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VALIDATING COMPLEX CONSTRUCTION SIMULATION MODELS USING 3D VISUALIZATION

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ABSTRACT

One of the primary impediments in the use of discrete-event simulation to design construction operations is that decision-makers often do not have the means, the knowledge, and/or the time to check the veracity and the validity of simulation models and thus have little confidence in the results. Visualizing simulated operations in 3D can be of substantial help in establishing the credibility of models and in obtaining valuable insight into subtleties of modeled operations that are otherwise non-quantifiable and presentable. This paper presents a case study of a simulation model of an earthmoving operation with fairly complex control logic that was verified and validated by visualizing the operation in 3D. The simulation model for the example was developed using Stroboscope and was visualized using the Dynamic Construction Visualizer.

KEYWORDS

Construction Operations, Simulation, 3D Visualization, Credibility

1 INTRODUCTION

The state-of-the-art construction simulation systems allow the modeling of complex construction operations in great detail and with utmost flexibility. Notwithstanding, there has been limited use of discrete-event simulation (DES) in planning and analyzing construction operations (Halpin & Martinez, 1999).

Construction simulation tools typically provide results in the form of numerical or statistical data. However, they do not illustrate the modeled operations graphically in 3D. This poses significant difficulty in communicating the results of simulation models, especially to persons who are not trained in simulation but are domain experts. The resulting “Black-Box Effect” is a major impediment in verifying and validating simulation models. Decision makers often do not have the means, the training and/or the time to verify and validate simulation models based solely on the numerical output of simulation models and are thus always skeptic about simulation analyses and have little confidence in their results. This lack of credibility is a major deterrent hindering the widespread use of simulation as an operations planning tool in construction.

This paper illustrates the use of DES in the design of a complex dynamic earthwork operation whose control logic was verified and validated using 3D animation. The model was created using Stroboscope and animated using the Dynamic Construction Visualizer.

2 VERIFICATION, VALIDATION AND COMMUNICATION OF SIMULATED CONSTRUCTION OPERATIONS

Verification is the process by which the model creator looks at what has been actually modeled, compares it to what was intended to be modeled, and updates the model to accurately reflect the intention. On the other hand, the aim of Validation is to determine whether simulation models accurately represent the real-world system under study. This is typically carried out by consulting people who are intimately familiar with the operations of the actual system, but who are not necessarily proficient in simulation.

Simulation models are termed as Credible when the models and their results are accepted as being valid, and are used as an aid in making decisions (Law & Kelton, 2000). In the case of both Verification and Validation, the inner workings of a model and its output need to be communicated to others for discussion and input, in a way that is both comprehensive and comprehendible (Oloufa & Ikeda, 1997).

Visualizing simulated operations can be an effective means of achieving this (Law & Kelton, 2000, Robinson, 1997). It is a generally accepted fact that visually presented information is understood and grasped more easily than any other form of communication. The need to visually communicate simulated operations is more relevant in the context of construction because construction operations analysts (e.g., superintendents) typically do not have the necessary training in simulation to allow them to validate simulation results based on numerical analysis.

Realistic 3D visualization can substantially help to communicate intricacies of simulation models. In addition, it can provide valuable insight into details of construction operations that are otherwise non-quantifiable and presentable. It has the potential to enable the extraction of knowledgeable information from simulations. Visual communication can aid both verification as well as validation of simulation models. Volumes of data that take hours to review can be communicated in a few seconds. For instance, many techniques are available to simulation analysts to perform verification (e.g., looking at simulation logs). However, a visualization of what occurred in the simulation model can reveal such errors very quickly. Similarly, communicating the working of simulation models to domain experts through visualization can allow errors in logic to be easily identified and corrected. This is the process of validation, and can be significantly enhanced by animating simulated operations. Through visualization, more people can gain a better understanding of modeled systems.

The remainder of this paper describes how 3D visualization was used to verify and validate the control logic of a simulation model of a complex earthmoving operation. In addition, the paper also highlights how the improvement of the operation was facilitated due to the visual insights provided by realistic 3D visualization.

3 EARTHMOVING OPERATION CASE STUDY

The presented operation involved moving 975,000 bank m3 of material in 75 workdays (16 work hours each) from two possible sources to a common dumpsite as shown on the plan view in Figure 1. The two sources are located towards the bottom left part of Figure 1 and are labeled MLA (main loading area) and ALA (alternate loading area). The dumpsite is towards the top right part of Figure 1 and is labeled DumpArea. The haul distances from the main and alternate loading areas to the dump area were 1,670 meters and 1,920 meters. Both haul routes shared 1,370 meters and included a narrow segment 470 meters in length. The narrow portion was not wide enough to allow simultaneous traffic in both directions. Due to the obstruction shown on Figure 1 and other site constraints, it was not feasible to widen the curve. The dump area was 42 meters above the main loading area and 68.5 meters above the alternate loading area. The underfooting in several parts of the haul routes was soft. The maneuvering space at the load and dump areas was limited.

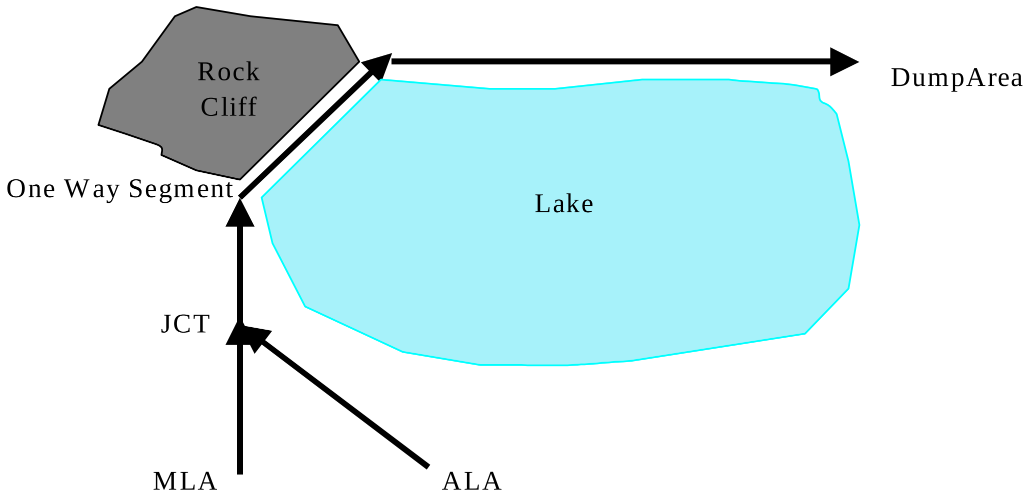

Figure 1. Plan View of the Earthwork Operation Jobsite

4 DISCRETE EVENT SIMULATION MODEL

The simulation tool used to design this operation, Stroboscope, is a programmable and extensible general-purpose system that is designed to model complex construction operations with utmost flexibility (Martinez, 1996). Stroboscope modeled in detail the transport portion of the operation, including dynamic truck routing strategies and the one lane (but bi-directional) haul road segment.

The primary control logic components that were verified and validated through 3D visualization were:

- Truck Routing Strategy to main and alternate loading areas
- Traffic Management on the narrow one-way segment

In the initial routing strategy, trucks returning after dumping were routed to the main and alternate loading areas with likelihoods of 8 and 4 respectively, indicating a 66.7% probability that a returning hauler would go to the main loading area, and a 33.3% probability that the hauler chose the alternate loading area. This initial truck routing strategy was rather naïve but was the easiest to set up in an initial simulation model. Based on the insights gleaned from visualization, subsequent stages of the operation design explored more sophisticated truck routing strategies by using dynamic formulas to define likelihoods.

The default operating logic for the one-way segment marked for travel in either direction was defined such that a truck arriving to the empty segment established the current direction of travel. This direction was maintained as long as trucks kept arriving at the same end of the segment. Trucks eventually stopped arriving at that end and the segment cleared as the last truck exited. At that point direction of travel reversed if trucks arrived and were waiting at the other end. Otherwise it was again established by the next truck to arrive. In this study, it was necessary to analyze and optimize the transport capacity of the narrow segment, as it was the most constrained control parameter.

5 THE DYNAMIC CONSTRUCTION VISUALIZER

The Dynamic Construction Visualizer (DCV) is implemented as a virtual environment application that can process ASCII text files (trace files) written in the DCV language to unambiguously describe the spatial and temporal configuration of simulated operations.

The trace file driven approach allows its seamless integration with numerous process modeling tools that are capable of generating formatted text output during a simulation run. The required trace file consists of sequential animation command statements such as CREATE, DESTROY, PLACE, and MOVE. In addition, the file also contains statements such as PATH and NONDIRECPATH that define resource movement paths during the animation. The statements in the input file are then processed sequentially to visualize the modeled operations in 3D virtual space.

This is accomplished using 3D CAD models of the involved system resources (e.g. Trucks and Loaders) and other model entities. The result is in essence a “motion picture” of the actual operations being carried out in the virtual environment. This “motion picture” can be replayed at varying speeds depending on the viewer’s preferences. In addition, the system also allows users to jump ahead or back to any point in simulation time which is fairly analogous to being able to instantaneously rewind and fast forward a motion picture tape to a desired location. The user is able to navigate easily in 3D virtual space and hence can position himself/herself at any vantage position he/she desires at any time during the visualization process.

Realistic animations can be created using 3D CAD models from supported data file formats such as .3ds (3D Studio™), .iv (Open Inventor™), and .wrl (VRML). Practically every CAD modeling program can export data files in VRML format. Thus, the DCV is practically independent of any CAD modeling software as well.

6 VISUALIZATION OF THE MODELED OPERATION

Stroboscope produces static output in the form of tables and charts. In addition, Stroboscope models can be instrumented to generate animation trace files conforming to the syntax of the DCV language during simulation runs. The trace files are then processed by the DCV visualization engine to depict 3D dynamic output in the form of animations.

The viewer was able to observe the presented operation in a very realistic manner. In addition, the viewer was able to see all the characteristics of the terrain such as the gradients of the routes, the limited maneuvering spaces at the loading areas, the configuration of the one-way segment, and the limited visibility (due to steep grades) available to truck drivers approaching the junction from the loading areas (point JCT in figure 1). At all times, the viewer could “move” to any desired location on the virtual jobsite using keyboard keys to steer. The level of detail at which the operation was visualized comprehensively established the veracity and the validity of the simulation model.

In addition, it provided numerous non-quantifiable and otherwise presentable details that were critical in making decisions. The basic problem with the narrow one-way segment was that loaded trucks, traveling uphill, were very slow. They arrived at the curve at such an interval that they entered when a previous truck was almost exiting. The direction of travel was thus maintained in the loaded direction for very long periods, during which empty trucks arrived and bunched at the other end. When empty trucks entered the curve, however, they traversed and cleared it very quickly. The dynamic output produced by the DCV provided a much better picture of the truck bunching and additionally revealed strategies that could be used to improve the operation. Figure 2 shows a snapshot of the animation with 5 empty trucks bunched up waiting to enter the big one-way segment; one loaded truck about to enter the curve before another loaded truck finishes traversing it; and one loaded truck heading towards the dump area. The slow speed of the loaded trucks and the fast speed of the empty trucks as they traverse the curve cannot be seen on the snapshot. Only the animation can convey that information.

Figure 2. Bunched up Trucks Waiting to Enter the Narrow Segment

Figure 3 shows snapshots of the animation a while later, when the trucks that had bunched up have arrived almost together to the main and alternate loading areas. A few trucks are out of view in the snapshot but will arrive soon to the loading areas. The visualization provided clear indications that the entry of loaded trucks to the segment had to be controlled so that empty trucks could traverse it in smaller bunches.

(a) Main Loading Area (MLA) (b) Alternate Loading Area (ALA)

Figure 3. Bunched up Trucks Waiting for Excavators

The visualization also revealed the ineffectiveness of the probabilistic (but random) truck routing policy; at times trucks were routed to an excavator that was busy and had a long queue of trucks waiting to be served even though the other excavator was free. Visualizing the operation clearly indicated that the percentages naively used in the preliminary design were not a bad choice, although the routing method itself was.

7 CONCLUSION

The purpose of using simulation to model construction operations is to obtain insights into the consequences of using different techniques and strategies and thus helping the planner in making the most advantageous decisions. This paper demonstrated that visualizing simulated operations in 3D enhances the credibility of simulation models by realistically communicating the modeled operations. In addition, it also demonstrated that the dynamic visual output provided by 3D visualization can provide subjective details about the operations that can be of immense help in decision-making. The paper also introduced the DCV system that provides numerous simulation languages and packages with the support necessary to visualize the simulated operations in 3D, enabling planners and designers to obtain a more realistic and comprehensible feedback from simulation analyses.

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