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A RESOURCE_BASED SIMULATION APPROACH WITH APPLICATION IN EARTHMOVING/STRIP MINING

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ABSTRACT

Construction simulation is unique as it involves complex systems characterized by a great deal of uncertainty, dynamic interactions of system components and large numbers of tasks and resources. Simulation methods used in construction must be capable of addressing issues often encountered in large and complex systems yet be easy to use by an unsophisticated simulationist, the construction engineer. This paper discusses how simulation can be implemented in the earthmoving sector of the construction industry. A summary of a method that enables assembling a simulation model by reference to the main resources involved in the operation is first presented. This is followed by an example application from the field of earth moving that was observed in a strip-mining application of oil-sands at the Syncrude mine in Fort McMurray in Alberta, Canada.

1 INTRODUCTION

System simulation has achieved great success in the manufacturing industry in general. Its advantages over other techniques are numerous and have been documented in many references (Halpin 1977, Lunar 1991, and AbouRizk and Shi 1994). Simulation concepts have been applied to enhance modeling and analysis of construction operation. Construction systems are, however, unique involving very complex components, large number of tasks and resources combining under uncertain conditions. Many attempts have been made in the recent past to alleviate these problems and enable construction practitioners to make use of this powerful tool. Amongst the first and most successful attempts are those made by Halpin with the development of CYCLONE (Halpin, 1977, 1990). Many other attempts are documented in the literature (AbouRizk et. al, 1992). Withstanding the success of CYCLONE on the research and academic side, simulation has to yet be adopted by the construction industry on a large scale. The problem can be attributed to many causes. Our experience, however, reveals that the major ones are as follows:

a. Properties of the construction system itself: construction projects are relatively complex and large involving numerous activities and resources. They are also one of a kind with little repetition except at the very low level of the work breakdown with many factors external to the construction system affecting progress and contributing to uncertainties in the plan. These properties make it economically unfeasible (or at least not justifiable) to develop simulation models under the current methodologies of general purpose simulation languages.

b. Resources available for planning in construction: construction planners are often faced with limited time and budget for plan development which is considered to be secondary and even not required for medium to small projects. Furthermore, many of them became project managers through field training and not necessarily through engineering or management education. This makes it difficult for them to embrace new quantitative methods such as simulation. It is for example not uncommon for a 250 bed 3 story general hospital building costing approximate 50 million dollars to be planned and controlled using a bar chart of 30-50 activities.

c. Properties of the current simulation systems: Currently available general purpose simulation systems are very difficult to apply in the construction field because they do not address the unique nature of construction. Such models are both taxing to build and technically and mathematically involved. Systems like

CYCLONE primarily developed for construction have been more widely accepted primarily because they are easy to implement.

In attempting to introduce more useful applications of simulation in construction we selected a well defined construction system namely earth-moving and researched how we could achieve effective simulation-based planning in this industry. Our approach was to proceed in three steps: 1) study the earth-moving industry and work with practitioners to better understand how they plan their projects, 2) observe, document, and model a representative and on-going project, and 3) develop a framework for simulation-based project planning with specific application in earth-moving.

The remainder of this paper details this research project and provides a summary of our findings and experiences.

2 OVERVIEW OF THE RESEARCH IN EARTH-MOVING CONSTRUCTION

Earthmoving is one of the most common construction systems, which can be found in foundation work of building construction, dam construction, airport construction, road construction, strip-mining, and others. Peurifoy and Ledbetter (1985) described earthmoving operations in five basic processes including excavating, hauling, placing, and compacting. For this equipment-intensive construction system, proper selection of equipment will enhance productivity and reduce project cost. Many techniques have been tried to find the better solutions for earthmoving operations. Easa (1987) developed a linear programming model which could solve the earthwork allocation problem with non-constant unit costs. Christian and Caldera (1987) developed another operational research model by considering the swell and shrinkage of soil. Recently, more researchers are attempting to apply expert systems to assist in the selection of earthmoving equipment (Alkass and Harris 1988, Amirkhanian and Baker 1992).

3 FRAMEWORK FOR SIMULATION BASED PROJECT PLANNING OF EQUIPMENT INTENSIVE APPLICATIONS

Because the difficulty and amount of work involving in building up the simulation model, the reusability of simulation models becomes an interesting topic in simulation. Halpin et. al. (1990) developed a standard library of simulation (CYCLONE) models that encompass a number of widely used construction processes. In a similar way, McCahill and Bernold (1993) implemented a library for a specific user (The U.S. Navy Civil Engineering Laboratory). While such libraries are effective, their major drawback lies is the fact that they must account for all of the possible user needs in terms of simulation models, a formidable task in general. With the diversity in construction practices and the uniqueness of construction projects such libraries though useful for targeted users, are not effective in general practice.

This section describes the development and implementation of a methodology termed "resource-based modeling" which can simplify the modeling process in construction simulation. With the user specifying the required resources and site conditions, the system will automatically generate a base simulation model for the user to experiment with and embellish.

3.1 Equipment-based modeling concepts

In construction and other related industries, the real-world systems are categorized by dynamic resource interactions (e.g. earthmoving equipment). The operating processes of these resources can be defined as atomic components and stored in model libraries using object oriented representation technologies. For the proposed environment, it is envisioned that the user would first specify the resources that will be assigned to a project, and the physical attributes of the site being considered. The corresponding sub-model constructs of the specified resources will be collected from the available libraries or built by the an engineer using the provided model-building environment. The system will then identify the appropriate linking structures and assemble the working model of the system by coupling or integrating atomic resource models and while incorporating project site information. Zeigler (1987) and Luna (1992) suggest using a hierarchical and modular approach in modeling complex large systems. This may be achieved by integrating atomic components or coupling models stored in model libraries. This approach is intended for general purpose simulation modeling and is of potential application in construction.

In general terms the following issues must be resolved in applying the hierarchical and modular approach in construction simulation:

1). Defining and designing the atomic models to be included in the model or libraries,

2). Construction of coupling models from atomic or coupled elements with the characteristics of construction projects in mind. Zeigler suggested creating new models by combining two or more atomic models through model input and output ports. Our early experimentation with this approach showed that the interface between two models can not always be directly linked through simple input-output ports. An intelligent environment that is specific to the real-world system (i.e. heavy construction in this case) must be developed and added to the interface to facilitate the linking process.

3). Integrating the attributes of the physical system environment and its boundaries (e.g. project site information) into the model. A simulation model reflects the behavior of the system and in many cases the levels of accuracy desired will prohibit high levels of abstractions which will require including the physical attributes of the system.

Resolving these three issues will be achieved by addressing three modules of work namely: (1) resource specification, (2) incorporating site specification into a simulation model, and (3) building the environment of linking structures.

Resource Specification

For the purpose of this research resources are classified as being either active or passive. An active resource actively performs an operation in the system. Equipment and labor are active resources, for example, while material is passive. An active resource is always associated with an operation and is normally used for a specific function in a specific field (e.g. trenching machine in pipeline construction, or a scraper in earthmoving). A resource "i" with an associate model "Model" and attributes "ATTR" can be fully represented for the purpose of simulation modeling as follows: *Resource i:* {Model, ATTR}. Where "Model" represents the operating process of the resource when it is used for a specific function (e.g. trucks for hauling, dozer for pushing dirt.). The "Model" is essentially the atomic component stored in the model library which are specific to certain construction works (e.g. for an earthmoving project, the library should include excavators, trucks, tractors, loaders, etc.). The atomic models in a given library have two features: (1) description of the operating process of the resource as it applies to performing required operation and (2) definition of the communication ports that the sub-model may use in interfacing with other sub-models. The model description include graphic and textual information. The first allows the user to visualize the simulation model structure of the involved process and its communication ports. The second represents the same information in programming code to enable direct manipulation by other parts of the environment. Communication ports define the locations within the model where an interface may occur. Finally, ATTR is a vector representing key physical and operational attributes of the resource. Much of the static information of the attributes of resources can be set in data bases since they do not change from project to project while project-specific factors would be specified by the user for each new project.

Site Information and System Boundaries

It is known that the boundary and environment of a system will affect, restrain, even control the operation of the system. The boundary and environment specifications identify the fundamental features of the operating conditions of the system, and must be incorporated into the model. The simulation results could be realistic and applicable only when the operation of the simulation model is running in the real boundary and environment conditions. For example, the simulation results of a pipeline construction project in cold weather can not be directly used for a similar project in hot weather. The following aspects should be included in specifying the project environment: functional specification of the resources, resource locations in the system, local environment specifications (physical attributes of the system e.g. distance of hauling, grade, soil conditions etc.), resource performance and output measurement mechanisms, and function and system objectives (e.g. how would the termination of the model's operation be achieved).

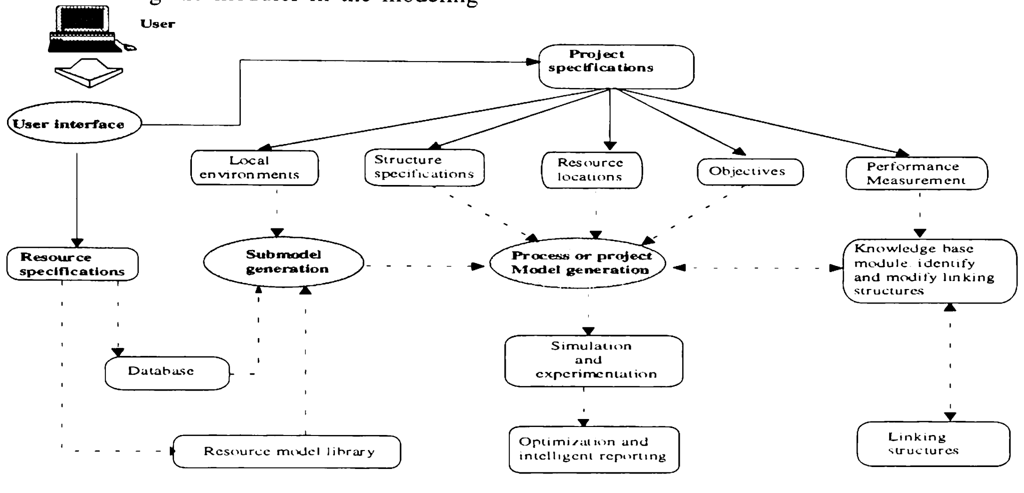
Linking Structures

The operating processes of a resource defined in a resource library can be categorized in one of the following groups: *independent*, *serving* and *served* processes. Two linking structures have been identified in the preliminary study to define interfaces between theses three classifications namely *transfer* and *replacement* links. A *transfer link* combines two processes simply by transferring the output (simulation entities) from one process to another. The coupling between two independent processes can use this structure. A *Replacement link* can be used in coupling a serving and a served process. In coupling the two processes, we can replace the served activity by its related serving activity, and keep the other activities unchanged.

Message passing a simulation system is performed using by simulation entities. An entity in a given model has its own meaning which is associated with the model, therefore the communication between the output port of a model and the input port of another model can not be directly carried on. In order to couple separate models, the equivalence between entities in different models must be created. One way to do it is to create a transition part and attach it to the linking structure with the transition part being associated with the real world system. For the purpose of general use, various transition parts will be defined and stored in a data base. A knowledge-based module will be implemented to aid a user in finding the appropriate part for a specific use. Moreover, this knowledge-based module will enable a user to define a transition part or linking structure which does not exist in the data base.

Implementation

The system is supplemented with a user interface environment for assisting the moduler in the modeling and analysis phases of the work. The implementation medium is personal computers as they are inexpensive to adopt in the industry and are widely available in most companies. The overall system can be illustrated as shown in Figure 1.



Note: The solid lines show user interfaces
The dotted lines show the automatic interfaces

Figure 1. Overall system structure

3.2 A Strip-Mining Application

The selection of earthmoving equipment has two aspects: to select the proper types of equipment and to select the number of each type of equipment. In this project, the comparison between CAT-777 and Titan (CAT-789), different backhoe capacity, and the different number of trucks will be addressed. The resource-based modeling methodology can be used to build up the simulation model for this actual strip-mining project. In this project, the equipment used includes: a CAT-D11N tractor at the cut location, a CAT-D9N at the dump location, an Hitachi EX-1800 backhoe for loading, CAT-777 and Titan trucks for hauling.

Our observation and discussion with practitioners revealed that the main factors which affect the production rate are loading efficiency and traffic conditions which affect the hauling process. In this model, the loading process is broken down into four tasks: excavate, swing to dump, dump, and swing back for next excavation. In order to analyze the effect of traffic conditions on production rate, we assume that a section of one way road is shared by the hauling units (loaded and empty) and other traffic. The hauling and return processes are divided into two sections each: Haul I - Haul II and Return I - Return II. To analyze these factors and examine productivity, we build the models around resources as explained earlier and then use SLAMSYSTEM to experiment with different scenarios.

Scenario 1: Titan trucks with EX-1800 backhoe. Let the truck number change from 3 to 8. The production rate per hour and unit cost can be plotted in Figure 2. The maximum production rate can be achieved with 5 trucks (581 m^3/h). However, four trucks yield the minimum unit cost of $2.31/$m^3$.

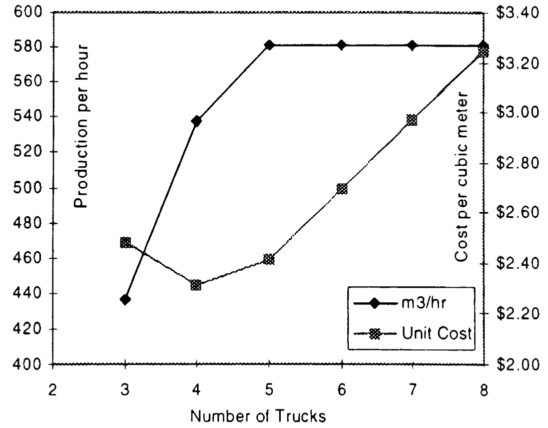


Figure 2 Titan--Production and unit cost Curve

For all other scenarios, the production and unit cost curves as shown in Figure 2 can be obtained. Experimenting with many scenarios, the final optimal solutions are summarized in Table 1. Except for scenario 2, only Titan trucks are used. Some other scenarios can be simulated according to practical requirements.

Table 1: Summary simulation results

Scenario description	Maximum production rate (m^3/h)	Minimal unit cost ($\$/m^3$)
EX-1800, Titan trucks	581 with 5 trucks	2.31 with 4 trucks
EX-1800, 777 trucks	550 with 8 trucks	2.69 with 7 trucks
Increase EX-1800 capacity by 20%	680 with 6 trucks	2.15 with 5 trucks
Position Ex-1800 from the top of the pile to the ground	510 with 5 trucks	2.45 with 4 trucks
position trucks from backup to straight forward	700 with 6 trucks	2.12 with 6 trucks
Reduce mean arrival time of other traffic from 10 to five minutes	575 with 6 trucks	2.48 with 5 trucks

The analysis illustrates that computer simulation can be used to develop a project plan and improve construction productivity. For planning, simulation provides the user with the optimum resource allocation. For productivity improvement, simulation provides the user with the best construction method and what construction conditions should be improved to increase productivity.

4 CONCLUSION

Our efforts led us to conclude that for equipment intensive applications such as earth-moving, simulation can be applied effectively at very little cost if the modeling environment is consistent with the way planners model their systems. In this case modeling is achieved by assembling equipment and crews in a well defined manner that does not vary considerably from one project to the other.

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