for implementing activity scanning method of discrete event simulation execution. ACD is a network model of the logical and temporal relationships among activities. After CYCLONE was developed by Halpin (1973), construction simulation has been advancing with computer technology and several construction simulation tools have been developed by identifying the involved entities of construction operations and representing the entities with graphical symbols (INSIGHT by Paulson 1978, RESQUE by Chang 1987, UMCYCLONE by Ioannou 1989, CIPROS by Tommelein and Odeh 1994, STROBOSCOPE by Martinez 1994, ABC by Shi 1999, SIMPHONY by AbouRizk 2000, etc.). The sequential relationships among the symbols are represented by a network. A sequential network is an effective tool for construction planning and scheduling.

Continuous research efforts were reported to enhance construction modeling and simulation capability. DISCO (Huang et al. 1994) and COOPS (Liu and Ioannou 1992) provide graphical interfaces to allow the user to construct a simulation model by manipulating graphical symbols on a computer screen. Halpin et al. (1990) studied model reusability. McCahill and Bernold (1993) developed a library consisting of standard simulation models that include widely used construction processes. HSM (Sawhney and AbouRizk 1995) introduced a hierarchical approach for project level modeling and simulation. Shi and AbouRizk (1997, 1998a) presented the resource-based modeling method to automate the modeling process for specific types of construction processes.

1.1.7. USING NETWORKS TO REPRESENT MODEL RELATIONS

In available construction modeling and simulation systems, networks that are made up of model elements and arrows can be visually evaluated by examining the logic flow as it goes through the defined network to reach each model element. Entities flow through the network during animated computer simulation, which can also help user to identify errors in their models.

Model elements, or “nodes” in a network, are symbols connected by arrows. CYCLONE (Halpin 1973) uses a small number of nodes (Normal Activity, Queue, Combi, Consolidator, Generator, and Counter) and simple rules (like Combi priorities) to model construction operation.

A typical network is illustrated in Fig. 1:

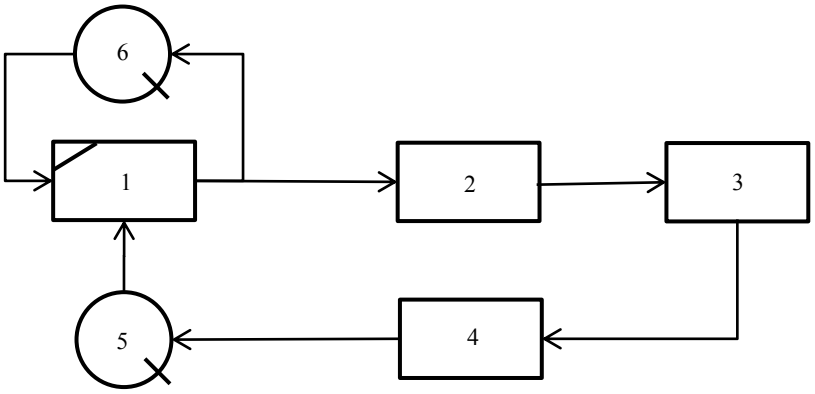

FIGURE 1: DESCRIBE MODEL RELATIONS WITH NETWORK (CYCLONE)

Network can only represent causal relationships, i.e., Combi 1 happens before Activity 2 is the "reason" or "precondition" of Activity 2, which limits the representing of model relationship to 2-dimension.

1.1.8. USING FUNCTIONS TO DESCRIBE MODEL RELATIONS

A system can be described by simulation languages with General Purpose Simulation tools. Rules of model interactions are summarized as functions (or namely "methods" in some programming language). The functions can be mathematical algorithms, logical conditions, event triggering / listing, etc. Functions are much more flexible and robust than pure network in describing model relations; however, they are confined to being used by experienced programmers, and the cost to build a complete construction process model is relatively high compared to traditional deterministic construction planning and scheduling tools and specialized construction simulation packages.

Modeling relations with functions is described in Fig. 2:

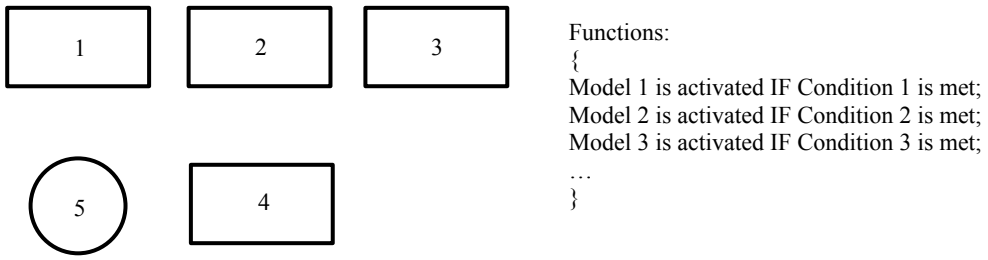

FIGURE 2: DESCRIBE MODEL RELATIONS WITH FUNCTIONS

Functions (Methods) are particularly associated with each model in object-oriented simulation languages, which can be illustrated in Fig. 3

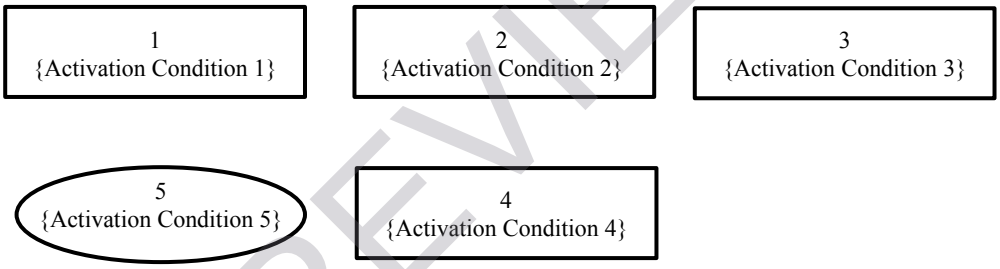

FIGURE 3: DESCRIBE MODEL RELATIONS WITH FUNCTIONS IN OBJECT-ORIENTED LANGUAGES

Advantages of using programming function over network lie within its flexibility of representing model relationships.

1.2. PROBLEM STATEMENT

All existing construction simulation systems use a network to represent a given construction process. Network can only represent causal relationships, i.e., “A” event / activity is the “reason” or “precondition” of “B” event / activity; however, in reality, lots of factors affect event / activity by enhancing or diminishing it, which is beyond the

scope of causal relationship. If considering the factors beyond the scope of causal relationship in a network, either the system becomes impossible to model, or the modeled system is too bulky to be examined and validated. This makes modeling of factors that affect construction operation, like weather, fatigue of workers, etc. very difficult or even impossible with pure network-based approaches.

There is a need to develop a new modeling method for simulating construction operations addressing the complex relations of model elements by using programming statements over network to represent model relations.

1.3. OBJECTIVES AND SIGNIFICANCE

1.3.1. RESEARCH OBJECTIVES

The purpose of this research is to remedy the limitation that lies within network-based models: 1) rigid logic chain that over-simplifies real world situation; 2) limited area of application that fits into the network framework; 3) bulky model if taking into consideration logics beyond sequential relationship.

The result of this research is a new modeling approach specialized for simulating construction operations that addresses complexity of model relations. Following objectives need to be achieved: 1) Precisely defined model elements that can interact with each other by describing the model behaviors with programming functions, so the structure of models can be more flexible; 2) Well suited programming statement for use of this modeling method under construction scenario that expands application area; and 3) Uniformly structured model data that enhances model reusability and model independency.

Specifically, the proposed modeling method uses only one type of model element as an abstraction of a simplest repeated process within a system, or an atomic cyclic process. This simplest process is modeled first with detailed specifications. The relationships of model elements are described by programming statements. A large construction process is represented by a combination of multiple atomic processes.

In addition, as a modeling method tuned specifically for simulating construction operations, two template models for activity process and resource process are provided for convenient construction related modeling applications.

Specific objectives in this research include:

1. Develop the modeling methodology with only one modeling element.
2. Provide detailed model specifications for single model elements to resemble a simplest repeated process.
3. Develop model interaction mechanism that enables logical programming.
4. Develop programming statements that are suited for this modeling method.
5. Provide the unified structure of model data.
6. Provide model templates for simulating construction operations.
7. Demonstrate the modeling method with construction examples.
8. Implement the modeling method with computer software.
9. Validate the results from the new method by comparing them with results from other construction simulation systems.

1.3.2. TARGET USERS OF RESEARCH PRODUCT

As a construction modeling and simulation tool, the research results are intended to provide guidance for model developers and users. As shown in Fig. 4. Diamond shapes

indicate that computer techniques and tools are involved. Rounded rectangle shapes indicate target users. Shaded shapes mean their detailed contents are covered in this dissertation.

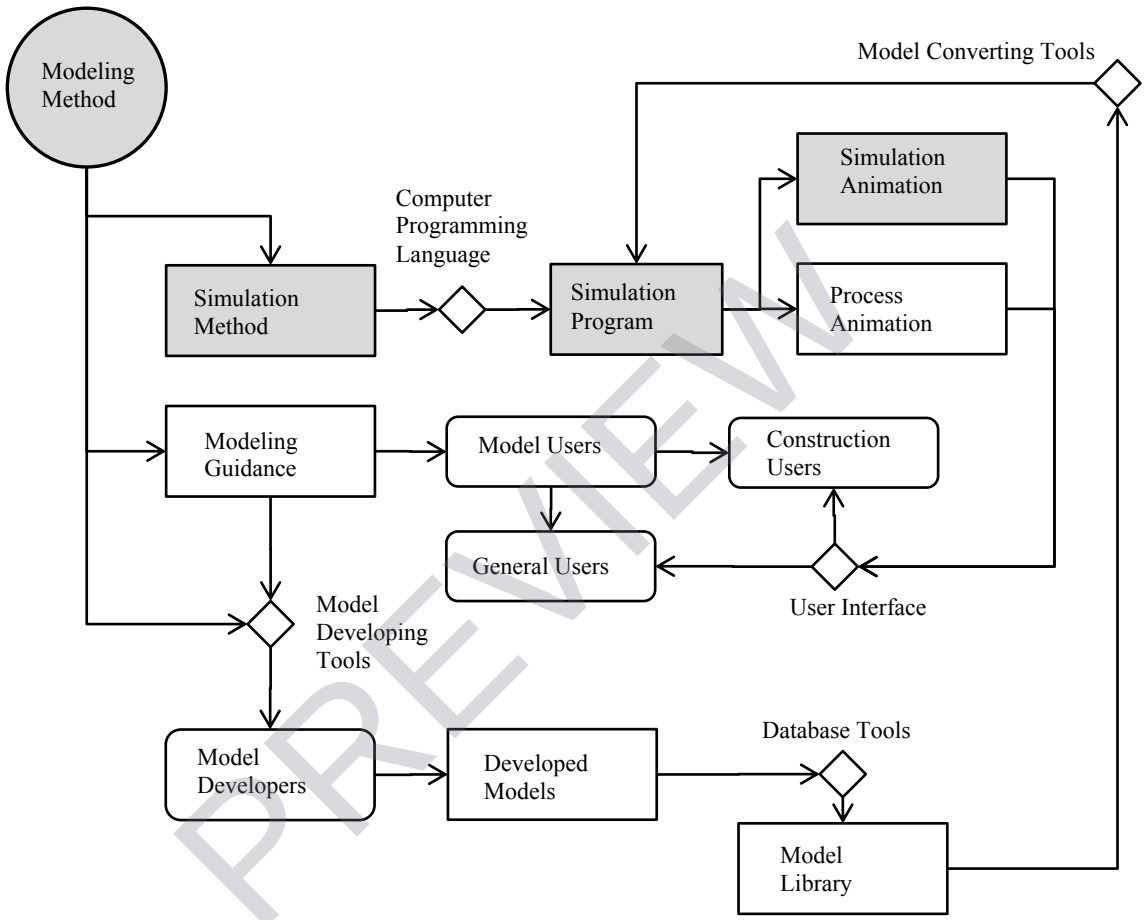

FIGURE 4: TARGET USERS OF THE RESEARCH PRODUCT

1.3.3. SIGNIFICANCE

This method provides a flexible and robust modeling experience, not only by defining relations of model elements with logical descriptions rather than networks, but also by employing only one type of model element, which can be modeled first

individually, and then assembled into a large process. This “Lego-like” approach potentially lowers the threshold of construction simulation by 1) allowing model builders to start modeling a breakdown of process first rather than the entire process first, 2) providing template atomic process models that can be readily used under construction scenarios, 3) promoting model reusability and data exchangeability by associating simulation and project information to individual models that can be re-used in other modeling project with minimal revising efforts.

1.4. DISSERTATION OUTLINE

Chapter 1 gives an overview of construction project management tools and techniques, highlighting construction simulation by introducing their potency, applications, related academic efforts, limitations, etc.

Literature review is presented in Chapter 2 with a summary of research activity in construction management, computer techniques, and modeling / simulation methods for justification of identified research. It is organized to introduce construction planning and scheduling tools, computing techniques related to this research, simulation and its history, modeling and simulation methods and their applications in construction.

Chapter 2 is a detailed presentation of the proposed methodology.

Modeling and simulation of sample construction operations are presented in Chapter 4. Two basic model templates are created and tailored for construction related problems.

Chapter 5 describes the implementation of the method on the computer using an object-oriented programming language.

Chapter 6 uses a case study to validate the modeling and simulation method by comparing the obtained results with results from ABC-SIM.

Chapter 7 summarizes the research work, its contributions, limitations and future work.

CHAPTER 2. LITERATURE REVIEW

2.1. CONSTRUCTION PLANNING AND SCHEDULING

2.1.1. CONSTRUCTION PLANNING AND SCHEDULING METHODS

Planning is the process of drawing out methods and considering alternatives to complete a project. Planning creates an orderly sequence of events, and defines the principles to follow in carrying out the plan. It serves the manager by pointing out the tasks in scope, their sequence, and how long each task should take. The goal of planning is to optimized resource expenditures while satisfactorily completing a given task. Planning aims to produce an efficient use of equipment, materials, labor, etc. and ensure coordinated effort.

2.1.1.1. Work Breakdown Structure

Construction managers employ practices, principles, and techniques that are derived from earlier concepts and experiences. People utilize Frederick Taylor (1856 - 1915)'s concept of breaking work into elementary parts: the work breakdown structure used for scheduling and cost control. Henry Gantt, an associate of Taylor developed the Gantt chart (bar chart). This is a visual tool for scheduling and planning work tasks. Gantt