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A FRAMEWORK FOR ACTIVITY-BASED CONSTRUCTION MANAGEMENT SIMILATION

Boong Yeol Ryoo, Ph.D.

Assistant Professor, Department of Construction Science, Texas A&M University, U.S.A.
Correspond to bryoo@tamu.edu

ABSTRACT: Due to various project delivery methods and the complexity of construction projects in the construction industry, developing the framework of construction management for critical, highly complex projects in the construction industry has become problematic. Currently, a set of construction manuals play a pivotal role in planning and managing construction projects as subcontractors try to complete their scope of work according to the instructions of a general contractor. It is challenging for general contractors to write a construction management procedure manual to cover various types of project delivery methods and construction projects. In construction, the construction procedure manuals describe specific actions to be taken through the project. In reality a few contactors own such manuals and their construction schedules include more construction operation activities. Thus, it is hard to estimate the workload and productivity of construction managers because the manual and the schedule do not present the amount of management efforts required to complete a project. This paper proposes a framework to present construction management tasks according to project delivery methods which can be applied to various construction projects. Actions for management tasks were mapped and were integrated with construction activities throughout the project life cycle. The framework can then be used to give specific instructions to project participants, collect management actions, and replicate management actions throughout the project life cycle. The framework can also be can used to visualize complete construction project to analyze and manage construction management activities in each phase of a project in order to enhance productivity and efficiency. The studies of existing construction manuals were carried out to identify construction managers' responsibilities. An artificial intelligence program, CLIPS (C-Language Integrated Production System) was used to search for appropriate actions for impending tasks from a set of predefined actions to be performed for a given situation. The framework would significantly help construction managers to understand interrelations among management tasks or actions within a project. Furthermore, the framework can be embedded into Building Information Modeling (BIM) or Facility Management Systems (FMS) so that designers and constructors would execute constructability review before construction begins.

Keywords: Construction Management, CM simulation, Artificial Intelligence, CLIPS. CM Task Map

1. INTRODUCTION

1.1 Introduction to Simulation in Construction

Simulation has been used as an effective tool in a variety of industries such as science, technology, entertainment, and business to resolve complex situations within uncertainty [11]. Simulation models enable us to analyze trends and patterns prior to considered situations by predicting intricate and diverse real-work processes in advance. Especially, as construction projects become more complex, complicated, and competitive, it is essential to identify potential project risks during design or pre-construction phase and to estimate the negative impact of the risks on the project. It is also a crucial step to achieve intended project goals on the subject of scope management, time management, cost management, quality management, and safety management efficiently.

In construction, Halpin [7] developed CYClic Operations Network (CYCLONE) modeling system for construction operations simulation based on Activity Cycle Diagram (ACD). However, the system was considered to be impractical and improper modeling by non-programmable simulation approach [12]. Even though the system had problems, the CYCLONE modeling framework has been adopted as a basic construction simulation tool for a variety of construction production modeling for over 20 years. Huang[8] has proposed Deployable Intelligence Simulation for Collaborative Operations (DISCO) to design and observe the results of simulation models graphically by adding visual features to CYCLONE. After a few evolutions of

simulation technologies, a simulation language of construction operations based on State and Resource (STROBOSCOPE) was developed. STROBOSCOPE enables users to develop complicated construction process simulation models effectively by using activity scanning simulation paradigm and Activity Cycle Diagram (ACD) [13]. The Activity Based Construction (ABC) modeling and simulation method using construction activity as the only key factor was proposed by Shi [19] which is beneficial when the modeling of general construction processes are considered. Agent Based Modeling and System (ABMS) is a latest developed application compared to other applications. It is an agent based framework that provides solution for supply chain coordination in construction through multi-attribute negotiation mechanism on the internet [21]. Additionally, a variety of applications have been developed such as INSIGHT [17], RESQUE [1], UMCYCLONE [9], and CIPROS [20] and so forth.

1.2 Problem Statement

Construction Management becomes an alternative project delivery method in the competitive global construction market. Although productivity has been a continuing issue in the construction industry, construction simulation has been focused on construction operations rather than construction management activities. In order to complete a project successfully, it is vital to define management tasks in accordance with the project delivery methods, the responsibility of construction managers, and the procedures of the tasks or subtasks for the project. It is also necessary to measure the performance of management activities in order to simulate multilayer construction management activities executed by participating organizations.

The formulation of construction activities is subject to continuing debates. Most systems are limited to academic experimentation because of the complexity and difficulty of the nature of construction [10]. Also, existing models focus on construction activities rather than construction management activities. In recent construction industry, the scope of work and responsibility of construction management members become more important since various project delivery systems are being implemented. Construction managers are not only helping contractors but also have a variety of management responsibilities throughout the project life cycle such as planning, design, procurement, and construction [5].

This paper proposes a framework for Activity-Based Construction Management (ABCM) simulation using construction operations and construction management activities. The proposed model can be used to analyze the status of construction management. It is also helpful for project planners to predict potential risks prior to project initiation. And it can be used to replicate construction management (some word is missing here) throughout the project. The proposed model can also be used as a teaching tool as it allows users to suggest actions to complete work orders which are management activities. It allows quantifying the amount of workload, the resource requirements, and the impact of management activities.

2. APPROACH

In construction simulation, mathematical models have become old-fashioned because of its limitation in representing management activities. Due to enhanced management techniques and computerization, a non-mathematical model is required for construct management activities to be measured. This research focuses on the development of a framework for non-mathematical simulation in construction management. Thus, users will be able to construct multidimensional management models without prior knowledge of built-in programming languages. It is also designed to capture management activities using an artificial intelligence program, C Language Integrated Production System (CLIPS). This research includes 3 elementary studies to achieve the proposed research objectives.

(1) Study of construction management practices in the industry: It is to formulate a standard format of management process throughout the project life cycle. A construction management task matrix of construction management activities and contractual responsibilities will be developed.
(2) Propose the scope of work and level of responsibility matrices based on the project delivery methods in the industry. It is considered in order to define the structure of management and operation processes for construction management. Line items of construction management and construction operation activities will be combined.
(3) Propose approaches to capture information generated during simulation.
(4) Study of business process(es) reengineering and reverse engineering technologies. It is included in order to downsize multidimensional management spaces into two dimensional spaces.

3. IMAGES OF CONSTRUCTION MANAGEMENT

3.1 Framework of Construction Management

Construction Management (CM) is a project delivery method that uses construction managers to facilitate the design and construction activities by organizing and directing manpower, materials, and equipment to accomplish the purpose of the designer. It requires the implementation of effective management techniques in the planning, design, and construction of a project from inception to completion to control time, cost, quality, and safety as defined by the Construction Management Association of America [4]. CMAA identified about 200 activities have been identified as basic construction management services for construction practitioners [3].

Two types of tasks, construction operation and construction management are major elements of construction project management. A Work Breakdown Structure (WBS) is used to identify all elements of project deliverables and line items are used to identify

management tasks required to complete the project deliverables. Generally, general contractors use construction management procedure manuals to describe appropriate actions and procedures for the management tasks.

In order to define the interrelationships between management processes the management tasks must be formulated into data flow diagram. Figure 1 shows how the management tasks are organized. The management process of administrative tasks, i.e. project administration, is often referred to as workflow management as described in Figure 1. In practice, scheduling, costing (accounting), and contracting (procurement) are handled by different individuals or departments. These tasks should be tied together for efficient management. The workflow management scheme controls actions taken on documents moving through a business process. Thus, through workflow management, construction planners know how jobs flow through an organization

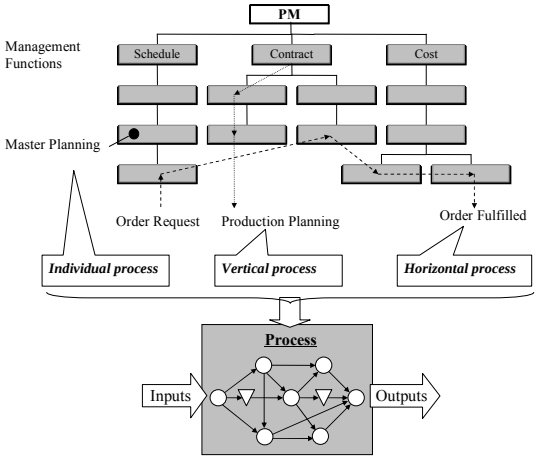

Figure 1 Property Template Image of Process Model

Figure 2 shows a framework of the proposed CM Task Map for a construction project. The map has five major functions such as CM Tasks, Sequences, Inputs/Outputs, Methods and Tools as described in Table 1. "CM Tasks" contains construction management tasks and associated subtasks identified based on a project delivery method selected. At least one responsible party is assigned to each task or subtask and the level of responsibility is described. "Sequences" shows line items in the right order for the project. The tasks and subtasks from "CM Tasks" will then be arranged by the right order as defined in "Sequences" and then become "Task Schedule." "Task Schedule" is also a list of prioritized activities based on input or output information required. "Inputs/Outputs" is to define information required to take actions and expected outcomes. "Methods" and "Tools" are to suggest reasonable methods or practical tools accordingly. "Procedures" include step-by-step instructions for each task or subtasks including forms or reports. "Deliverables" contains all actions taken during the project life cycle. "Methods" and "Tools" are essential elements of the framework to understand how construction managers carry out tasks and subtasks.

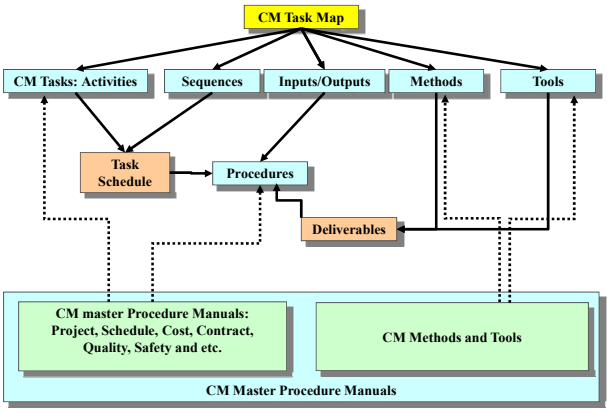

Figure 2 Internal Architecture of CM Task Map [Modified from (SDS 1997)]

Table 1 Description of CM Task Map

Elements	Description
CM Tasks	Activity that is classified by Phase, Task, and Activity
Sequences	Desired relationship between activities depending on work precedence
Procedures	Step-by-step instruction for construction managers along with methods, tools, and reports
Inputs/Outputs	Required input or output deliverables to/from activity
Methods	Methodology that is applicable to activity
Tools	Applications or solutions that are applicable to activity based on selected Methods
Task Schedule	Activities that are arranged or approved by project owners or managers
Deliverables	Collection of inputs, outputs, forms and templates that are produced from activity

3.2 Structure of Construction Management Tasks

Construction Management activities can be illustrated in a multidimensional space as described in Figure 2. The first three dimensions are assigned to illustrate project phases and management functions associated with management tasks. CMAA classifies six management functions in five construction phases (CMAA 2003a). The tasks in these five phases, considered as contractual responsibility, are adopted (CMAA 2003b). There are twenty-four tasks in Pre-design Phase, twenty-five in Design Phase, twenty one in Procurement Phase, forty-six in Construction Phase, and twelve in Post-Construction Phase [14], [16], [15]. Additional pre-construction, procurement, closeout activities, and post construction activities were added to increase the level of detail of project management.

The five phases of construction were considered to group operations and management tasks such as Pre-construction, Design, Procurement, Construction, and Post-construction. The six management functions were used to classify the tasks according to their characteristic and they are Project Administration, Time Management, Cost Management, Quality Management, Contract Administration, and Safety Management. In this research, 4 additional management functions will be added as demanded. They are Environment Management, Human Resource Management, Risk Management, and Integration.

In general, a construction management activity has a series of sub-tasks (activities or actions) to be executed since multiple organizations/participants are involved in project management. As in Figure a three dimensional space was considered to illustrate relationships among the management tasks.

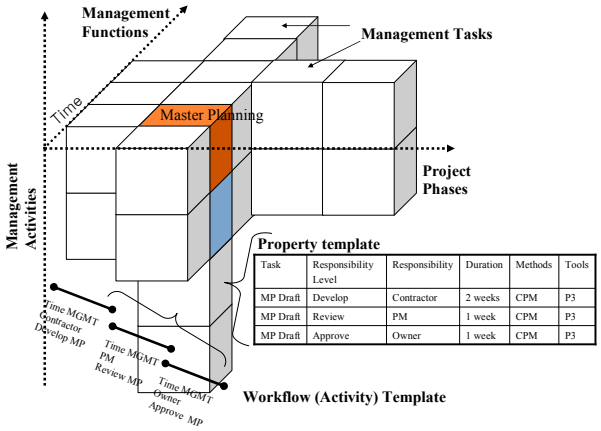

Figure 2 Construction Management in Multidimensional Space

3.3 Analysis of Construction Actions and Management Performance

Figure 3 shows an image of construction management activities in a time-step format. The property information of each activity or sub-activities (actions) must be accompanied in order to construct a model. The property information includes activity information, responsible parties, level of responsibility, and estimated durations. This information enables us to create workflow of management activities for a project. Based on the level of responsibility, the workload and the performance of each organization can be measured.

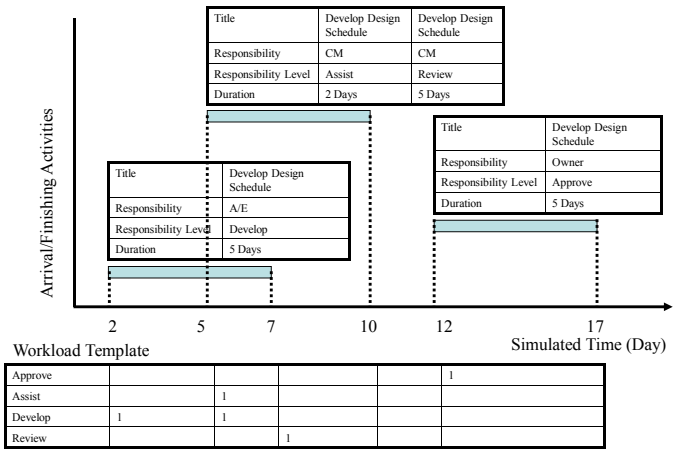

Figure 3 Management Activities in a Time-Step Format

A template of the property information is shown in Figure 4. Several "CM Task Maps" were used for various project delivery methods. Once a "CM task Map" is selected, recommended construction management tasks are selected automatically. Each task is then divided into several levels. A route, a series of required actions with corresponding responsibility, was defined for the lowest level tasks. Detail process and procedures, route property in Figure 4, for the lowest level tasks were then defined.

This model allows multiple levels in order to avoid redundant managerial intricacy. Priority or preference over other tasks is available to enforce specific tasks in the right order. This outlines the line items foe the project. Construction management procedure manuals were used to clarify "Process(es)" and "Procedures". Once "Responsibility" is identified, "Action Words" were used to define the level of responsibilities. Fifty six verbs were extracted from the standard agreements of American Institute of Architects (AIA), Construction Management Association of America (CMAA), Association of General Contractors (AGC) and (National Society of Professional Engineers (NSPE).

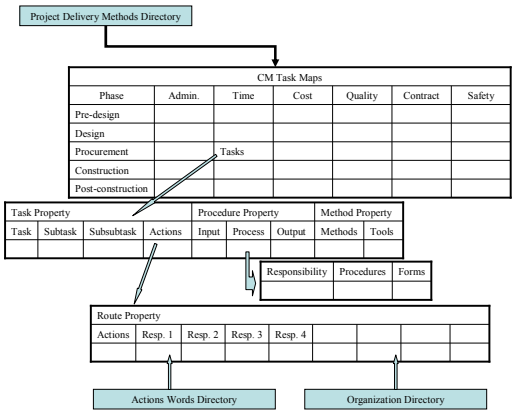

Figure 4 Framework of Property Information for CM Simulation

3.4 Rule-Based Simulation and Simulation Engine

C-Language Integrated Production System (CLIPS), a rule-based expert system developed by National Aeronautics and Space Administration (NASA) in 1985, was used to experiment the framework. CLIPS offers three different types of expert system programming method; rule-based, object-oriented and procedural. CLIPS consists of three basic elements: fact-list (rules), knowledge–base (data), and inference engine. The inference engine executes rules based on conditions using the knowledge-base. A variety of actions are designed prior to the project but actions will only be activated until applicable situations occur. This method enables us to present knowledge as heuristics based on a set of predefined actions when a given situation is satisfied. Thus, it has been widely used for decision making systems because its rule–based system allows us to develop a system without heavy logic programming effort.

3.5 Rule-Based Simulation and Simulation Engine

Deftempletes and Deffacts were used to translate the hierarchy of the tables into a data structure as shown in Figure 4. Deftemplate is to define the types of data and rules and Deffacts is to insert rules. Relationships among project delivery methods, project phases, and management functions are prearranged as below:

```
(deftemplate project-is (slot current-pdm- is
(type SYMBOL) (allowed-symbols cm-for-fee
cm-at-risk design-build traditional)))
(deftemplate phase-is (slot current-phase-is
(type SYMBOL) (allowed-symbols pre-design
design procurement construction post-
construction)))

(deftemplate management-functions-are (slot
current-management-funtions-are (type
SYMBOL) (allowed-symbols administration
time cost contract procurement quality safety)))
(deftemplate management-is (slot current-
management-is (type SYMBOL) (allowed-
symbols administration time cost contract
procurement quality safety)))
```

Deffacts activates recommended actions according to up-coming tasks as below. These facts were abstracted from construction project manuals. Recommended procedures for each action were inserted in the knowledge base. Step-by-step actions required to complete a task are designed as follow:

```
(deffacts MAIN::assert-routing (activate-
routing-subtask (current-subtask-is mobile-
office) (responsibility construction-manager)
(required-action prepare) (duetime 3days))

(activate-routing-sub-subtask (current-sub-
subtask-is deliver-office-building) (responsibility
subcontractor) (required-action complete)
(duetime 2days))
(activate-routing-sub-subtask (current-sub-
subtask-is setup-office) (responsibility
construction-manager) (required-action
complete) (duetime 1day))

(activate-routing-subtask (current-subtask-is
utility-hookup) (responsibility construction-
manager) (required-action prepare) (duetime
2days))

(activate-routing-sub-subtask (current-sub-
subtask-is call-utility-company) (responsibility
field-engineer) (required-action complete)
(duetime 1day))

(activate-routing-sub-subtask (current-sub-
subtask-is check-hookup) (responsibility
construction-manager) (required-action
complete) (duetime 1day)))
```

A CLIPS rules, similar to an IF THEN statement in conventional programming languages; the rule produces recommended actions when certain conditions are satisfied. However, these rules can be fired by many different input conditions unlike conventional programming languages. Three sample rules to activate recommended actins are as below.

```
(defrule MAIN::what-is-task (current-
management-is administration)
(activate-tasks (current-task-is ?task)
(responsibility ?resp) (required-action ?act)
(duetime ?days))
=>
(printout t "the current task is (" ?task ") -
responsibility is (" ?resp ") - required action is
(" ?act ") - duetime is (" ?days ")."  crlf))

(defrule MAIN::what-is-subtask (current-
management-is administration)
(activate-tasks (current-task-is ?task)
(responsibility ?resp) (required-action ?act)
(duetime ?days))
(activate-subtasks (current-task-is ?task)
(current-subtask-is ?subtask) (duration-is ?dur))
  =>
(printout t "the current task is (" ?task ") -
responsibility is (" ?resp ") - required action is
(" ?act ") - duetime is (" ?days ")."  crlf)
(printout t "the current subtask is (" ?subtask ")
- duration is (" ?dur ")."  crlf))

(defrule MAIN::what-is-sub-subtask (current-
management-is administration)
```

```
(activate-tasks (current-task-is ?task)
(responsibility ?resp) (required-action ?act)
(duetime ?days))

(activate-subtasks (current-task-is ?task)
(current-subtask-is ?subtask) (duration-is ?dur))
(activate-sub-subtasks (current-subtask-
is ?subtask) (current-sub-subtask-is ?sub-
subtask) (duration-is ?duration))
=>
(printout t "the current task is (" ?task ") -
responsibility is (" ?resp ") - required action is
(" ?act ") - duetime is (" ?days ")."    crlf)
(printout t "the current subtask is (" ?subtask ")
- duration is (" ?dur ")."    crlf)
(printout t "the current sub-subtask is (" ?sub-
subtask ") - duration is (" ?duration ")."    crlf))
```

8. CONCLUSIONS

A rule-based expert system, CLIPS, is used to produce appropriate actions according to various situations at construction projects. Types of actions taken and work loads are monitored and analyzed to evaluate the performance of the project management team. Through the study of actions taken, the timeliness and suitability of the actions can be measured and studied.

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