SYSTEM MODELING OF OBJECT-ORIENTED CONSTRUTION PROCESS SIMULATIONS

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Abstract: The CYCLONE methodology has become well established and its six standard modelling elements provide a simple, straightforward tool for the study of various construction operations. Many construction-specific simulation systems employ CYCLONE or CYCLONE-like symbols for system modelling. However, CYCLONE's simplicity also limits its functionality in model construction operations in terms of realism and accuracy. This research took advantage of recent developments in object-oriented design to formulate a new simulation system, COMSim (Construction Object-Modelling Simulation), aiming at enhancing the simulation capability. Four modules and one database are included in the system and introduced in the paper.

Keywords: simulation, modelling, construction, CYCLONE

1 INTRODUCTION

Computer simulation is a valuable management tool that is well suited to the study of resource-driven processes. It gives the analyst an insight into resource interactions and assists in identifying the important factors in a problem. Interest in applying computer simulations to the planning and analysis of construction operations has been generated by the introduction of the CYCLONE methodology by Halpin in 1973. Studies on various construction operations, such as earthmoving, road paving, tunnelling, the segmental construction of an elevated structure, and concrete placement in a high-rise building, can all be found in the literature (Halpin and Riggs 1992, Halpin 1990). The CYCLONE modelling methodology employs a simple set of graphical elements, namely NORMAL, COMBI, QUEUE, CONSOLIDATION, COUNTER, and ARC, for model building, and provides a convenient tool for the study of various construction operations. The methodology is well established and has been very well received in the construction area due to its simplicity. Many construction-specific simulation systems, such as MicroCYCLONE, UM-CYCLONE, INSIGHT, COOPS, STROBOSCOPE, and so on, employ CYCLONE or CYCLONE-like building blocks for their system modelling.

Nevertheless, its simplicity impairs its functionality in modelling construction operations realistically and accurately. In the CYCLONE methodology the flow entities have to be identical and can not possess individual attributes. Therefore, only one resource type can be assigned in a QUEUE node and only one entity type can flow through a route. This shortcoming complicates system modelling resulting in ineffective simulations. Figure 1 shows a CYCLONE model diagram of an earthmoving operation. Only one type of hauling truck (e.g. a Komatu PC300 with a capacity of 10 CY) can be assigned in the operation. In the reality, however, trucks with different attributes (e.g. varying capacity, horsepower, or age) are frequently used in an operation. To accommodate this, the same operating cycle has to be repeated for each type of truck. Figure 2 shows the CYCLONE model for the same operation but involving two types of hauling trucks (10-cy and 20-cy). The duration at each task in the operating cycle, namely "load", "haul", "dump", and "return", is clearly different for the two types of trucks, but since the flow entities in one passing route have to be identical, and only one duration can be assigned for each task, two separate operating cycles (one for 10-cy and one for 20-cy trucks) with different sets of task durations are required to model this situation. The number of operating cycles will obviously increase as more and more different types of trucks join the operation. In addition, to further compound the matter, if more than one type of loader with different attributes is employed, the system model will become even more complicated. Similarly, if other varieties of resources, and/or more complex interactions among the resources are involved in the operation, system

modelling could become very tricky or even impossible!

This research takes advantage of recent development of object-oriented paradigms to develop a construction object-oriented simulation system that employs the CYCLONE building blocks. The idea is to preserve the simplicity of the CYCLONE modelling methodology, while on the other hand to enhance its functionality for simulations through object-oriented design. With the new system, resources with different attributes can be initialized in the same Queue with no redundant operating cycles required in the model. Thus, the simulation of a construction operation can be conducted in a more realistic and accurate fashion, and its planning and analysis applications in construction operations can be facilitated.
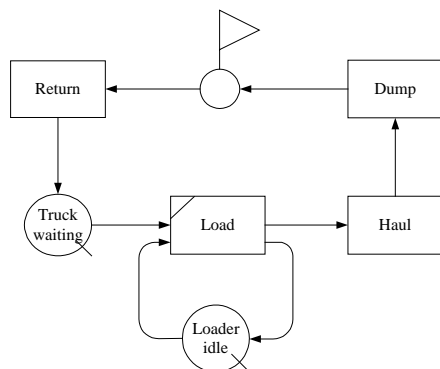

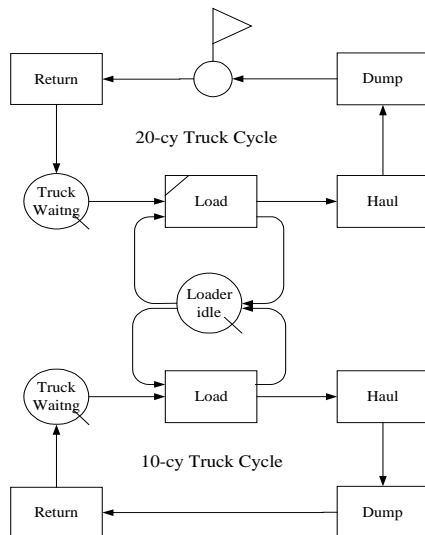Figure 1. CYCLONE Model of an Earthmoving Operation

Figure 2 CYCLONE Model of Earthmoving with 10-cy and 20-cy Trucks

2. COMSim SYSTEM DESIGN

The idea for design of the COMSim (Construction Object-Modelling Simulation System)

system is to still use simple construction model building blocks, while enhancing their functionality by introducing object-oriented design. CYCLONE's six model building blocks are chosen for their simplicity and broad acceptance in the area of construction simulation. Figure 3 shows the framework of the COMSim system. It consists of four modules and one database, namely the object module, the simulation module, the GUI (Graphical User Interface) module, the DSS module for the task duration, and the construction resource database. Their contents and functions are introduced in the following sections.
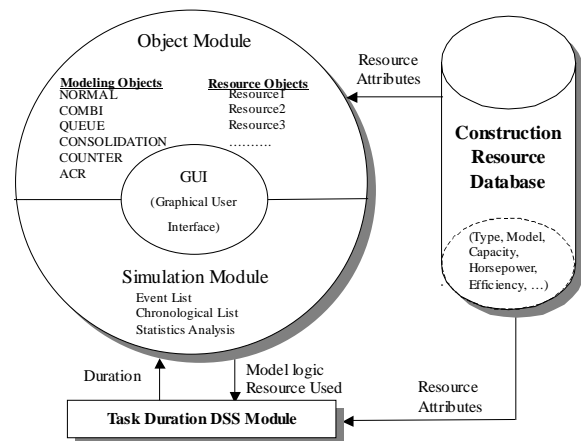

Figure 3 Framework of the COMSim System

2.1 The Object Module

The object module defines and traces both the resource objects and the modelled objects. Each of the resources (e.g. a labourer or a machine) involved in an operation is treated as a single entity or an object with its own set of attributes. The COMSim system is designed in such a way that different types of resources, or the same types of resources with different attributes, can flow through the same route and engage in the same task node. Therefore, in contrast to the aforementioned CYCLONE model, multiple resource objects can be initiated in a QUEUE node during modelling and simulation. Moreover, the resource objects are further linked to the "construction resource database" for their corresponding attribute values. Thus, resource definition in system modelling and data handling during the simulation process are greatly facilitated.

In addition, each of the six CYCLONE building blocks is defined as an object class with the attributes and operations necessary to accommodate the object design described above. Their functionality and design are described below:

1. NORMAL & COMBI: Both NORMAL and COMBI represent the tasks in an operation. Since the resource entities flowing through the operation cycle have their own attributes, the task duration is no longer fixed, either

deterministically or stochastically. For instance, if two loaders (3-cy and 5-cy) and five hauling trucks (two 10-cy and three 20-cy) are assigned for the earthmoving operation as shown in figure 1, the duration of the "load" task is determined by the type of hauling truck and the type of loader engaged in the task at the time. The COMSim system is equipped with a DSS (Decision Support System) module for determining the proper duration of tasks in the operation, according to the related resource attributes and site conditions. The NORMAL and COMBI objects are linked to the DSS module for the determination of the task duration.

2. QUEUE: QUEUE represents an idle state for a particular resource entity or a transient state for the whole system's operations. Usually the system's resources are initiated at a QUEUE node. Since it is built into the COMSim system to allow for the initialization of more than one type of resources in a QUEUE node, a proper queuing mechanism has to be designated for each QUEUE node to adequately process the resource entities entering and exiting the node. FIFO (first in, first out) is the default mode. In addition, on certain occasions the QUEUE node also serves as a resource multiplier. For instance, a ready-mix concrete truck needs 10 crane-bucket cycles to empty the truck, a hauling truck needs five loader cycles to load the truck, and so on. Usually the magnitude of the multiplier is determined and is pre-set during the modelling of the operation. However, since different types of resource entities, with different capacities or other attributes, could flow through one QUEUE node, then in the COMSim system, the magnitude of the multiplier is decided during the simulation run time, depending on the attributes of the resource passing through the node.

3. CONSOLIDATION: The CONSOLIDATION node is used to consolidate the number of flow entities in the model. Usually it is used by pairing it with the GENERATION (QUEUE) node. For instance, a ready-mix concrete truck needs 10 crane-bucket cycles to empty a truck at the site, so a QUEUE node with a generation of 10 is used to represent the waiting state of the arrived ready-mix trucks, to ensure 10 operating cycles that are necessary to empty the truck. On the other hand, a ready-mix truck will not leave the site and return to the batch plant until it has been unloaded 10 times. Therefore, a CONSOLIDATION node with a consolidation number of 10 is used to ensure this procedure. Similar to the GENERATION (QUEUE) node, the node consolidation number is also decided on during the simulation, depending on the corresponding resource entity attributes passing through the node.

4. COUNTER: The COUNTER is used to track and calculate the system's production. The system's production is updated each time an operating cycle is completed. Depending on the capacity of the resource entity passing through it, the cycle production differs accordingly. For instance, the cycle production for completing an earthmoving operation with a 10-cy truck cycle or a 20-cy truck cycle will differ.

5. ARC: The ARC serves as a connector to define the logic relation between the nodes. On certain occasions it also serves as a probability branch. An ARC object is designed to have the attributes that only certain resource entities can pass through it. Thus, the resource entities can be routed properly.

2.2 The Simulation Module

The COMSim system adapts the discrete-event simulation mechanism. An event list and a chronological list are maintained throughout the simulation. Statistics in regard to the performance of the operating system, as well as the individual resource and task, are updated as the simulation goes along. Several statistical reports, such as the system's production, the percentage of idle time of resource, the percentage of busy time of task, and so on, are provided by the system.

Figure 4 shows the simulation steps in the COMSim system. As the simulation begins, the system checks to see if the clock time has passed the simulation end time, or if the total production at the COUNTER has exceeded the target production. The simulation ends whenever either condition is met. Otherwise, the system proceeds to the next end event and schedules new events. When no new event can be scheduled, the system moves on to the next end-event time and updates all the statistics. The simulation clock time advances accordingly. The same steps are then repeated until the simulation is ended.

2.3 The Graphical User Interface

The COMSim system provides the user with a graphical user interface to facilitate the system input and output, so that its usability can be enhanced. Basically, the GUI is build on the DISCO platform, originally designed to incorporate CYCLONE's six building blocks and to serve as a pre-processor and post-processor of the MicroCYCLONE program. With the GUI, the user can build a model graphically on the screen for an operation. Dialogue boxes are used wherever necessary for data input

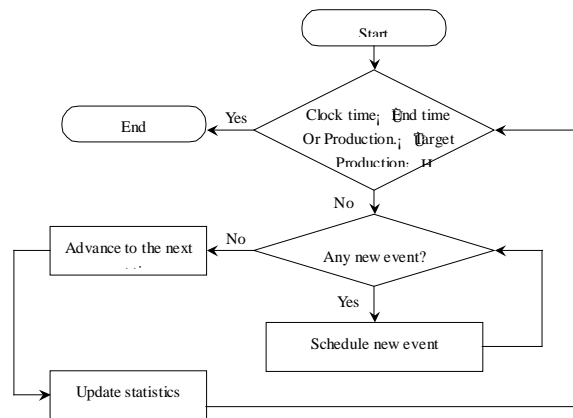and for setting the related parameters. Simulation results are then shown graphically or in tabular form.

Figure 4 Simulation Steps in the COMSim System

2.4 The Task Duration DSS Module and the Resource Database

Both the task duration DSS module and the resource database act to support the main modules in the COMSim system. The task duration DSS module is linked to the NORMAL and COMBI objects and serves to determine the duration of a task during the simulation, according to the related resource attributes and site conditions. On the other hand, the resource database is designed to facilitate the assignment of resources during system modelling, as well as the management of information regarding various construction resources. The database can include as many types of labourers, equipment, and materials as necessary for the various operations. The modeller can define the resources during the modelling process by simply selecting the proper resources from the resource database.

3. CONCLUSIONS

This research takes advantages of recent developments in object-oriented design to design the COMSim simulation system, aiming at enhancing the simulation capability of the CYCLONE modeling methodology. The COMSim system preserves the use of simple building blocks for construction operations modeling, while on the other hand enhancing their functionality, by introducing object-oriented design. Features of the COMSim system are summed up as follows:

1. With the developed COMSim system, the same set of already familiar CYCLONE model building blocks can be employed to model construction operations in a more accurate and realistic fashion.
2. With object-oriented design, similar resources having different attributes can be initiated in one QUEUE node.

Modeling effectiveness is greatly improved when similar resources are involved in the operation.
3. With the task duration DSS module, the task duration is determined automatically during the simulation, according to on-site conditions and the related attributes of the resources involved in the operation. Thus, system modeling of an operation is facilitated.
4. With the "resource database", the assignment and the initiation of various resources become easy and effective in system modeling. Also, better information management regarding the various resources necessary to construction can be achieved.
5. When the GEN-CON mechanism is employed, COMSim can automatically determine the multiplier during the simulation for resource entities having different attributes.
6. The GUI in the COMSim system provides user-friendly graphical modeling and simulation environment. It assists in the application of simulations to the planning and analysis of construction operations.

The design framework for the COMSim system is established and explained in this paper. However, future work needs to be done in the future to implement the COMSim system. In addition, more modules, such as for sensitivity analysis and report printing, can be added to the system to further enhance the capability of the COMSim system for the planning and analysis of construction operations.

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