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SIMULATING CONSTRUCTION OPERATIONS OF PRECAST-CONCRETE PARKING STRUCTURES

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ABSTRACT

Modern construction operations involve many different resources such as labor, equipment, and materials. The interactions among these resources can be realistically modeled and analyzed using discrete-event simulation. During construction planning, it is necessary to model and simulate construction operations and develop a work plan that minimizes idleness, eliminates bottlenecks, increases productivity, and reduces costs. Among the various applications in the construction industry, discrete-event simulation has been successfully used in modeling the construction of precast-concrete parking structures. This paper presents the application of discrete-event simulation to model and analyze the erection process of a precast concrete parking structure. Simulation is conducted by using a graphical discrete-event simulation system named COOPS. Construction equipment, labor, concrete members, erection times, and operating strategy are modeled and simulated to investigate the productivity, resource utilization, and unit costs.

1 INTRODUCTION

Precast concrete parking structures are becoming increasingly popular for above-the-ground parking facilities, especially in urban areas. The construction of precast concrete parking structures is very similar to the assembly process in a factory. Simulation provides a practical and cost-effective means to investigate the characteristics of an operation before actual construction. Work plans for resource utilization and processing strategies can be tested using computer simulation to investigate resource utilization, bottlenecks, productivity, and costs. Different scenarios can be experimented to obtain the optimal operating strategy without engaging in real-life/consumable resources.

To simulate construction operations, many general-purpose simulation systems can be used, such as GPSS, SLAM, or SIMAN. Several others were developed specifically for the construction industry. Unlike a factory floor, a construction site changes according to the project progress. Ease-of-use and flexibility to change simulation models become very important for construction applications. This paper presents the use of a graphical-based simulation system, named COOPS, to simulate the construction operations of a precast-concrete parking structure. The results of simulation can potentially help construction engineers adjust resource allocations to increase productivity and avoid resource idleness and operation bottlenecks.

2 PRECAST-CONCRETE CONSTRUCTION

The construction of a precast concrete parking structure involves the use of many different resources, such as labor, equipment, and materials. For planning and control purposes, construction operations are broken down into activities/tasks, so that resources can be economically allocated and controlled. These activities/tasks are similar to processes in the assembly lines of a factory. The only difference is that the widgets being assembled are heavy/large precast concrete members, such as beams, columns, or slabs. These concrete members typically are constructed in a nearby laydown yard, where they are casted, cured, and stored in large open space. Heavy trucks/trailers are used to transport these precast concrete members to the construction site where cranes are used to unload, lift, and position. These members are then bolted/welded through connectors to form a structure. Figure 1 shows a typical set up for a precast concrete construction for a parking structure project.

The durations to complete a construction task is not always the same. Many construction tasks are performed above the ground, and many other factors may influence the times to complete the tasks. The uncertainties in durations complicate the analysis of optimization of resource use. Although possible, experimenting with real resources might not be

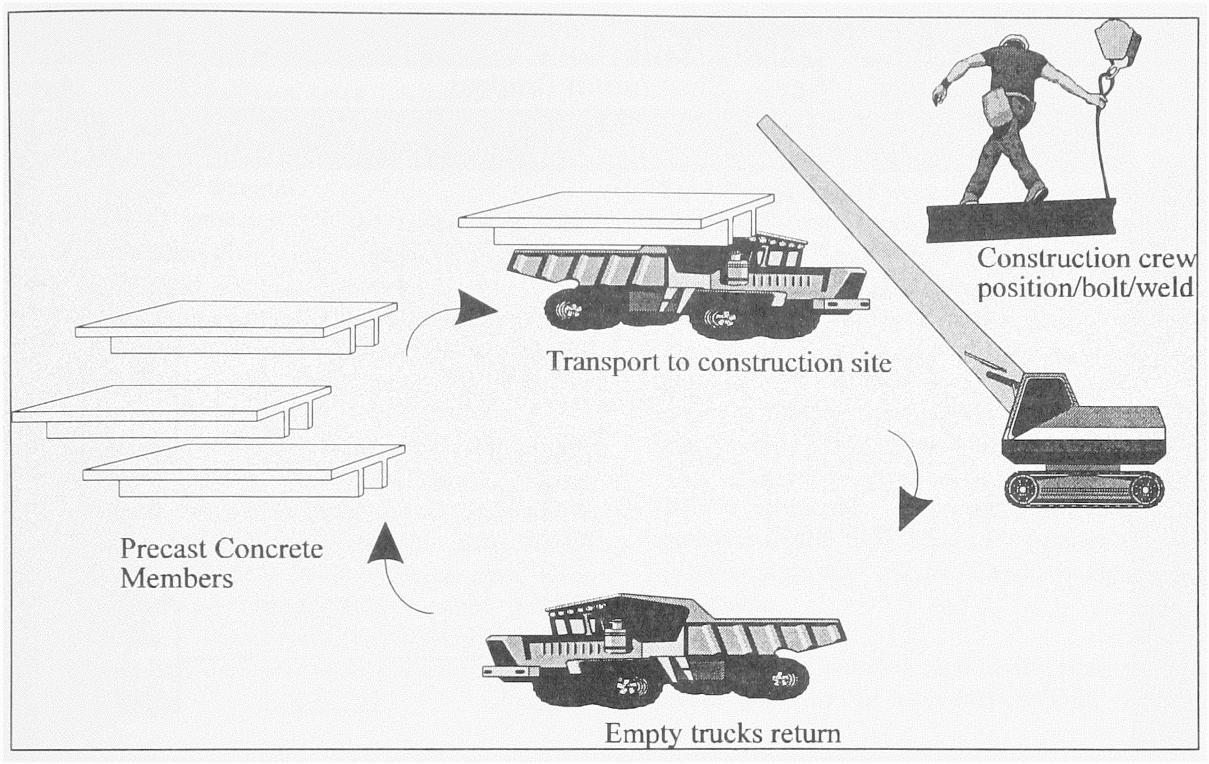

Figure 1: Construction of Precast-Concrete Parking Structure

desirable, because most construction resources are expensive. Computer simulation has provided a practical means of investigating the operational characteristics without engaging in real resources (Law and Kelton 1991). Computer simulation also allows the decision maker to experiment with what-if scenarios to find the optimal strategies (Schriber 1991). The following sections describe how one can utilize a graphical simulation system, such as COOPS, to simulate the construction operations of a precast concrete parking structure.

3 COOPS SIMULATION SYSTEM

COOPS is a graphical general-purpose simulation system developed by Liu and Ioannou (1992). COOPS can model a variety of discrete-event systems including construction operations. A COOPS simulation model is a network of nodes and links, which represent the resource routing and operational characteristics. Figure 2 shows the COOPS modeling environment, which contains toolboxes to allow the users to create simulation models. Data are put into the nodes representing different functions, and the arcs represent the direction of resource flows.

The main window of COOPS consists of several functional areas. The up-triangular button on the upper right corner of the window allows for maximizing the display to full screen and the down-triangular button will minimize the main window into an icon. The window caption bar displays the path and file name of the current model. Below the caption bar is the menu which provides the functions such as file access, editing, viewing, and simulation control. Two numbered bars, one horizontal, the other vertical, are rulers that show the current drawing area relative to the selected page size. The measurements on the rulers are in inches. On the left of the window is the selection toolbox that contains icons for creating COOPS modeling elements. The area to the right of the vertical ruler is the model drawing area. This drawing area is set up with grids to help line up modeling elements and draw links easily. One can select a modeling element from the toolbox and place the mouse cursor in the model drawing area to create a COOPS modeling element. Once a modeling element is created, data for that modeling element will be solicited through interactive dialog boxes. There are two scroll bars on the right and lower side of the window for panning/viewing different areas of a model. There are 11 available selections on the tool box and their corresponding functions (from top to bottom) are:

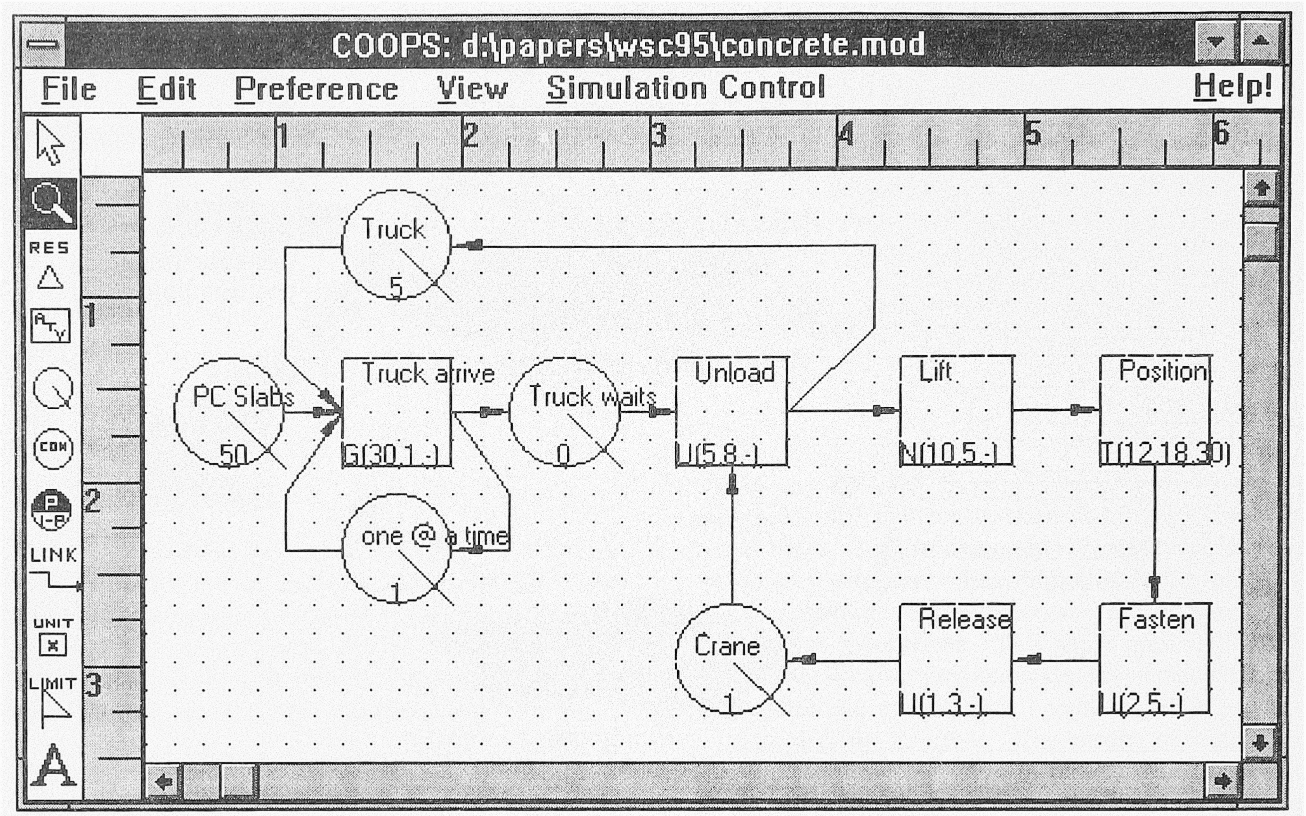

Figure 2: COOPS Simulation System and Model

1) Chooser: a drawing tool for positioning, moving, and selection.
2) Zoom: a tool for setting a zoom area.
3) Resource: a COOPS modeling element representing realworld resources.
4) Activity: a COOPS modeling element representing tasks that consume time and resources.
5) Queue: a COOPS modeling element representing resources at idle state.
6) Consolidation: a COOPS modeling element representing the merging and creation of resources.
7) Router: a COOPS modeling element representing binary random routing of resources.
8) Link: a COOPS modeling element representing the resource flow.
9) LRR: a label that is attached to a link to specify the units of resource flow or consumption.
10) Flag: a label to specify the stopping condition.
11) Text: additional descriptive text.

4 COOPS SIMULATION MODEL FOR PRECAST CONCRETE CONSTRUCTION

The model shown in Figure 2 represents the construction operations of a precast concrete parking structure. This example shows the tasks involved during the installation of concrete slabs. Five trucks are used and 50 slabs are to be transported and installed. The trucks haul the members from the laydown yard to the construction site. Because of the traffic condition, the travel times vary. Once the loaded trucks arrive at the site, a crane is used to unload, lift, and position the concrete members at their final location, where crew bolt/weld these members into their final position. The model shown in Figure 2 represents the operation.

Each node in the model has their special functions, and links represent the resource flows. The model in Figure 2 is the result of a case study for a precast concrete parking structure in the City of Urbana. The observed durations are random variables with the following characteristics:

- Truck Arrival: G(30,1) represents that the arrival process follows an Exponential distribution with an average interarrival time of 30 minutes (equivalent to Gamma distribution with K parameter=1).
- Unloading: U(5,8) indicates that the loading activity follows a Uniform distribution with lower and upper bounds of 5 and 8 minutes respectively.
- Lift: N(10,5) indicates that the duration for lifting

process follows a Normal distribution with mean of 10 minutes and standard deviation of 5 minutes.

- Position: T(12,18,30) indicates that the duration for positioning follows a Triangular distribution with iower bound of 12 minutes, mode of 18 minutes, and upper bound of 30 minutes.
- Fasten: U(2,5) indicates that the fastening process follows a Uniform distribution with lower bound of 2 minutes and upper bound of 5 minutes.
- Release: U(1,3) indicates that the duration to unhook a crane follows a Uniform distribution with lower bound of 1 minute and upper bound of 3 minutes.

In addition to activities, this model also utilizes Queue nodes of COOPS modeling elements. These Queues represent the storage place for resources at the beginning of the simulation. For example, there are 50 precast concrete (PC) slabs in the laydown yard. Five trucks are used to transport these slabs to the construction site. Truck travel times vary, and this model assumes only one truck arrives at a time.

5 SIMULATION RESULTS

Once a model is constructed as shown in Figure 2, the pull-down menu "Simulation" will start the simulation. Table 1 shows the results of a simulation for an ordinary 8-hr work day (480 minutes). The statistical report of the simulation contains information that can be converted to unit cost, productivity, or resource utilization rate. For example, in this particular simulation, 10 units of concrete slabs (from the output of activity "Release") were installed during the 8-hr workday, and the crane seemed to be the bottleneck for the operation, because on average there are 1.8 loaded trucks waiting (from the queue report of "Truck wait"). This information gives construction planners insights into construction operations, so that additional resources, such as a crane, can be added. COOPS simulation system generates the following statistics after simulation:

(1) Stopping Condition reports why simulation stops by either time limit or a production limit. For example,

Table 1: COOPS Simulation Report

```
**** COOPS SIMULATION SYSTEM ***    MODEL:
D:\PAPERS\WSC95\CONCRETE.MOD

SIMULATION TIME LIMIT:   480.00
RANDOM NUMBER SEED:      266301881
PRODUCTION LIMIT

STOPPING CONDITION:
=========================================================
TOTAL SIMULATED TIME = 482.52


             GENERIC RESOURCE UNITS
QUEUE        @START      @END     OUTPUT    AVERAGE      STD_DEV
=========================================================
Crane           1          0        11       0.051        0.220
PC Members     50         34        16      41.917        4.243
Truck           5          0        16       1.997        1.253
Truck wait      0          4        11       1.857        1.241
one @ a time    1          0        16       0.001        0.037


ACTIVITY  OUTPUT GROSS_RATE NET_RATE    AVG_DUR      STD_DUR
=========================================================
Fasten         10      0.021    0.025       3.181        0.883
Lift           11      0.023    0.024      13.207        4.679
Position       10      0.021    0.024      18.915        3.316
Release        10      0.021    0.025       2.051        0.485
Truck arrive 15        0.031    0.032      31.568        6.447
Unload         11      0.023    0.024       6.474        0.771
```

one can simulate the operation for an 8-hr day, or until the production limit for a particular task has been met.

(2) Queue Statistics

NAME:	identifier of a queue.
UNITS@START:	units of resource in the queue at the start of simulation.
UNITS@END:	units of resource in the queue at the end of simulation.
OUTPUT:	number of times resources depart the queue.
AVERAGE:	time weighted average of the resource units stored in the queue during the simulation.
STD DEV:	standard deviation of the number of resource units stored in the queue during the simulation.

(3) Activity Statistics

NAME:	identifier of an activity.
OUTPUT:	number of times the activity has finished.
GROSS_RATE:	output / total simulation time.
NET_RATE:	output / (last finish time - first start time).
AVGDUR:	average activity duration.
SDDUR:	standard deviation of the activity duration.

6 CONCLUSION

The construction of a precast-concrete parking structure involves the use of many expensive resources, such as cranes, heavy trucks, and skilled labor. Simulating the operation on a computer provides a cost-effective way of identifying operational bottlenecks and resource idleness. The results of a simulation help the construction engineers plan and execute construction tasks more efficiently and productively.

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