

Dynamic Interface Simulation for Construction Operations (DISCO)

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ABSTRACT

Application of the Visual Simulation technique (VS) to assist in the planning and analysis of construction operations has become increasingly important in the research community in recent years. Benefits of applying VS have been reported in several publications. Nevertheless, the effort required to design and construct an "appropriate" representative display for the system to be analyzed in a VS experiment is frequently time consuming and data intensive. The magnitude of this activity is often increased due to certain characteristics of construction operations, such as their complexity and the distribution of work over large areas. An alternative approach, DISCO, which employs a schematic modeling format reflecting the system dynamics on the computer screen during simulation run is presented in this paper.

1. INTRODUCTION

DISCO is an alternative approach for the simulation of construction operations. It employs an abstract model diagram (e.g. CYCLONE model diagrams) of a system as the modeling framework and dynamically shows on the computer screen the associated simulation parameters, such as the simulation clock time, percent of time resources idle, number of resource units idle, percent of time work task busy, etc., during the simulation run-time. System dynamics can be better understood by monitoring the continuously updated information shown on the screen.

The idea of DISCO is conceived from the application of "Visual simulation" and "Schematic Abstraction" for process planning and analysis modified to reflect the characteristics of construction operations. DISCO preserves some of the benefits provided by using VS, while utilizing a schematic model diagram to reduce the amount of data and time required for model building. Both VS and "Schematic abstraction" are briefly reviewed in the paper prior to the further discussion of DISCO.

A prototype program, also named DISCO, is developed to implement the DISCO methodology and is introduced in this paper. A dry batch delivery and concrete placement model is used to demonstrate the application of the DISCO program. Findings and conclusions are presented.

2. VISUAL SIMULATION (VS)

Visual Simulation applies modern computer graphics techniques for facilitating the development and study of simulation experiments. Its utilization of computerized visualization conveys the

physical configuration of the system of interest graphically in a format that appears very much like the real thing and allows the user to visualize the dynamic behavior of the system model during the simulation run-time.

Many "expressions" have been used to refer to this type of simulation with each of them featuring its special capabilities. "Animation" (System Modeling Corp. 1990; Johnson and Poorte 1988) is probably the most popular one with its capability of generating cartoon type of visualization. "Visual Interactive Simulation (VIS)" allows the user to "interact" with the model during the simulation (Bell & O'Keefe 1987). Other expressions such as "Graphical Simulation" (CII Source Document 68 1991), or "Visual Simulation" (Rodriguez 1992) are employed to refer to VS systems which feature realistic 3 dimensional visualization.

In general, there are two types of VS applications depending upon the level of display reality - pictorial and iconic. Figure 1 shows an emulated construction job site using a VS system - ICV (Rodriguez 1992). Users are able to see the movement and operation of "cranes", "trucks", "front-end loaders", "fork-lifts" on the screen as the simulation goes on, very much in the way the modeler would see these resources in the real world. This pictorial type of VS frequently involves 3-D CAD modeling and requires the presence of graphical workstations.

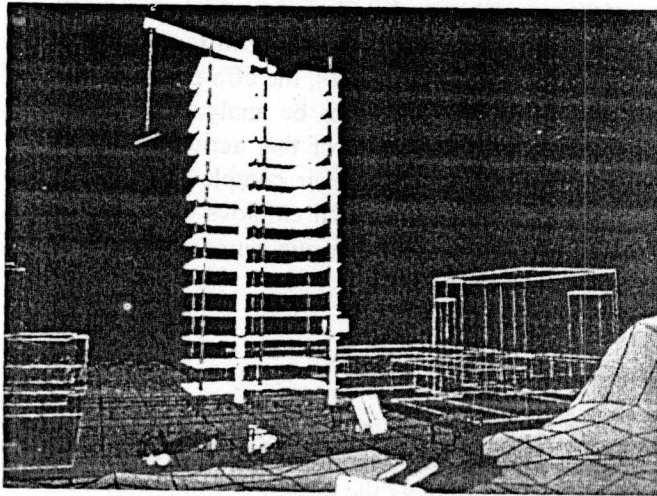


Figure 1. An Animated Construction Job Site (Adapted from Rodriguez 1992)

In contrast to pictorial representation, iconic VS models use icons to represent object components in the interested system. The reader is referred to the "CINEMA IV Reference Guide" (Systems Modeling Corp. 1990) for examples.

The benefits of applying VS have been reported in several publications (Rodriguez 1992; CII SD 68 1991; Griffis et. al. 1991; Cleveland & Francisco 1988; Johnson 1988; Bell and O'Keefe 1987). VS modeling provides the following advantages:

- VS enables the evaluation of project design and construction terminology by all members of the team to facilitate the manufacturability and constructibility review.
- VS enables greater understanding and awareness of the project and helps the site personnel to visualize how and what should be constructed in the coming period.
- VS facilitates the communication among all the parties involved in a project, which helps to alleviate fragmentation during the project realization.
- VS assists in planning the sequence of activities in a process and in organizing people, materials and machines to allow the most productive efforts in a particular area.

- VS helps to prevent safety problems like a collision between two cranes.
- VS serves as a medium for training and education purposes, etc.

Nevertheless, the activity of designing and constructing an appropriate representative display of the interested system is still very data and time intensive. The magnitude of this demand is increased due to certain characteristics of construction operations.

- Construction operations are complex in their nature due to the involvement of dynamic and complicated resource interactions.
- Construction operations are frequently performed on highly diverse one-of-a-kind job sites. The representative display for construction operations can be very different in different job sites.
- Construction operations frequently involve great dimensions, such as in long-distance earth-hauling processes, a long tunnel excavation, a high-rise building construction, and so on. Design and construction of representative visually accurate displays is made more difficult and a schematic diagram may be more informative.
- The dynamic nature of construction sites as the work progresses causes the display of the job site to be continuously changing and generates a large number of viewing perspectives.

3. SCHEMATIC MODEL ABSTRACTION

Model abstraction has become standard practice for engineers in approaching problems in the real world since such problems are often complicated and the underlying interactions involved are better reflected by considering abstract models. An abstract model captures system behavior and enables engineers to perform analysis so as to better understand the targeted problem. In general, the degree of abstraction can range from the reality of a photo image to the abstraction of a mathematical formula (Figure 2).

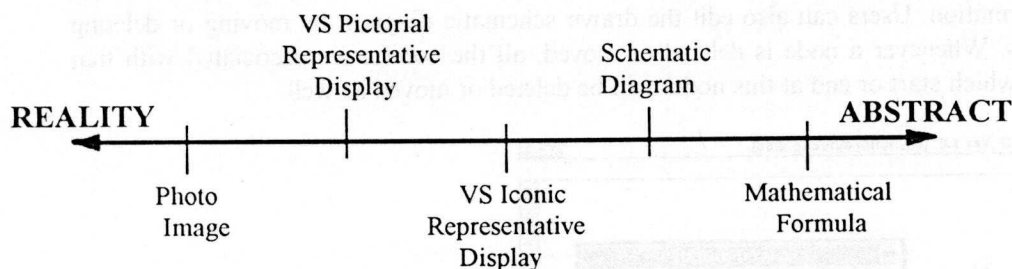


Figure 2. Relationship of "Schematic Diagram" to the Other Model Abstraction

The unique, complex, and dynamic nature of construction operations creates difficulties for the design and construction of representative displays and therefore hinders the application of VS for the purpose of engineering analysis. Schematic abstraction, on the other hand, has long been used for network modeling and analysis in simulation experiments and simplifies model definition. This type of modeling is not data-intensive (no need for geometric information), not dimensionally confined, and logically well defined. In many cases, it is arguable that schematic modeling suits the purposes of engineering planning and analysis of construction operations much better than a pictorial display.

Typical schematic diagrams are like those constructed by using a set of standardized building blocks in general simulation languages, such as GPSS, SLAM II, or construction specific systems, such as MicroCYCLONE (Halpin 1990). A MicroCYCLONE schematic diagram of a dry batch delivery and concrete placement model will be shown later.

4. DISCO

DISCO is a prototype program developed to implement the aforementioned DISCO approach. It is written in MicrosoftTM Visual Basic language and runs under the WindowsTM operating environment. CYCLONE modeling methodology (Halpin 1973) was selected for the abstract model building due to its emerging popularity in the construction research community. Its set of standard building blocks (namely, NORMAL, COMBI, QUEUE, CONSOLIDATE, COUNTER, and ARC elements) constitute the basic drawing icons in the DISCO graphical menu bar. Readers should refer to "Planning and Analysis of Construction Operations" (Halpin and Riggs 1993) for details regarding the CYCLONE modeling methodology.

Basically, the DISCO program serves as a post-processor of MicroCYCLONE program data because it takes the chronological list file generated by running MicroCYCLONE program as its input and then recreates the entire course of simulation dynamically on the computer screen. The DISCO program performs three major functions as follows:

- (1). It builds a schematic model diagram graphically on the screen.
- (2). It displays the model dynamics by continuously updating the associated information for each node during the simulation run.
- (3). It reports node statistics information graphically and tabularly at any simulation event time point.

4.1 Build the schematic model diagram

DISCO allows the user to create the schematic model diagram, using CYCLONE standard building blocks, for the system being studied. The user can create nodes or connectors between nodes by simply clicking on the appropriate icon from the DISCO graphical menu bar (Figure 3) and dragging it over to the drawing area. A dialogue box will pop up asking for the input of information associated with that particular node, such as label number, node description, initial unit number in the QUEUE node, and so on. Users can always double click on any node to recall the dialogue box for editing the node information. Users can also edit the drawn schematic diagram by moving or deleting nodes and connectors. Whenever a node is deleted or moved, all the connectors associated with that particular node (i.e., which start or end at this node) will be deleted or moved as well.

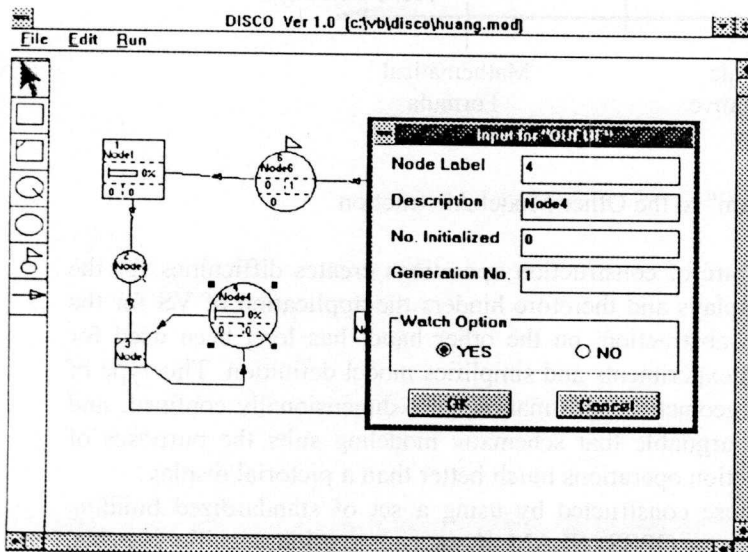


Figure 3. DISCO Menu and Display Screen

It should be noted that the "Watch Option" (Yes or No) information in each node determines whether the simulation run-time information associated with a particular node such as % time idle, will be "watched" (shown) later during the simulation or not. Nodes with "yes" in the "Watch Option" box have a bigger node size in order to display simulation run-time information (e.g., Node 4 in Figure 3). Again, users can always go back and forth to change the option except for the COUNTER node for which the "Watch Option" is automatically invoked and must be used. This mechanism provides the user opportunities to watch nodes alternatively and enables the user to focus on watching certain nodes and not to be distracted by too many "watched" nodes during the simulation run.

The completed schematic model diagram will be used later as the background display during the simulation.

4.2 Display of model dynamics

After the schematic model diagram is drawn on the DISCO drawing area and the chronological list file (.DIS) is generated by running MicroCYCLONE program, the user can trigger the simulation and DISCO will recreate the entire course of simulation dynamically on the screen. A simulation clock will be shown on the screen to indicate the updated simulation time point T-NOW. As the value of simulation time advances, run-time information for those nodes being "watched" are continuously updated throughout the simulation. The display format of the run-time information contained in "watched" nodes is as shown in Figure 4.

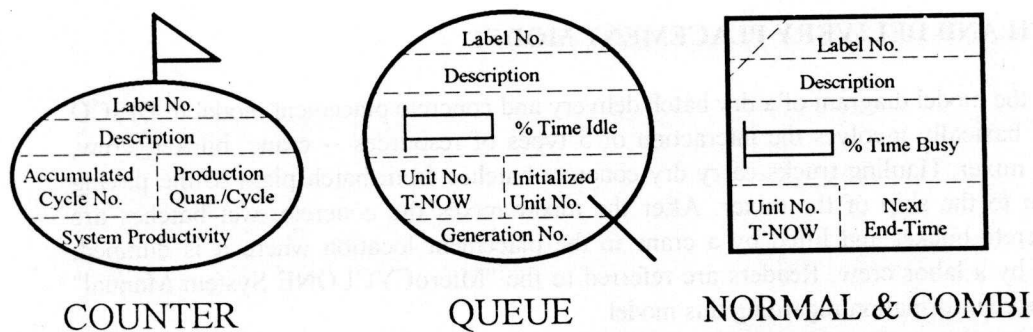


Figure 4. Format of DISCO "watched" Nodes

Most of the legend shown in Figure 4 is self-explanatory except for the two values at the bottom of the NORMAL & COMBI nodes. It is not uncommon for a construction operation to have parallel work tasks. In an earth-hauling process, for instance, two trucks can be loaded at the same time if there are two front-end-loaders available. "Unit No. T-NOW" at the left bottom indicates the number of units presently transiting that particular work task at T-NOW, while "Next End-Time" at the right bottom shows the closest next event time when the realization of that task will be completed.

The DISCO program attempts to create the impression of "animation" during the simulation run by employing colors. Each type of node is assigned a different color (except NORMAL and COMBI which share the same one.) The color goes on if an unit "enters" an empty node. The entering unit can be a truck returning to an empty queue, or the realization of a task which has no parallel ones going on. Similarly, the color goes off when the last unit "exits" a node. Once the simulation starts, the user is able to see colors flashing on and off on the screen, along with continuously updated run-time information. This mechanism allows the user to experience system dynamics during the simulation run.

4.3. Report node statistics

Throughout the simulation, the DISCO program keeps track of all the run-time information associated with each node. The user can request reports on the statistical information of a particular node at any simulation time by double clicking on it. A report box will appear on the screen and the execution of the simulation will be interrupted. The user has to select the type of report to be viewed and the report is then displayed both graphically and in tabular format. Table 1 lists the types of reports provided by DISCO program.

Table 1
DISCO Report Types

	NORMAL	COMBI	QUEUE	CONSOLIDATE	COUNTER
Unit No. Profile	✓	✓	✓	✓	
% Time Idle (Busy)	✓	✓	✓		
Duration Histogram	✓	✓			
System Productivity					✓

The execution of the simulation resumes automatically once the user has completed viewing the reports. The overall statistical information of each node can be obtained in the same manner at the end of simulation.

5. A DRY BATCH AND DELIVERY PLACEMENT MODEL

Figure 5 shows the model diagram of a dry batch delivery and concrete placement model in DISCO format. This model basically involves the interaction of 5 types of resources -- crane, bucket, crew, truck, and concrete mixer. Hauling trucks carry dry concrete batches from batch plant to the paving site and dump them to the skip of the mixer. After the mixer mixes the concrete, wet batches are dumped into a concrete bucket and lifted by a crane to the placement location where it is dumped, spread and finished by a labor crew. Readers are referred to the "MicroCYCLONE System Manual" (Halpin 1990) for more information regarding this model.

In order to monitor the performance of the trucks, mixer, crane and labor crew in this particular simulation run, Node 9, 13, 17, and 23 are set to be "watched." In addition, selective work tasks such as "Load Truck" (Node 2), "Dump to Skip" (Node 6), "Fill Bucket" (Node 12), etc., are "watched" so as to better understand the system dynamics. As shown in Figure 5, prior to the beginning of the simulation, the simulation clock is set to 0.00. Green color (not visible in the figure) in all the QUEUE nodes with initialized resource (e.g., crane, bucket, trucks, etc.) signals the availability of a resource. The % Idle time in these nodes is set to 100 initially. It is immediately apparent that "Load Truck" (Node 2) will be the only task to be scheduled at simulation clock (T-NOW) 0 due to the availability of both required resources -- loading tower and hauling truck.

Once the simulation starts, the node color of "Load Truck" (blue) signals the commencement of this task and the unit No. at the left node bottom is updated to 1. The next-end-time at the right node bottom is updated to 15 to indicate the time loading of the first truck will be completed. Meanwhile, the node color of "Tower" goes off and the unit No. is decreased to 0 since it is busy loading the truck. In addition, the unit No. in the "Truck Queue" (Node 9) is decreased to 3 meaning that 3 trucks are now idle at the truck queue.

T-NOW is advanced to 15 at which time the loading of the first truck is finished. The node color of "Load Truck" goes off. The first truck carries dry concrete batch and travels to the site for mixing. The node color of "Travel" (Node 4) flashes on. The tower is now available (node color on) for loading another truck. Since three trucks are waiting in the truck queue, another "Load Truck" task can be

scheduled at this time point. Again, the node color of "Tower" and "Load Truck" flashes off and on respectively. Meanwhile, all the run-time information contained in these nodes is updated accordingly.

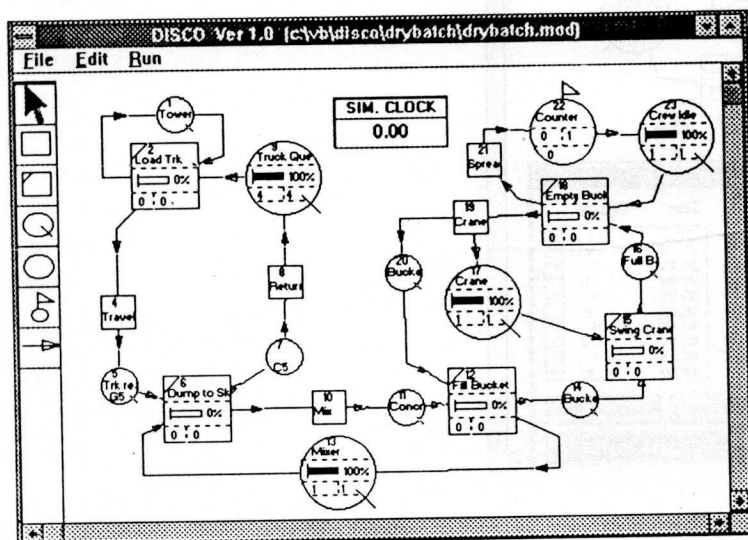


Figure 5. Model Diagram of a Dry Batch Delivery and Concrete Placement Model in DISCO

As the simulation continues, the user can view the loaded truck as it arrives at job site and dumps dry concrete to the mixer skip. The mixer mixes the concrete and fills the crane bucket with wet concrete. The crane then lifts and swings the bucket to the paving site and labor crew empties the bucket, spreads and finishes the concrete while the crane swings back for lifting another concrete bucket.

A crane utilization profile (Figure 6), which records the crane status (busy or idle) through time, is obtained by double-clicking on the "Crane" node (Node 17) at simulation clock time 56.25. It is obvious that, so far, the crane was idle most of the time, which is reflected by its 77% idle time. In fact, it remained idle until time 29.5.

Similar reports on the trucks, the mixer, and the labor crew at different simulation clock times can be obtained in the same manner. By double clicking on the "Counter" node (Node 22), a report on system performance (productivity) is shown in the report box.

6. FINDINGS AND CONCLUSIONS

Instead of pictorial or iconic display, as in Visual Simulation, DISCO employs schematic diagrams as the background display to demonstrate system dynamics during simulation runs and provides an alternative approach for the simulation of construction operations.

Simulation run-time data as well as the end results are more meaningful to analysts when they are displayed on the screen along with the schematic model diagram. System dynamics are better understood through the use of "node color on and off" mechanism and also the continuous updating of the node information. DISCO graphical and tabular reports allow monitoring of chronological information on each node at any simulation time point. This further facilitates the use of the DISCO program for planning and analysis of construction operations.

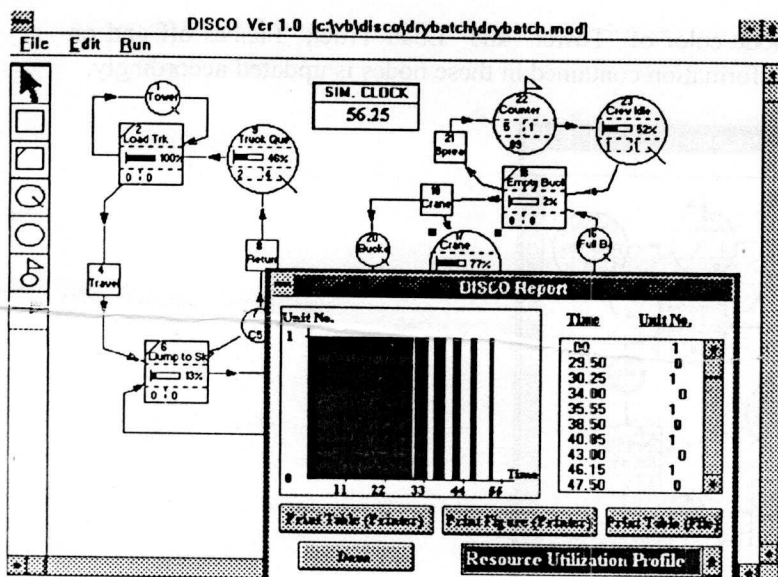


Figure 6. DISCO Report: Crane Utilization Profile

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