Proceedings of the 1985 Winter Simulation Conference
D. Gantz, G. Blais, S. Solomon (eds.)

PRESENTING SIMULATION RESULTS WITH TESS™ GRAPHICS

Charles R. Standridge, Ph.D.
John R. Hoffman
David K. LaVal
Pritsker & Associates, Inc.
P.O. Box 2413
West Lafayette, IN 47906

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's beginning or end correspond to the events in the trace.

TESS (1) 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);
```

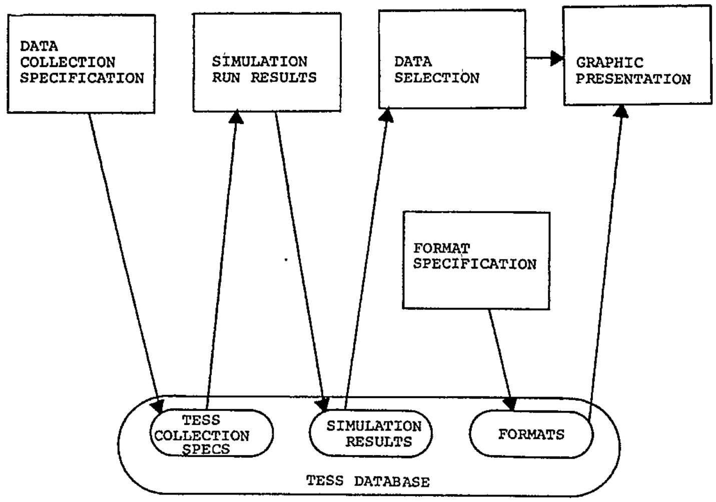

Figure 1: TESS Data Flow for Graphics Presentation

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(QUEUES)
      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 GRAPHS OF SIMULATION RESULTS

TESS capabilities for graphically presenting simulation results will be illustrated in terms a sample 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(ANALBYSIZE)
        SCENARIO(BASELINE,NEWLINE)
        FORMAT(SIZE);
```

is used to generate the graph.

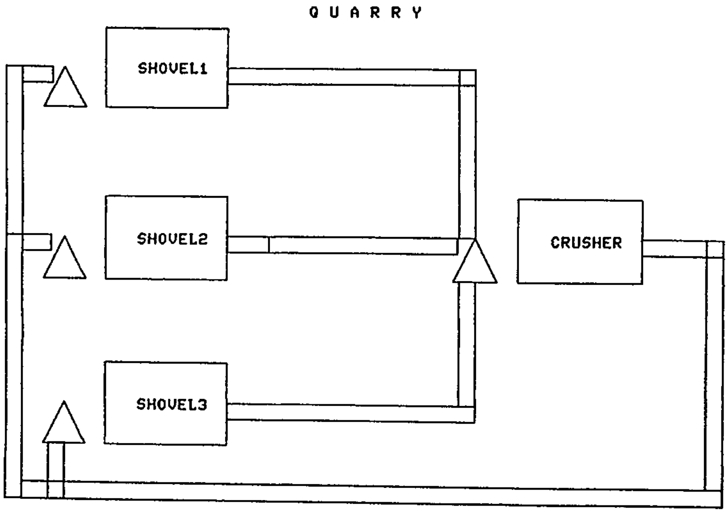

Figure 2: TESS Facility of the Quarry Structure

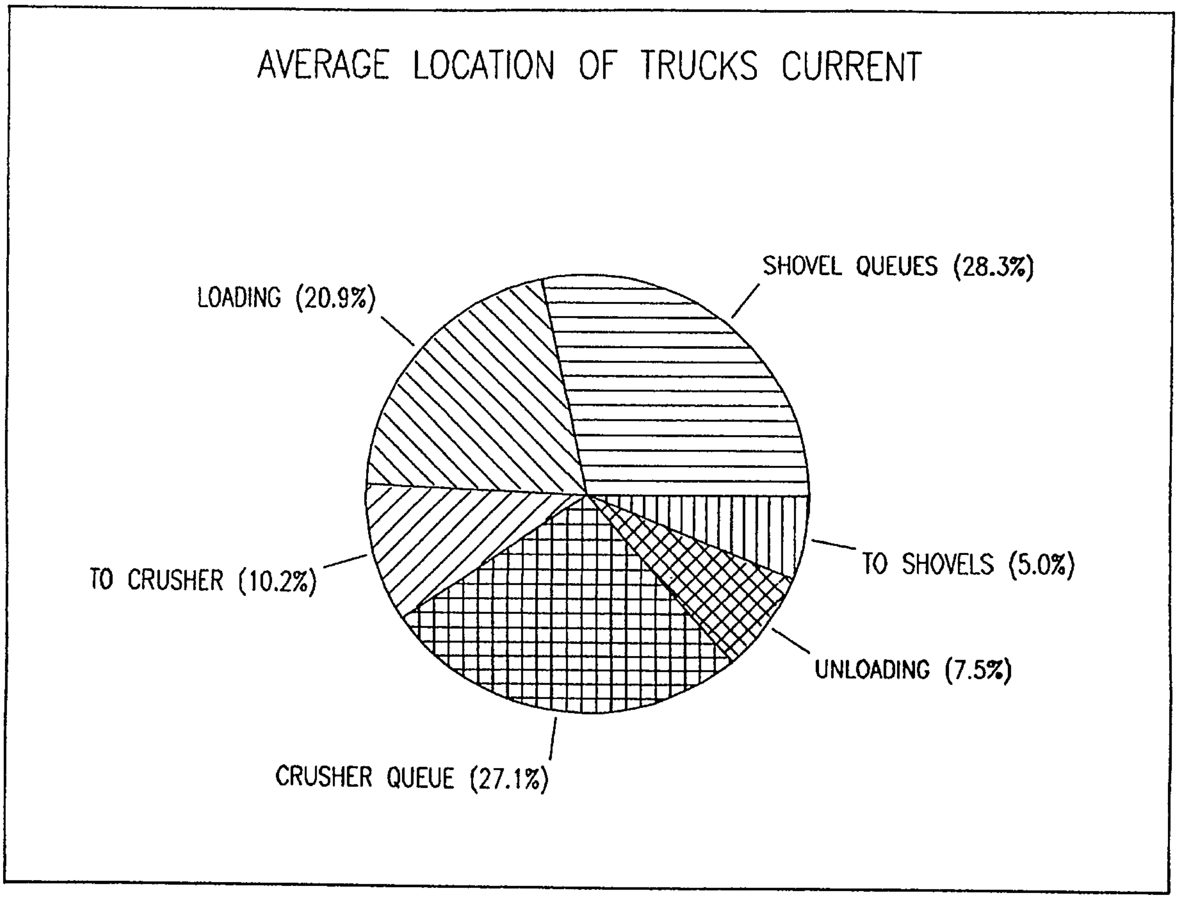

Figure 3: Pie Chart of Truck Status

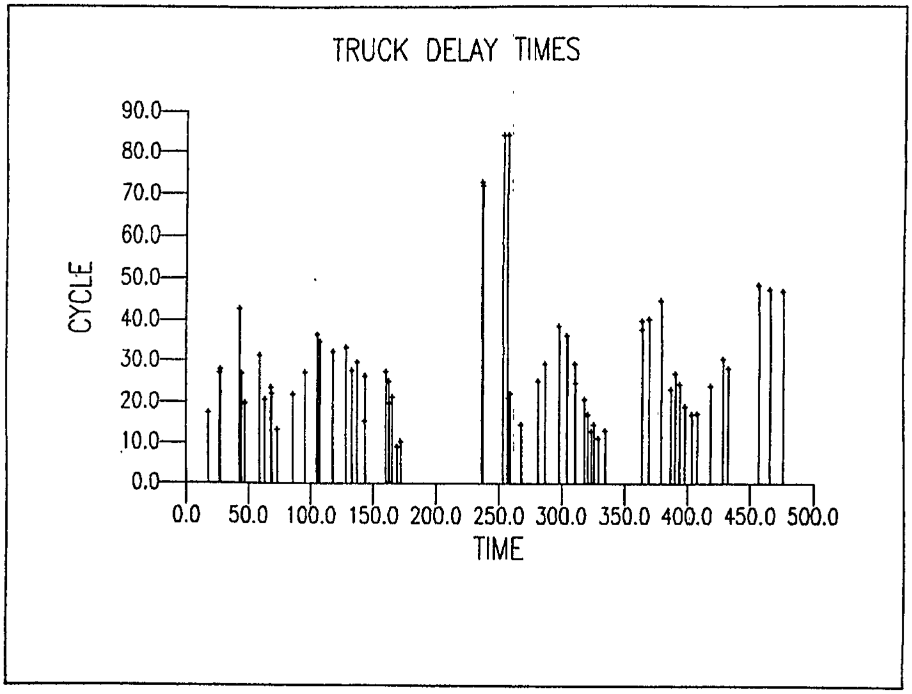

Figure 4: Spike Plot of Time Delay Observations

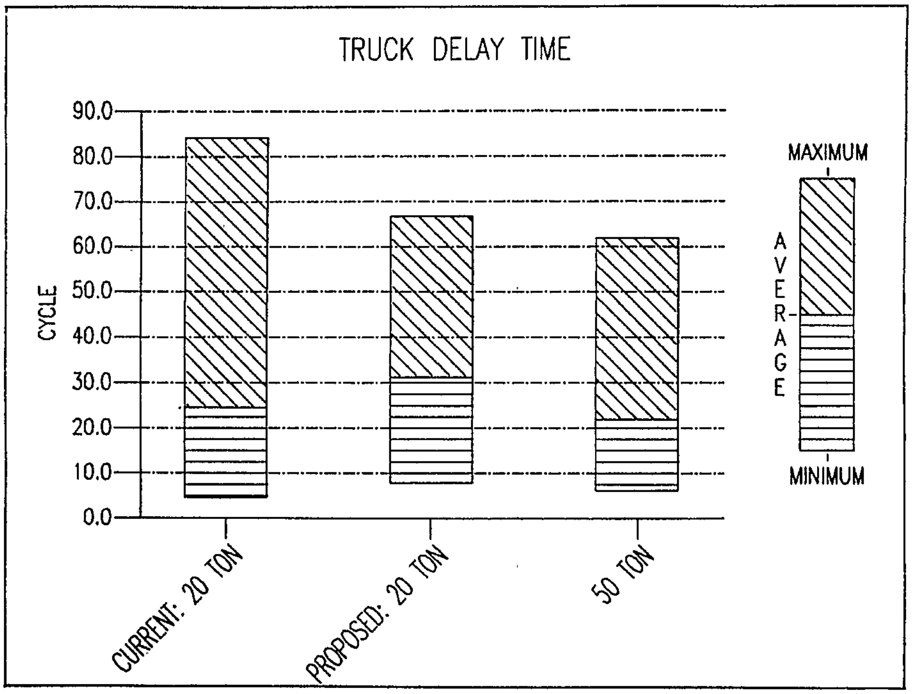

Figure 5: Range Chart of Time Delay Statistics

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(CRQUEUE,TNOW)
           FORMAT(CRQPLOT);
```

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

1. Standridge, Charles R., David K. Vaughan and Mary L. Sale, "A Tutorial on TESS: The Extended Simulation System," Proceedings, 1985 Winter Simulation Conference, December 1985.

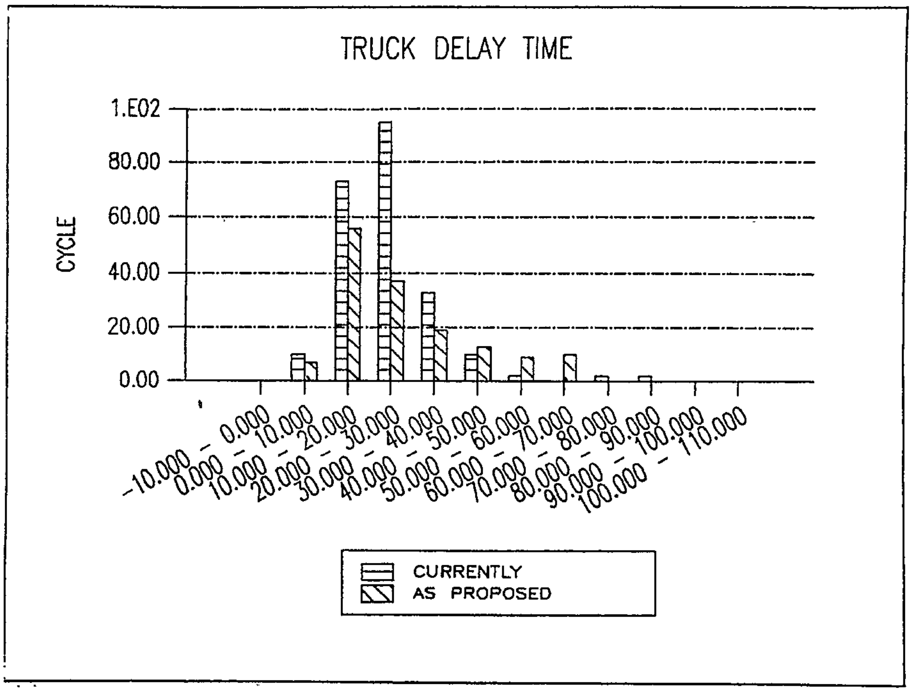

Figure 6: Histogram of Time Delay Observations

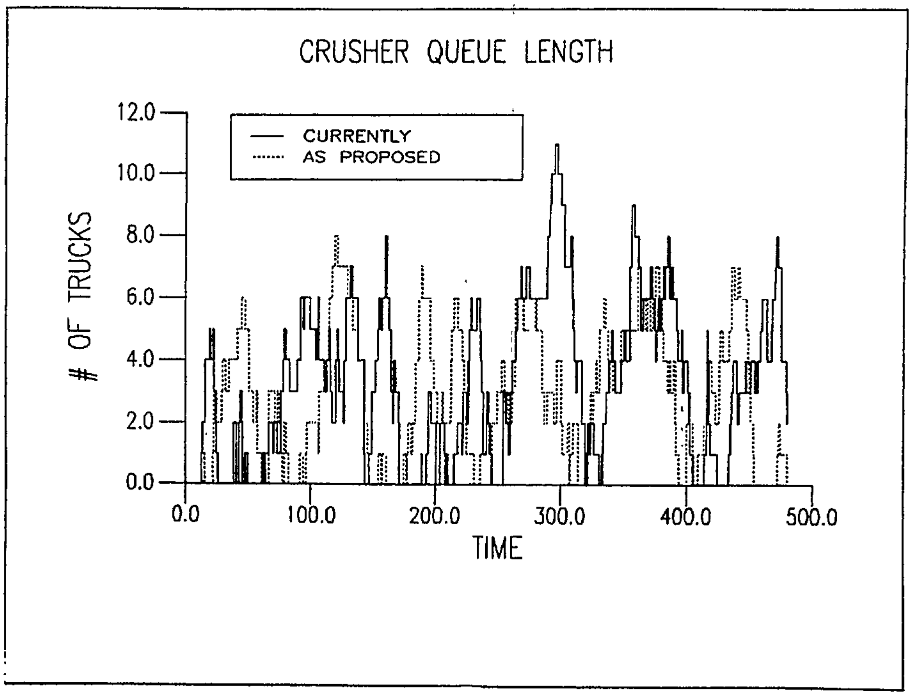

Figure 7: Discrete Plot of Queue Lengths

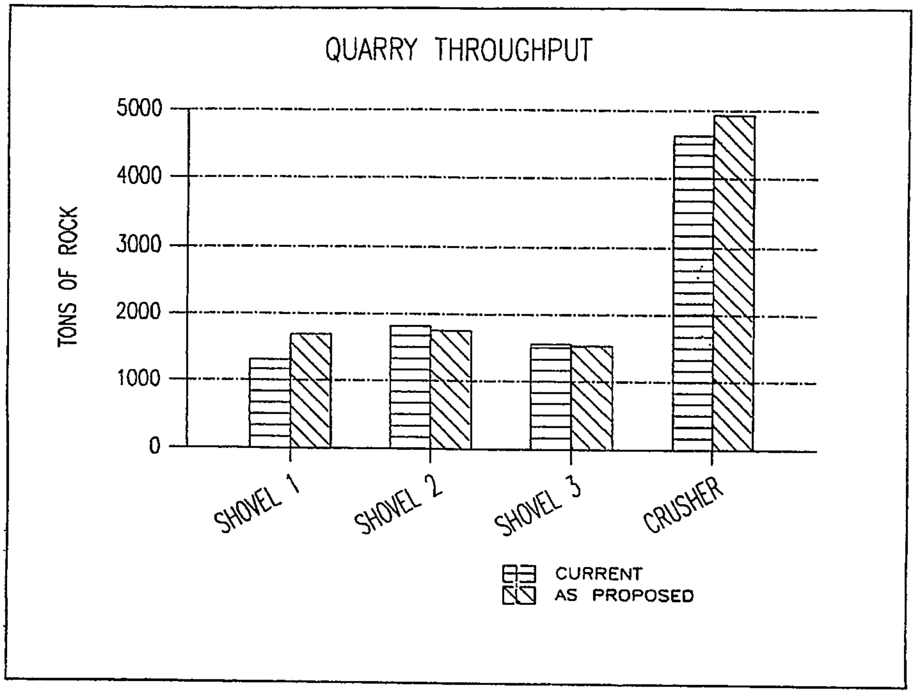

Figure 8: Bar Chart of Throughput

CHARLES R. STANDRIDGE, Ph.D., is the TESS product leader for Pritsker & Associates, Inc. The TESS group is responsible for database management and graphics software development and application. Dr. Standridge led the development of TESS. Previously he led the development of the Simulation Data Language (SDL). He is the author of several journal articles dealing with concepts for using database management in simulation, the application of database management in simulation, the application of simulation in health care delivery, and concepts for a systems approach to performing simulation projects. His current interests are in the development of animation techniques and the structure of simulation support systems. Dr. Standridge is a member of the Society for Computer Simulation, Institute of Industrial Engineers, the Association for Computer Machinery, and the Institute of Management Science.

JOHN R. HOFFMAN is an Analyst at Pritsker & Associates. He is working for a Bachelor of Science in Computer Science at Purdue University. Mr. Hoffman is involved in the development of TESS at P&A. He is a member of ACM.

DAVID K. LAVAL is an Analyst at Pritsker & Associates. He is working for a Bachelor of Science in Computer Science at Purdue University. Mr. LaVal is involved in the development of TESS at P&A.

Pritsker & Associates, Inc.
1305 Cumberland Avenue
P.O. Box 2413
West Lafayette, Indiana 47906
(317)463-5557