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FACILITATING SIMULATION MODEL DEVELOPMENT FOR CONSTRUCTION ENGINEERS

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ABSTRACT

This paper describes a decision support system for planning and analyzing heavy equipment operations in construction. History of simulation application and research in construction is briefly described and the reasons for sporadic use of simulation analysis in construction are discussed. One of the main reasons appear to be the lack of a convenient interface between simulation software and the construction end user. The potential for facilitating the process of simulation code generation is explored by developing a prototype decision support system. This system integrates expert system technology with simulation modeling to help the user choose an appropriate equipment fleet under given conditions and to generate simulation codes for modeling the operation.

1 SIMULATION IN CONSTRUCTION

Simulation applications in construction have been mainly limited to discrete system simulation. Early applications of simulation modeling to construction operations date back to early 1960's. These applications involved developing models of earthmoving equipment operations, statistical distributions for modeling equipment cycle times, and productivity analysis (Teicholz, 1963). Many of these consisted of developing special-purpose Fortran programs for modeling specific operations. Developing a new computer program for every specific operation was time-consuming and expensive. For this reason, construction researchers started using general-purpose simulation programs like GPSS (Gaarslev, 1969; Willenbrock, 1972). Simulation modeling spread to other areas of construction such as simulating the effect of weather on construction activities (Benjamin and Greenwald, 1973), planning of building construction (Ashley, 1980), probabilistic scheduling (Moder, et al, 1983), and tunneling operations (Touran and Asai, 1987). Cited references are only a sample of simulation applications and are intended to show the wide range of applications.

2 SIMULATION RESEARCH

As explained earlier, most of the effort in the first decade of simulation use in construction concentrated on developing simulation models of various construction processes. In the area of system development, introduction of CYCLONE (Halpin, 1973), a network-based discrete simulation system, provided a powerful yet easy-to-use software that could be taught in a reasonable amount of time to construction students at undergraduate or graduate levels. CYCLONE has also served as a major platform for simulation research in construction domain in the past two decades.

Much effort has been expended for developing convenient user interfaces with CYCLONE or similar systems such as INSIGHT (Kalk, 1980). Victor (1979) worked on graphical interfaces for these systems where the user could input the INSIGHT model graphically using icons rather than writing codes in system's language. Riggs (1987) developed a system that could automatically display, from CYCLONE codes, a graphical network on the computer monitor. Paulson et al (1983) worked on an automated data acquisition system that facilitated the process of obtaining construction field data and helped the user in data reduction and curve fitting for various cycle components. The source of raw data in this research was the video-tape of construction operations. The system developed allowed the analyst to use the computer for controlling the video-tape and rapidly extract cycle times that were needed. These cycle times were then organized, reduced and could be used as inputs to simulation models usable by INSIGHT or CYCLONE.

3 FACILITATING THE USE OF SIMULATION

While computer simulation is a powerful technique for analyzing complex construction and industrial processes, most applications in the field of construction have been limited to university research; it has seen limited use by the construction industry. There are several reasons for this. One is that construction decisions in the field have to be made quickly. Once the construction project has started, there is little time for modeling different strategies to help the decision-maker. Also, in order to develop a meaningful simulation model, the user needs a large amount of data in a format usable by the software. At the planning stage, where there may be enough time to attempt a simulation analysis, most construction planners are not skilled in simulation modeling. One of the major obstacles in using CYCLONE, or any other software system such as SLAM (Pritsker, 1986) by construction personnel, is that it takes a considerable amount of time to learn these systems and become proficient in modeling. Simulation is not widely used because of the lack of a convenient interface between the potential user and the simulation software. If such an interface is developed, the construction industry can gain from improved decisions that result from applying quantitative computer modeling techniques to the analysis of complex construction operations (Touran, 1990).

3.1 Objective

The objective of this paper is to describe a decision support system that helps a user select a suitable construction equipment fleet for a given set of job conditions, develops a simulation model for the operation either in CYCLONE or SLAM syntax, runs the simulation software, and presents the results of the analysis to the user. Future extensions to the system are envisaged and discussed. The system developed consists of an expert system and code generating programs. The expert system helps in selecting the most appropriate loading and hauling system under project conditions and also serves as an interface between the simulation packages, code generating programs, equipment databases, and the user. Simulation packages supported are CYCLONE and SLAM. For each package, a code generating program is designed that obtains relevant information and data about the operation from the expert system and writes simulation codes.

3.2 Why Earthmoving?

As mentioned earlier, most of the simulation modeling and applications in construction have been concentrated in the area of heavy equipment and earthmoving operations. It seems that compared to many other construction activities, equipment operations is more suitable for simulation modeling and analysis. Traditional simulation systems have been used in areas that are relatively simple and mechanical and where human beings are not intensely involved (Gilmer, 1987). Modeling human actions and decisions is usually more complex than modeling machine operations. In many construction activities labor involvement is intense, cycles are difficult to define, and repetition, although commonplace at the micro-level processes (such as setting rebars), is not easily identifiable at the macro-level processes (such as setting rebars in different configurations like setting rebars in walls or slabs)(Halpin and Happ, 1972). Even in earthmoving operations where most of the work is being done by heavy machinery, human involvement is more prevalent than, for example, in factory production lines. Despite this, most earthmoving operations can be reasonably modeled as a network of several queues and processes interacting with one another to accomplish the job objectives. Most of the operation's cost is a function of the cycle durations. These characteristics match the requirements and strengths of discrete temporal simulation systems.

Also, earthmoving is a major component of heavy construction operations accounting for about 1% of the U.S. GNP (Baecher, et al, 1989). Streamlining and optimizing heavy equipment operations will have significant impact in terms of cost savings and improved productivity in construction.

4 EARTHMOVING OPERATIONS

Earthmoving operations, as supported by the system described here, involve excavation of soil or rock, loading the excavated material into hauling units, and transporting and disposing of the excavated material. Several types of equipment are utilized depending on the job conditions. For example, if the haul distance is less than say, 300 ft, then bulldozers are used to excavate, haul, and spread the material. For haul distances of between 500 ft and two miles and when the soil is not too tough, scrapers are used. Scrapers are self-loading units that excavate, haul, and spread the soil efficiently under favorable conditions. In tough soils, it is common to use pusher-tractors to assist scrapers excavate the material. For haul distances in excess of two to three miles, or for cases where excavation is deep and confined, or excavation material consists mainly of rock, then a combination of shovels or loaders and a fleet of trucks is the most typical choice.

From a modeling standpoint, the operation of one pusher and a fleet of scrapers is similar to the operation of a loader and a fleet of trucks (Touran and Taher, 1988). The same way that a truck depends on a loader for obtaining a load, the scraper depends on a pusher-tractor for loading. Choosing the right type of equipment depends on a number of quantitative and qualitative factors, some of which depend solely on the experience of the construction engineer. Because of the nature of the problem, researchers have used expert system technology for modeling equipment selection decisions (Alkass and Harris, 1988; Amirkhanian and Baker, 1992).

5 SYSTEM DESCRIPTION

The system developed supports earthmoving planning in two stages. In the first stage it advises the engineer on the choice of equipment to be used based on job characteristics and objectives. In the second stage, it uses the information provided by the user and the data available in equipment database to generate a simulation code compatible either with CYCLONE or SLAM.

Main modules of the system is shown in Fig.1. The expert system consists of several modules that control the flow of data and information in the system. The expert system interacts with the user and helps the user to choose the appropriate equipment. It can access equipment database files (that are in dBASE format) to obtain relevant cycle time and cost data. The expert system can then activate the appropriate code generating program depending on the target language, and feed the input data to the program.

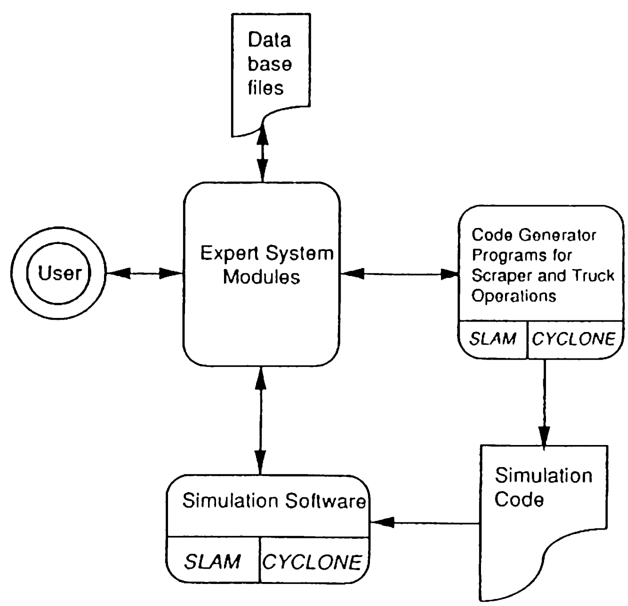

Figure 1: General System Layout

The code generator program writes a simulation file in the desired target language and returns the control to the expert system. The user then has the option to activate the appropriate simulation system from within the expert system and obtain the simulation results.

In this process, the user does not need to be familiar with the simulation software. Furthermore, the user only responds to construction related questions and is not exposed to simulation jargon. The benefit of this approach is that any construction engineer with a general appreciation of simulation modeling can use the system. The disadvantage is that the system supports a relatively limited number of scenarios. Despite this disadvantage, the scenarios supported by the system cover most of the practical cases of earthmoving operations.

The system also allows the user to change input parameters and repeat the experiment until he or she is satisfied with the outcome. The expert system modules allow the user to ask about the reasoning process, inquire about the exact meaning of various questions posed by the system and follow through the impacts that his or her answers have on the analysis outcome. The expert system technology provides a convenient vehicle for interactively giving this information during model development. This reduces the user's justifiable reluctance to accept the system's results if he or she were to input a number of parameters and get some results without knowing what the system was doing with the inputs and how it had come to its conclusions.

Code generating programs in this system are simulation system dependent. These routines use the data supplied by the expert system modules to write simulation codes in a specific target language (i.e. CYCLONE or SLAM). As the present system is only a prototype, it always defaults to CYCLONE for scraper-pusher operations and to SLAM for truck-loader operations.

5.1 Equipment Selection Process

The expert system software used is EXSYS Professional Expert System Development Package (1988). It selects the most appropriate equipment (Bulldozer vs Scraper vs Truck) based on the following parameters (Touran, 1990):

- Haul distance
- Material type (soft soil, tough soil, soft rock)
- Maximum rock size
- Haul road conditions

Based on this information, the expert system selects one of the material-handling systems described previously. If the consultation with the expert system results in choosing a scraper operation, the system continues to classify the scraper type (such as a twin-engine scraper, or an elevating scraper) based on the following parameters (Nunnally, 1977; Alkass and Harris, 1988):

- Ground conditions in the loading and unloading areas
- Adverse grades in the loading and unloading areas
- Soil moisture content

After a generic scraper type is selected, the system allows the user to choose a specific scraper model by referring to a database containing scraper models (brand names) along with their cost and performance data. At this point the database contains a sample consisting of thirteen different models ranging in capacity from 11 cubic yards to 44 cubic yards. The scraper data is stored in a dBASE III file so it can be updated and augmented conveniently. EXSYS Professional can directly access dBASE III files.

After the type of equipment is identified, the expert system poses several new questions to develop a simulation scenario. The following information is requested to further refine the modeling process (Touran, 1992):

- Are there any limitations in the unloading area (for example is it permitted that several haulers unload at the same time)?
- What is the loading and unloading prioritization scheme?
- Are there any anticipated breakdowns for loaders and haulers?
- Does the fleet consist of various capacity haulers?

These information is used as input to the code generating programs that write the simulation code.

5.2 Code Generating Programs

These programs are written in Fortran and their main role is to use the information provided to them by the expert system to develop a simulation scenario. One main module generates SLAM codes and another one generates codes in CYCLONE syntax. In each case, the user is asked to input model parameters. These parameters include the following depending on a specific situation:

- Simulation duration
- Data about support equipment (i.e. pushers or loaders) such as number of units, bucket size, cycle time, probability of breakdown
- Data on hauling unit (i.e. scrapers or trucks) such as number of different size units, cycle time components, capacities

Code generating modules use these data along with information supplied previously to write simulation codes according to a specific target language. Contents of the simulation code file is presented to the user. The user will then have the option to start a simulation package (for example CYCLONE) and run the simulation file from within the decision support system. The result of the simulation analysis is then provided to the user. The user can also vary the parameters related to job conditions and run the simulation again to observe the impact of varying input data on the simulation outcome.

6 VALIDATION OF THE MODEL

The expert system uses a simplified deterministic approach to estimate the system production based on the parameters provided by the user. This deterministic estimate neglects the impact of the variability of the cycle times and interference of competing units for loading or unloading. It only provides an upper-bound estimate of the production by calculating the potential production rates of the hauling units and the support units separately and then selecting the smaller of the two. A potential enhancement is to use simple queuing models to approximately check the accuracy of simulation results (AbouRizk and Halpin, 1991).

7 SUMMARY AND FUTURE EXTENSIONS

The use of simulation in construction research has spanned the last three decades. Despite this background, the construction industry has not used simulation analysis in any significant way in practical situations. One obstacle in the use of simulation modeling has been the fact that most construction personnel are not familiar with simulation and are not likely to devote the needed time to become proficient simulationists. If use of simulation software is made more convenient, then the probability of more widespread use of simulation in construction increases. In this paper, an exploratory research is described that focused on a specific domain of construction, i.e. earthmoving, and developed a decision support system that utilized simulation modeling as a means of estimating the operation duration and productivity. Using a full-scale version of the prototype system described will allow the user to model alternative earthmoving scenarios and rapidly evaluate them.

Future enhancements to the system can include a module that allows the user input probabilistic cycle times based on the user's historical data and his experience. Methods of input data modeling should be explored and tailored such that their use become convenient for the construction engineer (Touran, 1992; AbouRizk and Halpin, 1992). Also, artificial intelligence techniques can be used for analyzing and reporting the simulation output. Every simulation run results in several reports and graphs and the user who is not thoroughly familiar with simulation jargon will have a hard time in obtaining relevant information from these outputs. One important step in facilitating the use of simulation will be to manipulate the output and report only the relevant data to the user in a format that is comprehensible to him and other project personnel. This will expedite the decision-making process. Although such an undertaking is extremely difficult under general conditions, it becomes more feasible in applications where the domain is narrowly defined.

Another area of research is model validation. It will be useful to provide checks and validation procedures at various points in the simulation process to assure the user about the accuracy of the simulation results. Expert system technology is very useful in this area as it allows the system to clearly describe the methods used, the type of data needed, and the impact of various decisions on the system output. The more this aspect of the system is strengthened, the higher the probability that the system will find acceptance by the industry.

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