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A CONSTRUCTION PROCESS SIMULATION WEB SERVICE

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ABSTRACT

This paper explores the potential of construction process simulation as a web service. This web service, or web based application, exploits the high accessibility characteristic of the web, to support easier information exchange and peer collaboration. Two concepts are discussed and presented. One web based prototype called "Interactive Simulation System (ISS)" allows a user unfamiliar with simulation concepts to evaluate construction process productivity (Kim 2000). A second prototypical web service called Web CYCLONE is built upon CYCLONE (Halpin 1973; Halpin and Riggs 1992) methodology and provides the power of simulation to all user levels, novice or professional. The framework of Web CYCLONE is a three-leveled structure, namely novice, intermediate and advanced level, in that each level caters to user needs depending upon the level of sophistication of the user. An asphalt paving operation simulation model is used to demonstrate each prototypical system.

1 INTRODUCTION

Simulation is widely regarded as an effective tool for process analysis based on its power for handling complex interactions. Construction processes are inherently complex with many uncertainties. Construction practitioners, however, make little use of simulation to handle complex production systems. This is due to the slow adoption of new technology characteristic of the construction industry. Difficulties in learning simulation methodologies and the costs of simulation tool acquisition and training have also slowed acceptance.

Much has been done to encourage simulation usage in the construction industry. Halpin (1973) pioneered the effort by introducing CYCLONE modeling elements. These CYCLONE elements conceptually match the construction operation and thus significantly reduce the complexity involved in modeling construction processes. CYCLONE modeling combined with computer technology has been instrumental in triggering improvements in the study of construction operations. DISCO (Huang 1994) extended the capabilities of CYCLONE by allowing the user to design CYCLONE models graphically and see the simulation results. GACOST (Cheng et al. 2003) incorporates Genetic Algorithms (GA) for optimization in resource selection and uses a spreadsheet as a user-friendly input format. STROBOSCOPE (Martinez 1996) is an advanced simulation language that can dynamically assess the state of the simulation and the properties of the resources involved in an operation. This allows simulation professionals to build complex construction process simulation models with greater ease. Activity Based Construction (ABC) (Shi 1999) uses only a single element, the construction activity, to model a construction process. ABC is intuitive for construction professionals since its modeling element has the same meaning and attributes as used in the critical path method (CPM). Hong et al. (2002) extends ABC's usability by providing a visual editing tool and 2-D animation for validation and verification. Special Purpose Simulation (SPS) (Hajjar et al. 2000) modeling and the later SIMPHONY (AbouRizk et al. 2000) use a set of icons to represent various construction resources and resource flow path indicators to build the simulation model. Those icons are all pre-built by designers to cater to different construction processes.

2 WEB-BASED SIMULATION

In recent years, web based simulation has attracted a great deal of attention mainly because of its ease of use, high accessibility, and information sharing potential. Improvements to the information technology infrastructure such as high speed Internet connection and wireless capabilities make distributed simulation even more feasible.

Integration of construction process simulation systems and the capabilities of the WWW offers a promising vehicle for expansion of the construction industry user base. In order to serve the need for interfaces which fit the sophistication level of the potential user, a new approach, is needed. Kim (2000) recognized this need and proposed a web based simulation prototype called Interactive Simulation System (ISS) to address the needs of users with limited simulation and modeling expertise. This prototype generates CYCLONE formatted simulation code from information collected through its web based interaction with the user. More advanced simulation modelers can work with more sophisticated interfaces.

Web based simulation also enables the establishment of centralized repositories of simulation models developed over time by advanced simulation users and stylized to special construction processes and site conditions. Such repositories can be further reused by users at other levels of sophistication through the use of mechanisms for implementing storage, cataloging, and retrieval of such models.

3 MODELING VARIOUS LEVELS OF USER INTERFACE

As noted above, the simulation and process modeling facility among practitioners within the construction industry varies widely. Most construction professionals have a very limited understanding of simulation and how it can be used to better understand construction process design and support productivity analysis. In addition, even knowledgeable professionals are often confronted with situations where limited information about a particular process is available during the pre-construction phase of project development.

This is similar to the situation which develops when estimating the cost of a project. Early in the process, information regarding the facility to be constructed is based on only conceptual design information. Conceptual estimates are typically developed from a very broad facility description (e.g. 400 bed hospital, etc.) and a rough estimate of the area or other gross parameters (e.g. 2.35 miles of interstate standard 4 lane construction) representing the size of the project objective. Parametric methods are available to develop estimates which have +/- 15% or a similar nominal level of accuracy.

As detailed design proceeds, more precise information regarding equipment, element dimensioning, etc. is developed. Based on this more exact information, a definitive or engineer's estimate can be developed. Differing levels of precision are achieved as design proceeds (e.g. 30% design estimate, final design, etc.) . In a similar manner, as the definition of a facility becomes clearer, the processes which will be used to build the final building or functioning item of infrastructure can be more exactly designed and analyzed.

Consequently, both due to the sophistication of the user and the availability of process information, varying types of modeling interfaces are needed when simulating and analyzing construction processes. Three levels of interface are proposed as shown in Figure 1. At level one the construction professional although a knowledgeable domain expert, has no simulation expertise. At level two, the professional is considered a domain expert with limited simulation knowledge. At the most advanced level, the modeler is proficient both in the technical aspects of the construction process as well as process modeling and use of simulation to design and analyze the construction operation.

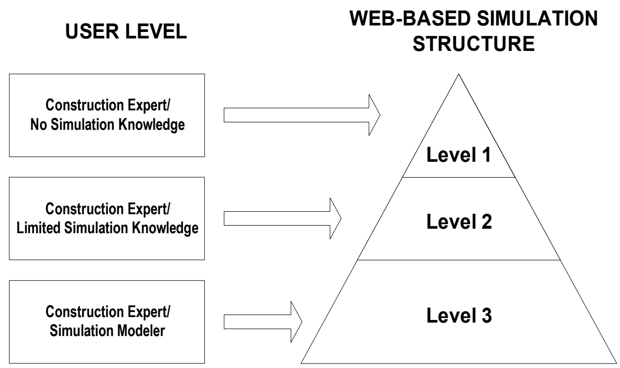

Figure 1: Construction Process Simulation Web Service Framework

In the proposed simulation web service for modeling construction processes, the first level interface is for the simulation beginner or novice user. At this stage, methods are selected and general construction process related questions are addressed. If, for instance, the process to be investigated related to a paving operation, the dimension of the site or the length of the pavement, the equipment to be used, and other quantitative aspects of the operation can be solicited from the user.

The second or intermediate level of the simulation web service gives more freedom to the user by facilitating the modification of existing simulation models. Based on input from the user, the model can be stylized to provide "site adaptation" of the model. Graphical aids which describe the job site characteristics and provide a vehicle for the modeler to customize the process model are provided. Again considering a paving operation, graphical aids such as those shown in Figure 2 can be used to elicit site or process specific information from the user to improve the accuracy of the process analysis (i.e. productivity assessment, etc.). Such aids will be available from support data bases and will be specific to the process type (e.g. concreting operations, paving, masonry, etc.).

The third or advanced level interface allows the sophisticated modeler to develop unique models at the schematic level. Such models can be based on previously designed process models available from level three libraries or totally new models developed for unique production

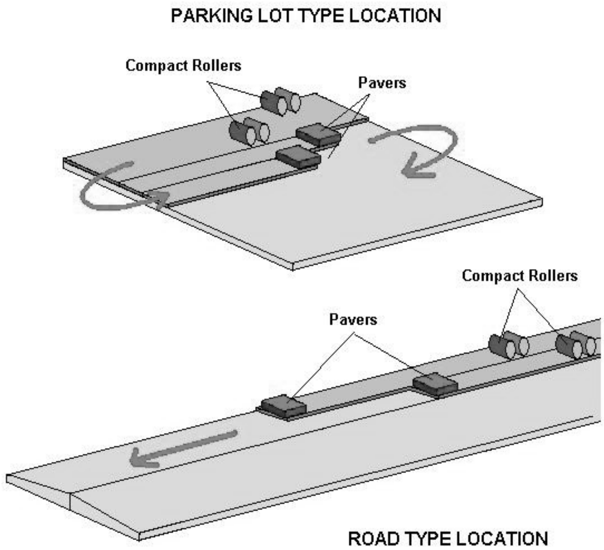

Figure 2: Typical Level Two Graphical Aids for Paving

situations. The modeling framework at this level will be anetwork model in a format such as CYCLONE or similar simulation modeling environment. These models, once tested and validated, can provide the basis for derived level one and level two process models to support process analysis by professionals who do not have advanced modeling expertise.

4 INTERACTIVE SIMULATION SYSTEM (ISS)

The Interactive Simulation System (ISS) as developed by Kim (2000) is well adapted to act as a level one interface. This web based system is designed to provide an easy-to-access, easy-to-manipulate environment for studying and analyzing construction processes. It uses a simple and attractive graphical user interface (GUI) to overcome potential resistance by the user to simulation as an analytical tool. ISS is accessed via the Internet.

ISS leads the modeler through the process of model development by relying upon a hierarchy of process types similar to that shown in Figure 3. This hierarchy is a living structure and is expanded as new models at level three are developed and added to the process library. Again, referring to paving operations, the levels of the hierarchy provide the basis for questions/queries given to the user to establish parameters to be used in selecting the appropriate level three model to be accessed.

Figure 4 indicates the flow of information developed by ISS for a simple paving process. ISS first establishes whether the user is accessing a previously developed model or starting a new simulation. The second screen (See Figure 5) provides a menu of available process types (e.g. tunneling work, etc.). Assuming that "Paving" is selected, this is followed by a series of screen queries which establish whether

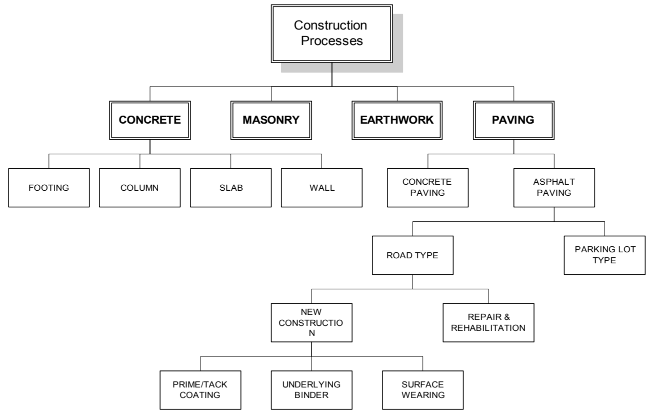

Figure 3: Construction Process Information Hierarchy

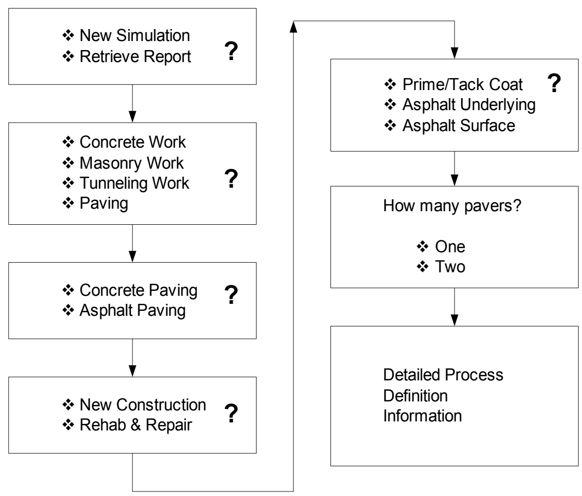

Figure 4: Information Flow Development for a Level One (ISS) Paving Model

the paving is concrete or asphalt, new or rehab construction, and (assuming asphalt paving) related to prime/tack coat distribution, an underlying binder course, or a wearing course. The number of paving machines is next established. Finally, a detailed process definition screen is presented to the user as shown in Figure 6. Based on user input to this screen, a level three model such as that shown in Figure 7 is generated. The input file is shown in the web based library and the user is given a URL that can be used to retrieve the model for modification if required. Obviously, manipulation of the level three input would require a user with advanced level simulation expertise.

5 WEB CYCLONE

Web CYCLONE is designed to implement the level three user interface and other web based functions described above. As shown in Figure 8, the advanced level can com-

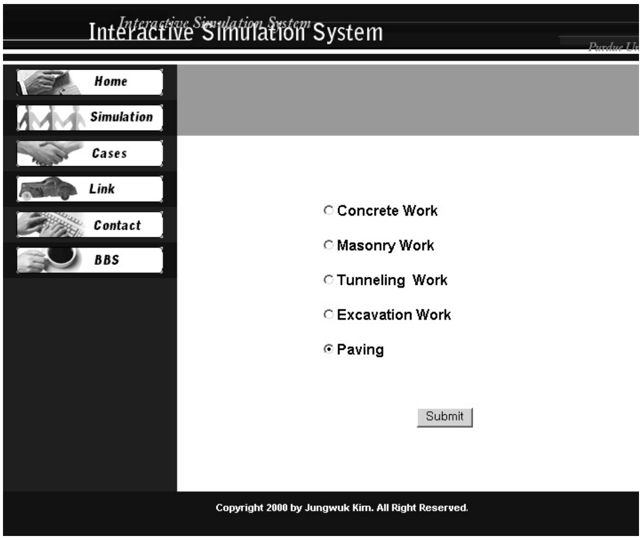

Figure 5: ISS Process Selection Menu

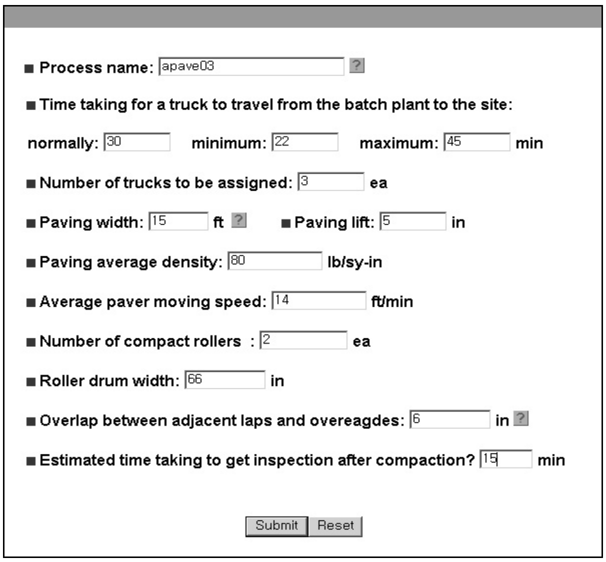

Figure 6: Detailed Definition Page

municate with data storage in both directions; other levels only perform retrieving functions from the data storage (i.e. model library). The advanced level acts as a foundation building block in this web service. It generates the models used at all levels. Although the simulation web service framework cascades from the beginner level to the advanced level, the development sequence of the web service is actually a bottom up process.

All simulation models are created in the third or advanced level and, if deemed necessary, the models are stored in the storage and retrieved as required. This advanced level facility is under development at Purdue and being tested by graduate and senior students in classroom format. Since the system can be accessed using a web browser, this level is readily available to any user who has an Internet connection.

INPUT FILE

File name: apave03.txt

```
 32
NAME ASPHALT PAVING OPERATION LENGTH 100000 CYCLES 100
NETWORK INPUT
1 QUE 'TRUCK LOAD AVAILABLE'
2 COM 'LOAT AT PLANT' SET 2 PRE 1 7 FOL 1 3
3 NOR 'TRAVEL TO JOB' SET 3 FOL 4
4 QUE 'WAIT FOR DUMP'
5 COM 'DUMP TO SPREADER' SET 5 PRE 4 9 FOL 6 8
6 NOR 'TRAVEL BACK' SET 6 FOL 7
7 QUE 'WAIT LOAD'
8 NOR 'SPREAD' SET 8 FOL 9 10
9 QUE 'SPREADER AVAILABLE'
10 QUE 'SECTION READY FOR BRK-DWN'
11 COM 'COMPACT ASPHALT' SET 11 PRE 10 12 FOL 12 13
12 QUE 'ROLLER IDLE'
13 QUE 'SECTION READY TO CHECK'
14 COM 'LEVEL CHECK' SET 14 PRE 13 17 FOL 17 18
15 QUE 'SECTION READY TO COMPACT AGAIN'
16 COM 'COMPACT ASPHALT II' SET 16 PRE 12 15 FOL 12 13
17 QUE 'CREW IDLE'
18 NOR 'DECISION MAKING' SET 18 FOL 15 20 PROB 0.1 0.9 SEED 1234
20 FUN COU QUA 1 FOL 21
21 QUE 'DONE TRUCK LOAD'
DURATION INPUT
SET 2 DET 5
SET 3 TRI 22 30 45
SET 5 DET 3.85714285714286
SET 6 TRI 22 30 45
SET 8 DET 0.428571428571428
SET 11 DET 8.15909090909091
SET 14 DET 15
SET 16 DET 5.71136363636364
SET 18 DET 1
RESOURCE INPUT
1 'LOADER' AT 1
3 'TRUCKS' AT 7
1 'SPREADER' AT 9
1 'ROLLER' AT 12
1 'CREW' AT 17
ENDDATA
```

Figure 7: CYCLONE Input File

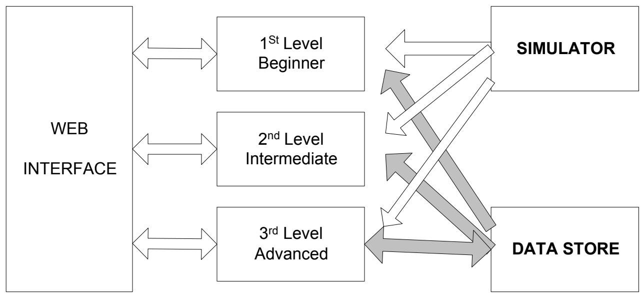

Figure 8: Web-Based Simulation Service Framework

At the second level of the construction process simulation web service framework, two issues must be addressed. The user must be able to modify existing models by changing duration data as well as resource requirements associated with the process. The user is also allowed to change the structure of existing models using graphical and numerical input, even though this must be implemented for users who are not familiar with the schematic modeling environment used in level three.

Web CYCLONE uses construction process modularization to address these intermediate level web modeling requirements. Construction process modularization is a means to package the entire process (e.g. asphalt paving) into a module. The module is designed to be versatile enough to address a wide number of modifications without changing the intrinsic structure of the module. For addition or deletion of an activity without user awareness or understanding of the modeling logic, it is necessary to find an effective algorithm to decide whether the addition or deletion is feasible (e.g. consistent with the modeling logic). If feasibility can be established, then an appropriate location within the model structure to insert the "plug in" must be determined. If a deletion is required, this surgical relinking to insure the model is consistent must be performed. This part of system and algorithm development based on model modularization is currently underway.

6 A CASE STUDY MODEL DEVELOPMENT – LEVEL 3

This section presents a case of level three development in the context of an asphalt paving process utilizing a paving machine and 20 ton capacity tri-axle trucks on the base layer of a 15' lane width road. The location of the process is central Indiana. The overall processes involved are:

- Hot-mix batch plant production.
- Placing asphalt pavement.

Details of the placement cycle are explained in the following:

6.1 Placing the Tack Coat

Before the paving operation starts, an asphalt distributor is used to spray asphalt on the unpaved surface. This film of asphalt serves as the prime and tack coats. The coats are then allowed to cure before the actual paving proceeds. The purpose of having these coats is to prevent any slippage between the surface and overlay during or after the compaction. (The Asphalt Institute)

6.2 Placing the Asphalt Mix

To start the paving operation, the paver is positioned properly onto the road. The screed of the paver is positioned to the level of the loose asphalt mat that is going to be laid on the road. (The screed is responsible for the setting the depth of the asphalt mix.) As soon as the haul truck arrives at the job site, the paving inspector must check that the asphalt delivered.

When loading the mix into the receiving hopper, the haul truck is placed carefully in front of the paver. The rear wheels of the truck should be in contact with the truck roller of the paver to avoid any misalignment with the paver. The paver will push the truck forwards as it paves the road. If skewness occurs, the whole process will be delayed because the truck in front of the paver must be repositioned.

As soon as the first load of asphalt mix has been spread, the uniformity of the asphalt texture should be checked. Operators will adjust the appropriate adjustment points to correct any non-uniformity. Any segregation of materials also should not be allowed. Operation should be stopped immediately if any segregation is detected.

The last process of paving is compaction. This process is highly influenced by major mix proportion; (1) asphalt content: aggregate size, shape texture and distribution gradation; (2) filler content, and; (3) mix temperature. Appropriate rollers and rolling methods should be used in accordance with these proportion. There are several roller combinations used for maximum results:

1. steel-tired static and pneumatic-tired rollers,
2. vibratory and steel-tired static rollers, or
3. vibratory rollers used in vibrating and static modes.

Four cycles are identified as asphalt paving processes and listed below:

- Hot-mix batch plant cycle.
- Tri-axle truck cycle.
- Roller cycle.
- Spreader cycle.
- Crew cycle.

The CYCLONE diagram describing the model is shown as Figure. 9.

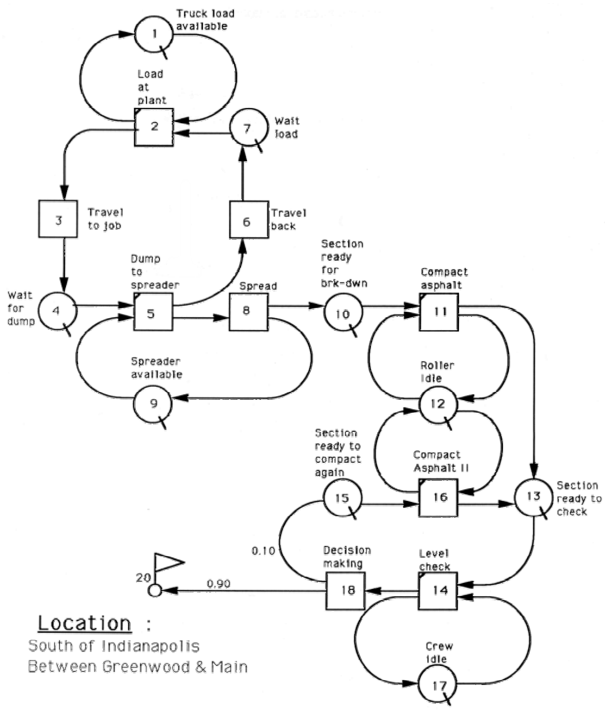

Figure 9: CYCLONE Diagram for Asphalt Paving Process (Paul et al. 1991)

The resources involved in the process are:

- Material: Aggregates; Hot mix asphalt material.
- Equipment: Trucks; Spreader; Roller;Batch plant (hot mix).
- Laborer : 4 laborer in a crew; 1 roller operator; 1 paver operator; 1 superintendent; 1 truck operators; 1 foreman.

The time duration for each activities were obtained from field for following activities:

- loading at batch plant.
- traveling to the job site.
- dumping the asphalt to spreader.

- back-cycle of the truck.
- spreading the asphalt.
- compacting the asphalt.
- checking the level.

The model shown in Figure 9 is typical of those developed at level 3 and stored for further use and retrieval.

7 SUMMARY

The WWW provides a level of accessibility to computer support for analyzing construction operations which is unprecedented. An expanding potential user base introduces the problem of simplifying access to analytical tools such as simulation. Interfaces must support access by users with varying levels of simulation knowledge and familiarity.

Web CYCLONE is a concept designed to allow users at the novice, intermediate and advanced levels of simulation expertise to study and analyze construction processes using computer based simulation systems. Three levels of user sophistication are identified and appropriate interfaces are proposed. This approach is based on a library of process models designed to provide varying levels of sophistication and precision. The level one interface utilizes the Interactive Simulation System (ISS) format and allows users with no simulation background to define construction process data. The level of precision of output is limited, but construction professionals with little or no simulation knowledge can use this level to obtain conceptual level estimates of process productivity.

The level two interface allows professionals with more simulation background to do some customizing of a given process by site adapting the generic model developed at level one. Graphical input aids and modularization of advanced simulation models support this level and provide an improved level of precision to the simulator.

The foundation of Web CYCLONE is represented by the libraries of detailed network based models using CYCLONE schematic model definition and the model retrieval capabilities supported by level three. These models are highly flexible and support the interfaces at levels one and two. Construction professionals with advanced simulation modeling skills can develop and store models at this level which are both comprehensive and flexible.

This approach to stylizing access to the power of construction process simulation is designed to exploit the WWW by providing a portal to process analysis for users with varying levels of need and sophistication.

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