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A TUTORIAL ON TESS™:

THE EXTENDED SIMULATION SUPPORT SYSTEM

Charles R. Standridge, Ph.D.
A. Alan B. Pritsker, P.E., Ph.D.
Catherine W. Stein
Pritsker & Associates, Inc.
1305 Cumberland Avenue
P.O. Box 2413
West Lafayette, Indiana 47906 U.S.A.

ABSTRACT

The Extended Simulation Support System, TESS, supports the model entry, simulation, statistical analysis, and result presentation tasks required in a simulation project. Based on user specifications, TESS provides automatic collection of simulation results during SLAM II®, MAP/1™, or GPSS/H ™ simulation runs into the TESS database. Animations can be shown both concurrently with simulations and after simulation runs. Business graphs and reports display variable values and their statistical summaries. These summaries, including confidence intervals, can be computed after simulation runs from variable values collected during the simulation. For SLAM II, network models may be entered using a graphical builder. The TESS command language provides a single user interface to all TESS capabilities. In addition, the TESS subroutine library provides access from user written programs to all data and summaries in the TESS database for ad hoc processing.

1. INTRODUCTION

TESS (Standridge 1985, 1987) provides a framework for problem solving. TESS integrates model building in SLAM II (Pritsker 1986), MAP/1 (Miner 1986) and GPSS/H (Henrikson 1983) with the simulation of models, the statistical analysis of simulation results and the presentation of simulation results using reports, graphs, and animations.

Figure 1 shows the TESS problem solving framework. The activities involved in problem solving using simulation are modeling, simulating models, analyzing and presenting results. TESS provides the mechanisms to jointly use a simulation language, database manager, and graphics capabilities to support these problem solving activities. This paper contains the slides of the tutorial followed by a discussion of the slides. An example of the use of TESS is given in Section 9.

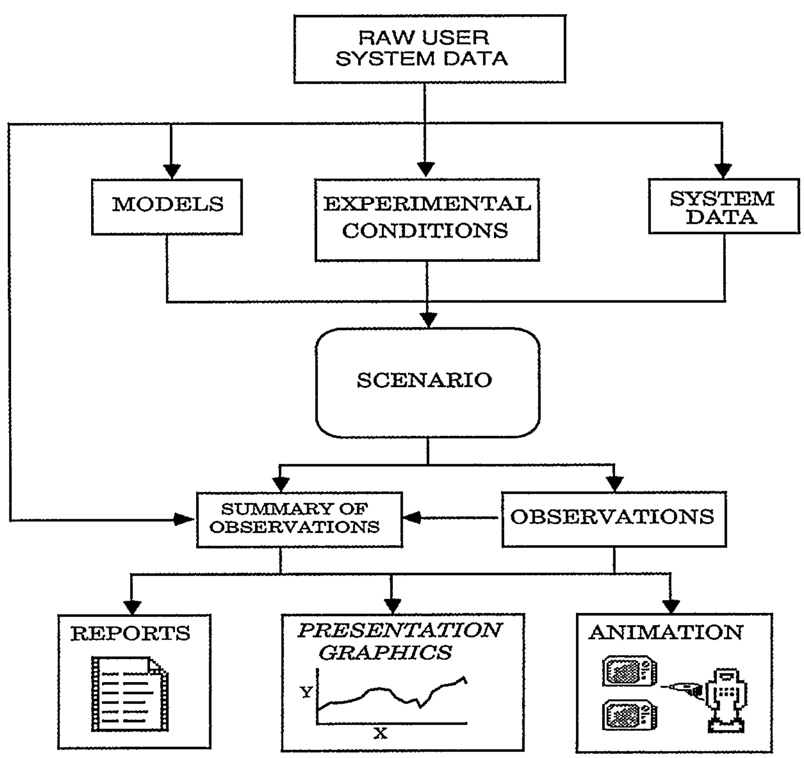

Figure 1. Simulation Project Framework

2. TESS OVERVIEW

TESS SUPPORT OF SIMULATION

- MODELING
- SIMULATING SCENARIOS
- DATA COLLECTION
  - VARIABLE VALUES
  - SUMMARIES
  - TRACES
- STATISTICAL ANALYSIS
- REPORTING AND GRAPHING
- ANIMATION

SLIDE 1

In TESS, a scenario is defined by a combination of a model, control information to guide the simulation of the model, and system data: all of which are stored in the TESS database. TESS provides for the automatic collection of results during the running of a simulation which are also stored in the database. These results include values of variables, statistical summaries of these values,and a list of the events which occur during the simulation run, commonly called a trace. TESS supports the statistical analysis of variable values and summaries stored in its database after the simulation run is completed. Thus, multiple analyses can be made from the same variable values. In addition, across-replicate analyses can be performed, including the computation of confidence intervals. Furthermore, all statistical analyses need not be known or specified at the time the simulation runs are made.

Information to appear on reports or graphs may be selected by specifying scenarios, replicates, variables, or simulation time intervals of interest as well as any logical condition in the information being selected. Plots, bar charts, histograms, pie charts and range charts display variable values and statistical summaries.

Animation shows the dynamics and control logic of the system as captured in a simulation of a model. TESS allows animations to be shown both concurrently with the simulation and after the simulation run is completed. Concurrent animation allows the user to interact with the simulation run to examine quantities of interest and make changes in simulation parameters. Post simulation animation is useful for presentation purposes. Time intervals or portions of the model of interest can be selected for animation. Repeated presentations of the animation can be made without rerunning the simulation.

TESS COMPONENTS

- TESS LANGUAGE PROCESSOR
- TESS DATABASE MANAGEMENT SYSTEM
- GRAPHICS GENERATORS
- FORMS PROCESSORS
- INTERFACES TO COMPUTERS, TERMINALS AND SIMULATION LANGUAGES

SLIDE 2

The components of TESS are shown in SLIDE 2. The TESS database management system controls all information relevant to a simulation project including models, data input to a simulation or resulting from a simulation, statistical summaries of data, schematics called facilities for showing animations, animation commands, icons for use in constructing facilities, scenario information, and formats for graphs and reports. Graphic generators support graphical builders for SLAM II network models, facilities, and icons. Forms processors provide for the entry of simulation run controls, animation commands, data values, summary values, and formats for reports and graphs.

TESS recognizes that simulationists work on non-homogeneous computing equipment which is evolving and improving over time. Thus, TESS interfaces with a variety of computers such as the DEC VAX series and engineering workstations such as those provided by DEC, SUN, and APOLLO. A variety of graphics devices such as the Tektronix 4100 and 4200 series terminals, Hewlett Packard plotters, and the DEC LN03 laser printer are supported. TESS supports modelers who use the SLAM II, MAP/1 and GPSS/H simulation languages.

3. TESS CAPABILITIES

TESS MODULES

- FORMS SYSTEM
- FORMAT SYSTEM
- NETWORK BUILDER
- FACILITY/ICON BUILDER

SLIDE 3

TESS includes a set of modules to interact with the user to model the entry and editing of information needed to perform a simulation project. The TESS forms system provides for the entry of simulation run control information, animation commands, data values, statistics values, and frequency distributions values. The format system is used to enter the parameters of formats for graphs and reports. The network builder provides for the graphical entry of SLAM II networks and their associated parameters. The facility/icon builder provides for the entry of descriptive models of systems. A facility diagram may represent an entire physical system, a single component of that system or any subsystem the user desires. Any facility diagram may be used as an icon in another facility diagram so that facility diagrams may be developed in a modular fashion. Standard facility diagrams including icons for standard manufacturing system components are provided with TESS.

TESS LANGUAGE

• STATEMENTS
  - MODULE SELECTION
  - TASK SETUP

• MACROS
  - SETS OF STATEMENTS

• UTILITIES
  - DATABASE MAINTENANCE
  - TASK SUPPORT

• LIBRARY ROUTINES
  - DATABASE STORAGE AND RETRIEVAL

SLIDE 4

The TESS language consists of statements that provide access to the TESS modules and the direct functions of statistical analysis, graphing, reporting, and animation. Each statement specifies the parameter values which control how that action is performed. TESS statements may be grouped together into macros to allow sequences of actions to be repeated with varying parameter values. For example, a macro may be useful in generating a set of graphs showing the results of one scenario where the scenario name is a parameter of the macro.

In addition to the TESS language, the TESS subroutine library permits storage and retrieval of all data and summary information in the TESS database to support the ad hoc, user defined manipulations of data.

A summary of the contents of a typical TESS project database is shown in Figure 2. Scenarios, formats, rules, facilities, controls, models, summaries, and data have been previously referenced. Definitions describe data and summary organization and are used by the TESS database processor to manipulate variable values. Since TESS defines the organization of the data to describe models, controls, facilities, rules, formats, and scenarios, standard processing of these data elements is possible.

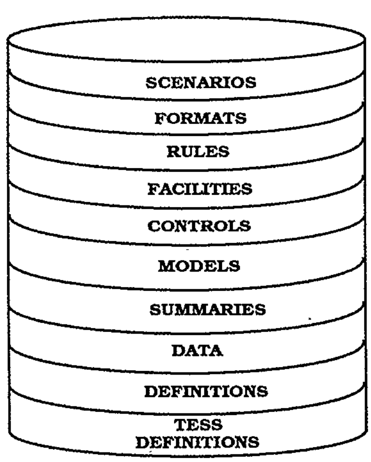

Figure 2. TESS Database

5. RESULT ANALYSIS AND PRESENTATION

TESS DATA/SUMMARY SELECTION

• SCENARIOS
• REPLICATES
• VARIABLES
• TIME INTERVALS
• ARBITRARY LOGICAL CONDITIONS IN THE DATA
• PRESENTATION WINDOWS

SLIDE 5

TESS provides flexibility in selecting data and summary values to appear on reports and graphs. The scenarios, replicates, performance variables, and simulation time intervals of interest can be directly selected. Data or summary values may be selected based on any logical condition among the data and summary values themselves. A portion of the terminal screen or plotter page in which a graph is drawn, a presentation window, may be user specified. The flexibility provided by these specifications supports the iterative development of individual graphs and combinations of graphs needed in presenting simulation results.

6. STATISTICAL ANALYSIS, REPORTING, AND GRAPHING

TESS STATISTICAL ANALYSIS

• COMPUTES
  - STATISTICS (AVG., MIN., MAX., STD. DEV.)
  - FREQUENCY DISTRIBUTIONS
  - CONFIDENCE INTERVALS

• GROUPS
  - BY INTERVAL OF TIME (BATCHES)
  - BY VARIABLE VALUE (PARTITION)

• REGROUPS SUMMARIES
• ANALYZES RESULTS STORED IN DATABASE
• UNLOADS DATA FOR USE IN STATISTICAL PACKAGES

SLIDE 6

TESS supports simulation specific statistical analyses of all data and summaries stored in the TESS database. Statistics, frequency distributions, and confidence intervals across simulation replicates may be computed. Data values may be divided by intervals of time. For example, summaries by day, week and month could be computed. Alternatively, data values can be divided by the value of another variable. For example, time in the system may be computed by part type. TESS has a capability to aggregate across groups of values to form another group. For example, daily statistics are aggregated into weekly statistics. All results of statistical analyses are stored in summaries in the TESS database for use in reports, graphs, and further analyses. TESS provides links to commonly available statistical analysis packages by permitting formated sequential files of data to be created for input to these packages.

TESS RESULTS PRESENTATION

- GRAPHS OF DATA
  - SPIKE PLOTS
  - DISCRETE PLOTS
  - CONTINUOUS PLOTS
- GRAPHS OF STATISTICS
  - RANGE CHARTS
  - PIE CHARTS
  - BAR CHARTS
  - HISTOGRAMS
- REPORTS OF DATA AND STATISTICS

SLIDE 7

TESS supports the graphing of all data and summary values in its database. Different types of graphs are provided for different types of data values. Spike plots, such as the one shown in Figure 3, show observed data. Observed data generally are variables such as part time in the system and time between departures from the system. Discrete plots, such as the one shown in Figure 11, show a variable that takes on a value at event times in a simulation. Typically discrete variables are the number in the queue, the number in the system, and the number of busy resources. Continuous plots are used to show variables values throughout a simulation which changes according to a set of equations.

Range charts such as the one shown in Figure 4, show average, minimum, and maximum statistics. Frequencies can be represented as pie charts, bar charts, and histograms. A typical pie chart and a typical histogram are shown in Figure 5 and 6, respectively.

All graphs and reports may be displayed using the: default formats supplied by TESS; formats supplied by TESS to present results from manufacturing simulations; or user developed formats.

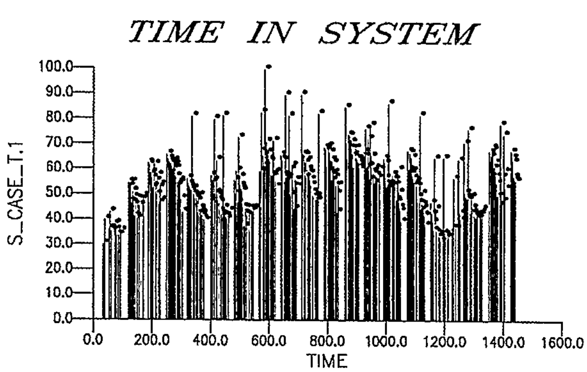

Figure 3. Spike Plot of the Time to Manufacture a Case

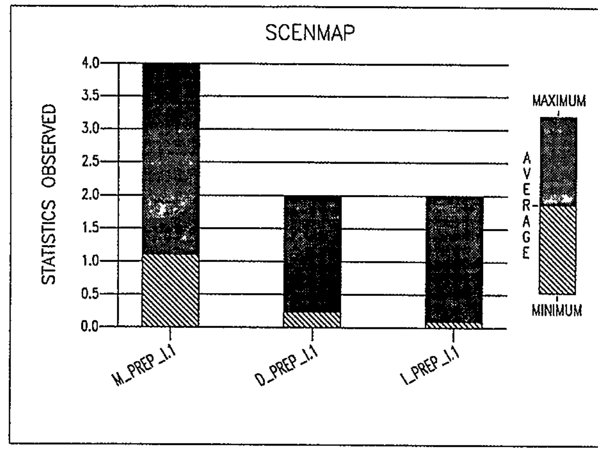

Figure 4. Range Chart of Wait Times

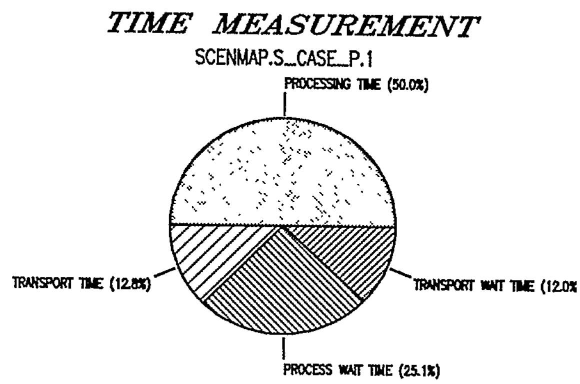

Figure 5. Pie Chart of Case Time Spent in System States

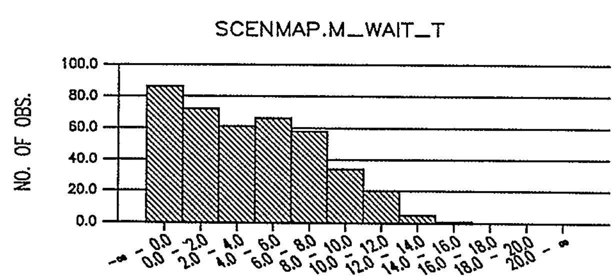

Figure 6. Histogram of Casting Waiting Times at the Mill Station

8. TESS ANIMATION HIGHLIGHTS

TESS MODES

- POST ANIMATION
  - MANY ANIMATIONS FOR ONE SIMULATION
  - DETAILED ANALYSIS OF PORTIONS OF A SIMULATION
  - DATA RETRIEVAL OPTIONS
- SIMULATION CONCURRENT ANIMATION
  - DIRECT VIEWING OF SIMULATIONS
  - USER INTERVENTION

SLIDE 8

TESS supports both post simulation animation and simulation concurrent animation. Post simulation animation is a presentation tool for showing the dynamics and control logic of a system as captured in the simulation. The same animation can be replayed many times without rerunning the simulation. Animation of simulations of large systems can be performed. Multiple animations of one simulation can be developed to give different views of the same system with varying levels of detail. An animation may concentrate on a selected portion of the system in detail. Time intervals for showing an animation can be selected. TESS data selection capabilities can be applied to simulation traces when used to drive animations.

Simulation concurrent animation is used to view and interact with the simulation and animation as they are ongoing. Relevant values can be examined, parameters can be changed to alter simulation behavior, state conditions in the simulation can be detected and responded to by the user, and the step-by-step progress of the simulation examined.

TESS ANIMATION COMPONENTS

- FACILITY BUILDER
- COMMANDS RELATING SIMULATION EVENTS TO ANIMATION ACTIONS
- USER DEFINED ICONS

SLIDE 9

TESS animations consist of facility diagrams, event traces, and animation commands. The facility diagram and the simulation model built in SLAM II, MAP/1 or GPSS/H can be constructed independently. Parameters of the graphical symbols used in constructing a facility diagram are entered using the TESS forms system within the facility builder. In Version 3.1 and higher of TESS, any facility may be used as an icon within another facility. Thus, some facilities represent entire systems, while some facilities represent individual components of the system.

Animator commands relate event occurrences to animation actions. A set of animator commands is called a rule. The rule builder is implemented in the TESS Forms System. Rules may reference other rules, so that animation specifications may be developed in a modular fashion.

TESS ANIMATION IMPLEMENTATION

- OPEN ARCHITECTURE
  - ACCEPTS SYSTEM DATA
  - TESS LIBRARY INTERFACES TO DATABASE
- ANIMATION CAPABILITIES INTEGRATED USING DATABASE AND TESS LANGUAGE
- ANIMATION SUPPORT GRAPHICS TAILORED TO HOST COMPUTER

SLIDE 10

TESS animation is implemented using a open architecture which excepts system data as well as simulation results for animations. System data may be stored in the TESS database using subroutines in the TESS library.

All TESS animation capabilities are integrated. Facilities, rules, and traces are all stored in the TESS database. The TESS language is used for accessing these individually or combining them into animations. Traces may be queried directly using report generation procedures to study the time-series behavior of a simulation. New facilities and rules may be created as needed and existing facilities and rules modified when required. The TESS animator takes advantage of graphics capabilities available on the host computer.

8. EXAMPLE: TRANSMISSION CASE MANUFACTURING LINE

8.1. System Description

The results of a transmission case manufacturing line simulation are shown in graphs, reports, and an animation. The animation screen shown in Figure 7 contains a facility diagram of the manufacturing line which transforms castings into transmission cases. The line consists of a mill station with 4 milling machines, a deburr station with 1 deburrer, an inspection station with 2 inspectors, and a rework station. The process flow begins at the mill station where castings enter the system. After the milling operation, castings are transported by a crane to the deburr station. Following the deburr operation, cases are transported to inspection. If a case fails inspection, it is routed to an rework area, otherwise it is transported to the assembly area.

This system could be simulated using either MAP/1, SLAM II or GPSS/H storing results in the TESS database for animation, reporting, and graphing. Tables 1 and 2 contain the names and descriptors of data and summary occurrences stored in the database during the simulation run. Data occurrences contain data values observed throughout the simulation or a trace of the event occurrences. Summary occurrences have standard statistics such as average, minimum, maximum, and standard deviation, and frequency distributions.

8.2 Animation Presentation

Animation presents the dynamics of a system as captured in the simulation model. The transmission case example demonstrates techniques commonly used in simulation animation. Icons are used to represent each station and are constructed using the TESS facility/icon builder. All stations utilize stacks to display the number of castings in preprocess and postprocess inventory areas.

Station status is coded as: no crosshatch is idle, double crosshatch is busy, and single crosshatch is down. A tank below the mill icon shows the number of busy milling machines. In Figure 7, a Macintosh is used as the output device for TESS and it shows that 3 milling machines are busy, and 1 is down. Similar to the mill station, the inspection station has a tank which displays the number of busy inspectors and shows that one inspector is busy. In addition, the assembly station is down, the rework station is busy, and the deburr station is busy. One casting is in the preprocess inventory of the mill station, another is the preprocess inventory of the deburr station, and two others are in the preprocess inventory of the assembly station. No other in-process inventory exists.

Paths are used to display the transport of castings between stations. One casting is being transported by a crane to the assembly station from inspection. No other material movement is ongoing. No cranes are down or moving empty to pickup a casting or case as indicated by the stacks in the upper right corner. Counters display the number of castings introduced into the system (50), currently in the system (12), produced (36), subcontracted (0), and scrapped (2).

8.3 Graphs and Statistical Analysis

The transmission case manufacturing model was simulated for 1440 minutes (1 day). The individual times in the system for each case are shown by the spike plot presented in Figure 3 which can be obtained by executing the standard TESS macro

```
MACRO SYSTIME1(SCENMAP,SYSTEM,S_CASE_T);
```

From Figure 3, it is seen that the first case took approximately 30 time units to manufacture. The periodic breaks in the spike plot are due to no cases being manufactured which can be attributed to failures at the assembly station.

The time in system can be further analyzed by viewing a pie chart which breaks average time in system down into four categories: processing, process waiting, transporting, and transport waiting. The macro generates the pie chart shown in Figure 5. From this figure, it can be seen that castings spend approximately 63 percent of the time in processing and transporting states and 37 percent of the time waiting to be processed or transported.

```
MACRO TMEAS(SCENMAP,PCTTIME,S_CASE_P);
```

An indication of the balance of the system is seen in Figure 4 where the statistics on the average, minimum, and maximum wait times at the first three stations are shown on a range chart. This chart shows that longest waiting times occurred at the mill station. The maximum wait times are due to station and transporter failures. The statement to produce this range chart is

```
GRAPH SUMMARY NAMED(SCENMAP.SUMWAIT)
        VARIABLE(M_WAIT_T,D_WAIT_T,I_WAIT_T)
```

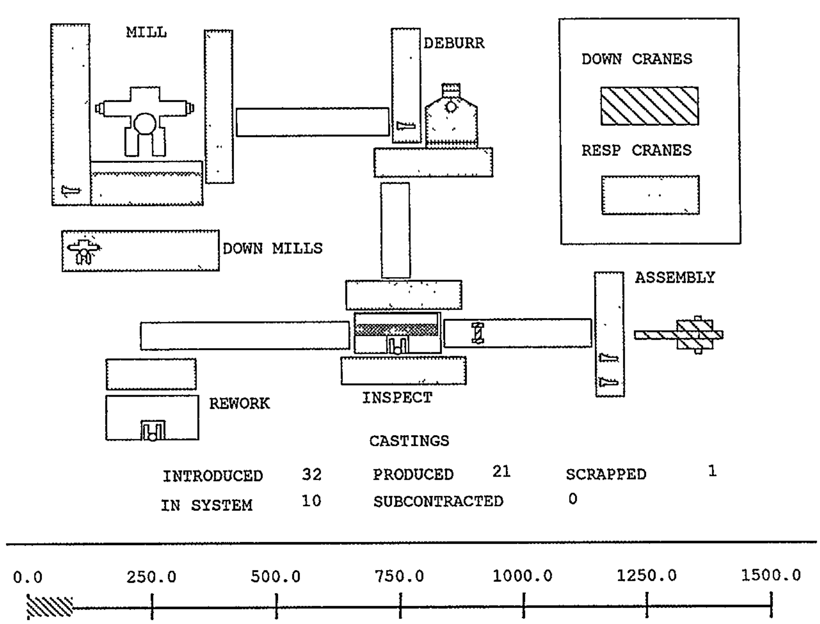

Figure 7. Facility Diagram Snapshot

An analysis of waiting time at the mill station can be made by preparing a histogram of this waiting time using the following statement

```
COMPUTE SUMMARY NAMED(MILLWAIT)
          DESCRIPTOR('HISTOGRAM OF MILL WAIT TIME')
          DATA(SCENMAP.WAITTIME)
          VARIABLE(M_WAIT_T)
          CELLS(M_WAIT_T,12,0,2);
```

The statement

```
GRAPH SUMMARY NAMED(SCENMAP.MILLWAIT)
        VARIABLE(M_WAIT_T)
        TYPE(HISTOGRAM);
```

produces the histogram shown in Figure 6 which indicates that over 80 castings did not have to wait and that over 200 castings waited less than 4 time units for a mill. It also indicates that over 20 castings waited more than 10 time units for a mill.

The previous figures have demonstrated the tools available for analyzing one run of a simulation. However, the system often must be analyzed over a number of scenarios consisting of multiple replicates. TESS provides the capability to view simulation results from multiple replicates and/or scenarios and to selectively display variables, intervals of simulated time, and relationships between variable values.The analysis which follows is based on 10 replicates of the transmission case simulation. TESS collects the specified data for each run and stores it in the project database. A summary of time in system for each of the 10 replicates is presented on the range chart shown in Figure 8 using the TESS statement

```
GRAPH SUMMARY NAMED(SCENMAP.SYSTIME)
        VARIABLE(S_CASE_T)
        FORMAT(SYSTIME);
```

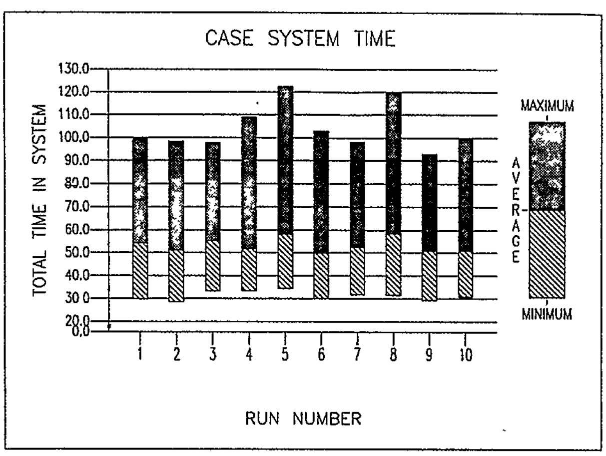

Figure 8. Range Chart of Total Time in System Statistics for 10 Runs

This chart indicates that the average time in system varies between 50 and 60 time units. The actual values are obtained from a report of this summary occurrence which is given in Figure 9 and obtained from the following statement:

```
REPORT SUMMARY NAMED(SCENMAP.SYSTIME)
        VARIABLE(S_CASE_T)
        MEASURES(MEAN,MIN,MAX,INTERVAL);
```

A confidence interval on the average time in the system can be computed using the statement

```
COMPUTE SUMMARY NAMED(SYSTIMECI)
        FROM(SCENMAP.SYSTIME)
        VARIABLE(S_CASE_T)
        DESCRIPTOR('95% C.I. ON CASE TIME')
        REREPLICATE(10,95);
```

ECHO REPORT PAGE 1
ECHO OF SUMMARY DATA

VARIABLE	MEAN	MIN	MAX	INT/CNT
S_CASE_T	0.542492E+02	0.298989E+02	0.993214E+02	0.338000E+03
S_CASE_T	0.511913E+02	0.285262E+02	0.982234E+02	0.331000E+03
S_CASE_T	0.554566E+02	0.332161E+02	0.977158E+02	0.339000E+03
S_CASE_T	0.516673E+02	0.333616E+02	0.109131E+03	0.340000E+03
S_CASE_T	0.580425E+02	0.344604E+02	0.122470E+03	0.340000E+03
S_CASE_T	0.499830E+02	0.300864E+02	0.102858E+03	0.340000E+03
S_CASE_T	0.526595E+02	0.317326E+02	0.980471E+02	0.334000E+03
S_CASE_T	0.585045E+02	0.314599E+02	0.119666E+03	0.336000E+03
S_CASE_T	0.510185E+02	0.293489E+02	0.928596E+02	0.331000E+03
S_CASE_T	0.511643E+02	0.308063E+02	0.992664E+02	0.331000E+03

Figure 9. Report of Total Time in System Statistics for 10 Runs

This statement computes a 95% confidence interval based on the ten runs which is displayed in Figure 10 using a range chart generated by the command

```
GRAPH SUMMARY NAMED(SCENMAP.SYSTIMECI)
        FORMAT(SYSCI);
```

The confidence interval specifies that with probability 0.95, the interval (51.22,55.57) includes the mean of the simulation model's case manufacturing time.

TESS can present multiple graphs and charts on a screen as shown in Figure 11.

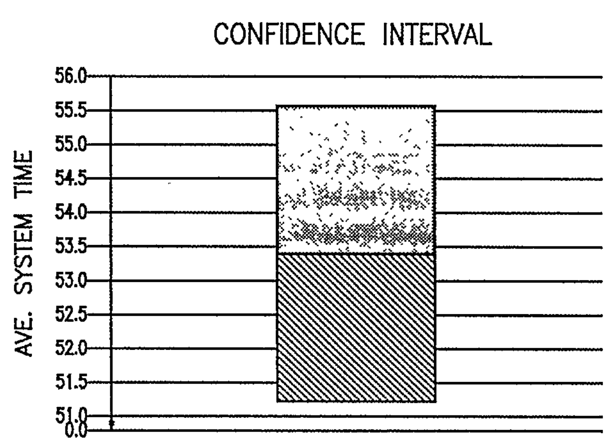

Figure 10. Confidence Interval for Average Case System Time

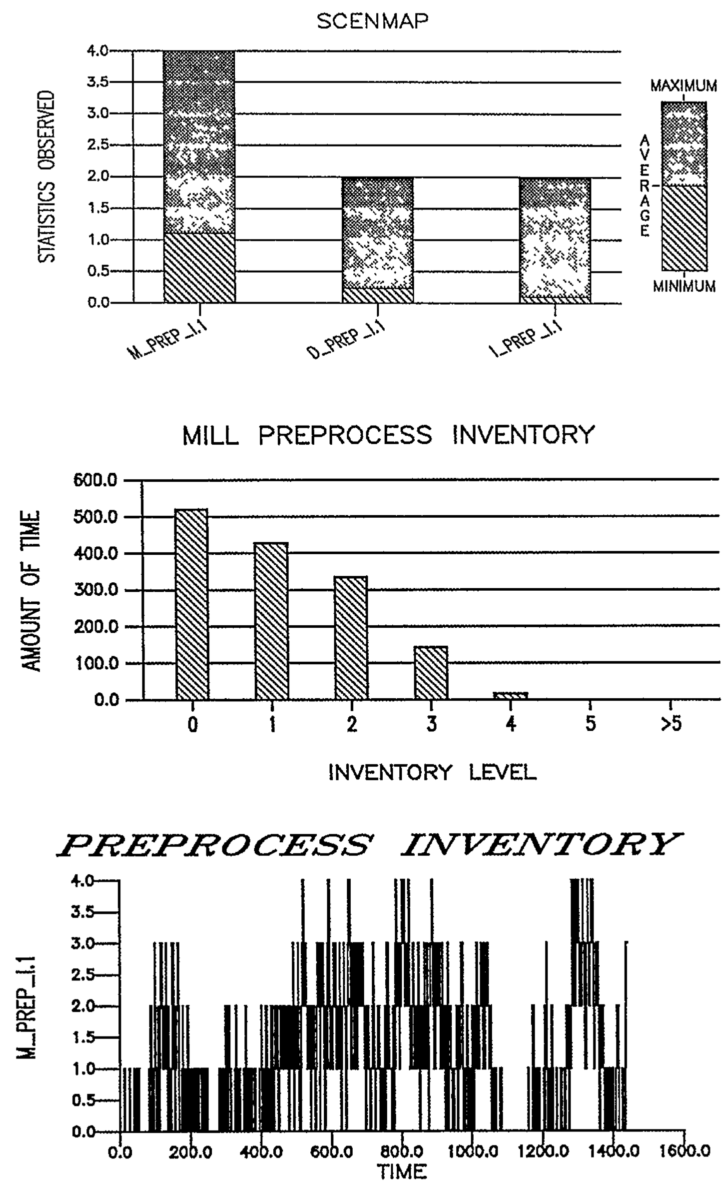

Figure 11. Display of Three Graphs on One Screen

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AUTHORS' BIOGRAPHY

CHARLES R. STANDRIDGE is a Senior Systems Consultant with Pritsker & Associates, Inc. He holds a Bachelor of Science in Applied Mathematics and Computer Science from Washington University in St. Louis, Missouri, and both a Master of Science and Doctor of Philosophy in Industrial Engineering/ Operations Research from Purdue University. Dr. Standridge has worked in the application of database management techniques in simulation including the development of integrated support systems for simulation. He led the development of the Simulation Data Language (SDL) and The Extended Simulation System (TESS). Dr. Standridge has been active in the application of this technology to industrial problems and in research to extend this technology. Currently, Dr. Standridge is a member of the software development group at P&A.

A. ALAN B. PRITSKER is Chairman of Pritsker & Associates, Inc. and FACTROL, Inc. He graduated from Columbia University with a BSEE and MSIE. He oftained a Ph.D. From The Ohio State University in 1961. From 1956 through 1962, Dr. Pritsker worked for Battelle Memorial Institute in Columbus, Ohio. From 1962 through 1981, he was Professor of Industrial Engineering At Arizona State University, Virginia Tech, and Purdue University. In 1973, he co-founded Pritsker & Associates. Dr. Pritsker has published more that 100 technical papers and six books. He is a Fellow of AIIE and a recipient of AIIE's Achievement Award. He is also a member of the National Academy of Engineering. Dr. Pritsker served as a member of the Board of Directors of the Winter Simulation Conference from 1970 to 1974 and 1979 to 1987, and as board chairman in 1984 and 1985.

CATHERINE W. STEIN is a Senior Systems Analyst with Pritskter & Associates, Inc. She holds a Bachelor of Science in Industrial Engineering from Purdue University. Since joining P&A, Ms. Stein has applied SLAM II and the Material Handling Extension to a variety of consulting projects. Her current responsibilities include user support and training for P&A software products.

Charles R. Standridge, Ph.D.
A. Alan B. Pritsker, P.E., Ph.D.
Catherine W. Stein
Pritsker & Associates, Inc.
1305 Cumberland Avenue
P.O. Box 2413
West Lafayette, Indiana 47906 U.S.A