PRESENTING SIMULATION RESULTS WITH TESS™ GRAPHICS

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ABSTRACT

Graphics provide an appropriate and effective mechanism for displaying the results of simulation runs. These results include individual observations of data values and statistical summaries of these values, as well as the structure and dynamics of models. Standard business graphics and animation techniques can be used to display these simulation results. TESS provides a framework for a collection of data during simulation runs, the selection of data to appear on graphs, and the generation of presentation graphs and animations.

INTRODUCTION

The advent of reasonably priced graphics terminals and hardcopy equipment has stimulated a great interest in using graphics to present the results of simulations. Furthermore, simulation results are well suited for graphical presentation. Simulation results may be classified as:

1. The number of entities currently doing something, such as residing in a queue.
2. The time taken by entities to do something, such as the time spent in a queue.
3. The status distribution of a resource, such as busy, idle, broken and under repair.

Results concerning these quantities are gathered from a simulation run either as individual observations of data values or statistical summaries of these observations. Typical summaries are: frequency distributions and basic statistics, such as average, minimum, and maximum.

Standard business graphs can be used to present these simulation results. Pie charts and bar charts are useful means of showing the status distribution of resources. Histograms can be used to show the distribution of the time taken to do something. A range chart shows the minimum, maximum and average of any variable. Plots show the number of entities concurrently doing something over time or the number of resources of having a particular status over time, such as busy. Other kinds of plots can be used to show individual observations of the time to do something.

Animation techniques can be brought to bear in displaying simulation results as well. Discrete simulations produce a time sequenced list of the events of the simulation. This list is commonly called a trace. The structure and dynamics of the system, as captured by a simulation, can be shown graphically by animating actions who begin or end correspond to the events in the trace.

TESS (I) provides a method for capturing simulation results and displaying these results graphically. Graphs produced by TESS of simulation results, TESS capabilities for choosing data to appear on graphs, and collection of data from simulations using TESS will be presented.

METHODS

TESS provides for the collection of results of simulation runs, both automatically and through user-written code; the selection of data to be placed on graphs; the formatting of graphs, either automatically or by user specifications; and the production of graphs of all simulation runs. Figure 1 specifies the flow information from data collection specification to the production of graphs.

Data collection specifications are made part of the simulation experimental control. Forms are completed to specify the collection of both individual observations and summaries. Individual values of the time taken by entities to do something are recorded as they are observed. Values of resource status or the number of entities concurrently doing something either can be observed as these variable values change or sampled periodically. Summaries computed by the simulation can be stored periodically during the run or only at the end of the simulation. All of these results are stored in the TESS data base.

TESS provides a powerful data selection mechanism for choosing the simulation results to be shown on a graph. For example, suppose that individual observations of the lengths of three queues, QUEUE1, QUEUE2, and QUEUE3 have been collected and jointly labeled QUEUES. Two simulation scenarios have been simulated with the first called CURRENT and the second PROPOSED. The TESS language statement

```
GRAPH DATA NAMED(QUEUES)
    SCENARIO(CURRENT);
```

will produce a graph showing the lengths of the three queues over time on the CURRENT scenario. The TESS statement

```
GRAPH DATA NAMED(QUEUES)
    SCENARIO(CURRENT)
    VARIABLE(QUEUE3, TNOW);
```

produces a graph containing only the value of the variable QUEUE3 versus time from the CURRENT scenario. The TESS statement

```
GRAPH DATA NAMED(QUEUES)
    SCENARIO(CURRENT, PROPOSED)
    VARIABLE(QUEUE3, TNOW);
```
produces a graph containing two lines, one for the
variable QUEUE3 in the CURRENT scenario and the other
for the value of this variable in the PROPOSED
scenario. The TESS statement

```
GRAPH DATA NAMED(QUEUE3)
    SCENARIO(CURRENT)
    VARIABLE(QUEUE3, TNOW)
    WHERE(TNOW, LE, 100);
```

produces a graph for the variable QUEUE3 versus time
from the current scenario from the beginning of the
simulation run to time 100. These examples
illustrate the ability to select variables,
scenarios, and subsets of simulation runs in choosing
the values to be shown on graphs produced by TESS.

All TESS graphs can be produced using default
formats. Alternatively, the analyst may use the TESS
format builder to specify the parameters of any
graph. The format builder consists of a set of forms
specific to each type of graph. User specified
formats are stored in the TESS data base for use at
the time the graph is created.

Graphs are created by combining formats, either user
specified or default, with simulation results
specified using TESS data selection procedures. The
types of graphs available in TESS, including
animation, will be presented in the next section.

EXAMPLE GRAPHES OF SIMULATION RESULTS

TESS capabilities for graphically presenting
simulation results will be illustrated in terms of
a simple problem. In a quarry to be studied, trucks
deliver ore from three shovels to a single crusher.
Trucks are assigned to two specific shovels, so that
a truck will always return to its assigned shovel
after dumping a load at the crusher. Currently, each
shovel is assigned four 20-ton trucks. Due to the
age of the current trucks and availability of new
equipment, quarry management is considering acquiring
several 50-ton trucks to replace some of the 20-ton
trucks. The objective of this initial study is to
evaluate the current quarry operation versus the
proposed operation in which two 20-ton trucks will be
replaced by a single 50-ton truck at each shovel.
The structure of the quarry system is illustrated in
the TESS facility diagram given in Figure 2.

The status of the truck resource in the system is
measured by the percentage of time trucks spend in
the various locations of the quarry. Results for the
CURRENT operation scenario, called BASELINE, are
shown in the pie chart in Figure 3. The pie chart
was generated using the TESS statement

```
GRAPH SUMMARY NAMED(TRUCKLOC)
    SCENARIO(BASELINE)
    TYPE(PIE)
    FORMAT(BLOC);
```

Time delays incurred by trucks are also of interest.
One such delay is the time taken from entry into the
queue of a shovel, the loading of the shovel, travel
to the crusher and loading at the crusher and return
to the shovel. The spike plot shown in Figure 4,
shows individual observations of the quantity of
trucks assigned to shovel 1. This graph was
generated using the TESS statement.

```
GRAPH DATA NAMED(DELAYS)
    SCENARIO(BASELINE)
    VARIABLE(CYCLE, TNOW)
    WHERE(SHOVEL, EQ, 1)
    TYPE(SPIKE)
    FORMAT(CYCLEOBS);
```

The height of each spike represents an individual
cycle time. The intersection of the spike with the
time axis shows the time the cycle was completed.
The distance on the X axis between spikes shows the
time between observations.

Statistical summaries of the truck cycle time to the
quarry can be graphed as well. Figure 5 shows a
graph of the mean, minimum, maximum of this value by
size of truck for each of the two scenarios. The
TESS statement

```
GRAPH SUMMARY NAMED(ANALYSISIZE)
    SCENARIO(BASELINE, NEWLINE)
    FORMAT(SIZE);
```

is used to generate the graph.
Presenting Simulation Results with TESS™ Graphics

Figure 2: TESS Facility of the Quarry Structure

Figure 3: Pie Chart of Truck Status
Figure 4: Spike Plot of Time Delay Observations

Figure 5: Range Chart of Time Delay Statistics
In addition, the frequency distribution of observations of the cycle time can be portrayed. The histogram shown in Figure 6 shows two frequency distributions, one for each of the two scenarios for the cycle time variable. In each group of two bars, the left bar represents the BASELINE scenario and the right bar represents a NEWLINE scenario. This histogram was generated using the TESS statement

```
GRAPH SUMMARY NAMED(CYCLEFRE)
   SCENARIO(BASELINE,NEWLINE)
   TYPE(HISTOGRAM)
   FORMAT(CYCLEHIST);
```

It is of interest to compare the number of trucks in the queue of the crusher over time. The graph in Figure 7 contains two lines. Each line represents the length of the crusher queue in a particular scenario. This graph was generated using the TESS statement

```
GRAPH DATA NAMED(QUEUES)
   SCENARIO(BASELINE,NEWLINE)
   VARIABLE(CROQUEUE,TCNOW)
   FORMAT(CROPLOT);
```

In a similar way, the quarry throughput in each of the two scenarios can be compared using a bar chart as shown in Figure 8. In each group of two bars, the lefthand bar represents the BASELINE scenario and the righthand bar represents the NEWLINE scenario. The bar chart was generated using the TESS statement

```
GRAPH SUMMARY NAMED(THRUPUT)
   SCENARIO(BASELINE,NEWLINE)
   FORMAT(THRUPUT)
   TYPE(BAR);
```

**ANIMATION**

TESS provides a framework for constructing and displaying animations of simulations, either concurrently with the simulation, after the simulation or both. Figure 2 shows a diagram of this framework. Animations consist of three parts: FACILITY, RULE, and trace DATA. A FACILITY is a schematic model of a system constructed to look like the system but omitting some details needed to simulate the model. Trace data embody the history of the simulation run, forming a record of a subset of the events that occur in a simulation. A RULE is a set of statements which tell what actions to take during an animation based on the events which occur in the simulation. An ICON is an elementary symbol from which facilities are built. TESS predefines certain basic ICONs such as rectangles and triangles. In addition, the user may define and draw ICONs, storing them in the TESS database for recall when facilities are built.

A TESS animation shows the dynamics of a simulation. State changes can be shown by changing the color of an ICON or displaying a different ICON for each state. Movements along predefined pathways show movements represented by the simulation. Variable values can be shown numerically as counters or by colored bars which dynamically change length. Items in a queue appear as a set of ICONs. Continuous movement of liquids for example, can be shown as a flow on a path.

**SUMMARY**

TESS provides necessary and sufficient capabilities for the graphical presentation of simulation results. These results include individual data values and statistical summaries of resource status, time taken to do something, and the number of entities currently doing something. Graphs such as plots, pie charts, bar charts, histograms, and range charts are used to portray the information. In addition to these graphical presentation capabilities, TESS provides for the automatic collection of data during simulation runs, selection of data to appear on graphs, and user controlled formatting of graphs. To supplement graphing capabilities, TESS provides for animations which show the structure and dynamics of simulation runs.

**REFERENCE**

Figure 6: Histogram of Time Delay Observations

Figure 7: Discrete Plot of Queue Lengths
Figure 8: Bar Chart of Throughput

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