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A TUTORIAL ON TESS™: THE EXTENDED SIMULATION SYSTEM

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ABSTRACT

TESS, The Extended Simulation System, integrates simulation, data management and graphics capabilities to provide a framework for performing simulation projects. Capabilities for building SLAM II® networks graphically, animating simulation runs without programming, and generating graphs of all simulation results are provided. Report generation and the post-run analysis of simulation results are included. Forms input for simulation run controls and user defined data are provided. The fourth generation TESS language provides a single user interface to all TESS capabilities.

INTRODUCTION

The Extended Simulation System, TESS, represents a new generation of software that integrates model building, simulation execution and the analysis and presentation results. TESS has evolved over a ten year period to provide support for problem solving using simulation.

The first generation of simulation software included languages such as Q-GERT® (5,7) and GASP II™ (3) which provided a single world view for constructing models. The second generation of simulation software recognized the value of integrating the world views of modeling into single languages. GASP IV™ integrated discrete event concepts with a continuous modeling framework (4). In the late 70's, SLAM® (6) added the Q-GERT network view of modeling to GASP IV to provide three alternative modeling frameworks in a single language.

In the early 1980's, it was recognized that software was needed to support other aspects of a simulation project, beyond the model conception and implementation provided by a simulation language. P&A developed software such as AID™ for input distribution function fitting (1), SIMCHART™ for graphical presentation of results (2), and SDL™ for the management of model inputs and simulation results (8, 9). These products were a part of a third generation of simulation related software.

TESS is fourth generation simulation software. Applications showed that the third generation, component approach to support software was valuable (9, 10, 11, 12) but required much learning and significant set up times. For each project, the analyst not only needed to know the details of each product but was required to design a framework for using the components together to meet project objectives. Since this was done on an ad hoc basis, it was difficult to transfer knowledge gained on one project to other projects. Furthermore, it was found that a considerable amount of user code was required to supplement the support software. These projects identified desirable additional support features and were a key input to the establishment of requirements for TESS.

CONCEPTUAL OVERVIEW

Figure 1 presents a conceptual overview of TESS. The top half of the oval portrays the activities involved in problem solving using simulation: modeling, simulating models, reporting and analyzing. TESS provides the mechanisms to jointly use a simulation language, database manager and graphics capabilities to support these problem solving activities. The relationship between these capabilities and the problem solving activities they support are indicated by the vertical arrows in Figure 1.

TESS CAPABILITIES

Specifically, TESS provides the following capabilities:

* A framework for problem solving using simulation.
* Separation of the analysis and presentation of simulation results from their generation in simulation runs.
* Integration of modeling and simulation execution with reporting, graphing and analysis capabilities.
* A command language to access each capability used in problem solving.
* Creation and management of network models.
* Independent specification of experimental conditions for controlling simulation runs (CONTROLS).
* Management of user defined data.
* Procedures for combining CONTROLS, data and models to specify alternatives called SCENARIOS.
* A report generator for presenting simulation results and other data.
* Graphing of networks, simulation results and user defined data.
* Procedures for dynamically presenting the operation of a model, that is, the animation of simulation results.

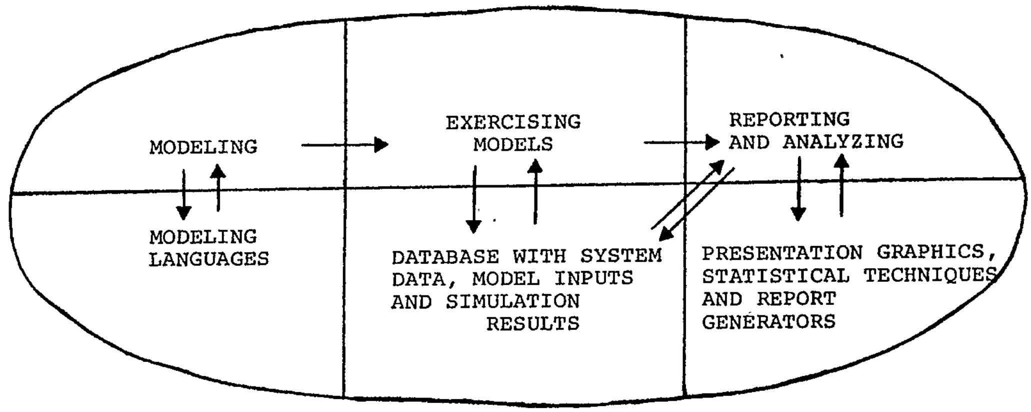

Figure 1: Conceptual View of TESS

* Computation of frequency distributions and statistics as well as estimation of confidence intervals.

* Support for database management tasks.

TESS supports the framework for performing simulation projects shown in Figure 2. Models are descriptions of a system. TESS provides an interface to SLAM II models. Both network model management capabilities and interfaces to discrete event and continuous models are included. The management of FORTRAN code that implements discrete event and continuous models is external to TESS.

Independent of the development of a model, TESS allows an analyst to specify the controls required to simulate models. This specification includes initial conditions, run lengths and output values to collect. In addition, TESS recognizes that models often require significant amounts of problem specific input data. Therefore, procedures for the management of such model inputs are a part of TESS.

The combination of a model, a run control and input data forms a scenario. Typically, a scenario is used to evaluate a particular alternative. The simulation of a scenario produces observations of data values. These individual observations are used to construct basic statistics and frequency distributions referred to as summaries.

Observations and summaries are stored in the TESS database and can be analyzed and presented independently of simulation runs. Individual observations can be selected (filtered) and summarized into basic statistics and frequency distributions. Construction of summaries independently of the simulation has several advantages. All analyses of the observations need not be specified before simulations are run. Multiple analyses of the same observations, or perhaps involving different subsets, can be made. Furthermore, the computation of summaries need not be included in the simulation program, thus, making the program easier to debug, change and maintain.

TESS provides three basic mechanisms: reports, graphics and animation, for displaying simulation results and data inputs. Reports display information on alphanumeric devices. Reports that can combine data inputs with simulation outputs can be used for validation purposes. Simulation outputs from many scenarios can be used for alternative evaluation purposes.

TESS provides for the graphical presentation of all simulation results. Graphics can be created at interactive terminals or on hard copy devices such as plotters or printers. Graphics for displaying statistics, frequency distributions and individual data values are included.

The animation capability in TESS shows the movement of entities and system status changes. Animation capabilities assist the analyst in communicating how a model represents a system. Both the elements of the system which were included in the model and the operating rules for these elements can be shown. The animation facility allows all members of a project team, both simulators and non-simulators, to participate in model verification and validation. They can see how the model operates by viewing the entity movement and the status changes. In this way, the decision rules that were employed in the model become evident.

TESS ARCHITECTURE

TESS operationalizes the framework for a simulation project shown in Figure 2. The architecture of the TESS implementation of this framework is shown in Figure 3. TESS capabilities revolve around a single integrated database shown at the center of the Figure 3. Whenever possible, TESS makes database operations transparent to the user, making it possible to perform a simulation project without any knowledge of database management. Conversely, one of the benefits of TESS is its inherent availability and use of database management techniques.

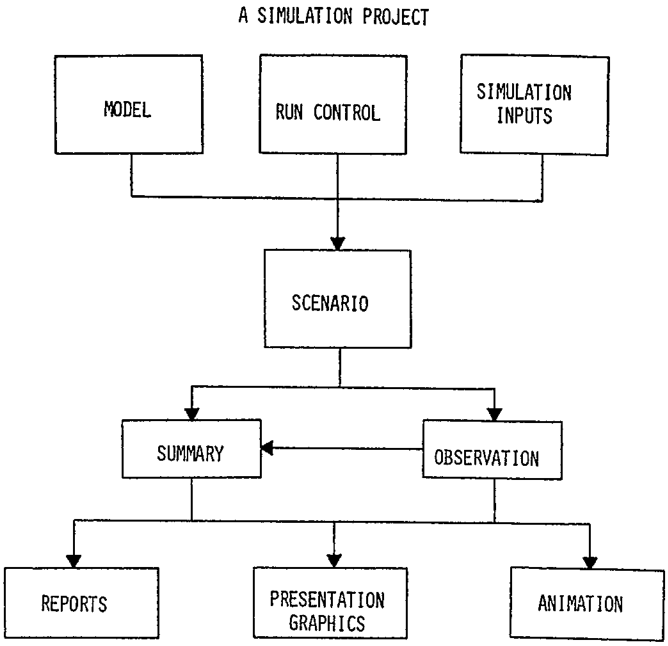

Figure 2: The TESS Framework for a Simulation Project

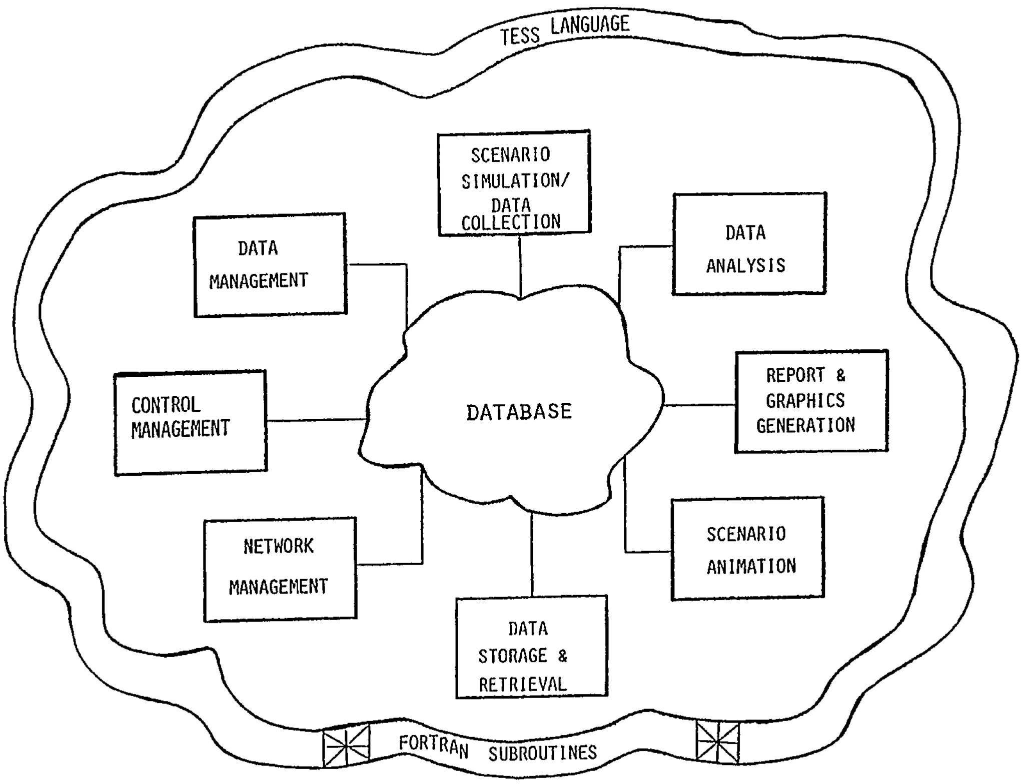

Figure 3: TESS Architecture

TESS provides capabilities for the management of SLAM II network models. These capabilities include creating network models from scratch or from existing network models as well as editing existing network models. These operations are performed using the network builder. This builder uses interactive graphical techniques to link together SLAM II network symbols to provide a network model of the system. In addition, graphs of network models can be constructed for inclusion in reports or for display in work areas. Many network models can exist simultaneously in the TESS database.

TESS provides similar capabilities for managing controls. A control may be built from scratch, built starting with a previously existing control or edited. Controls are built or modified using TESS forms procedures which are graphically implemented. In addition, a TESS formated report of a control can be obtained.

The data management component of TESS is used for simulation results, simulation inputs and historical data. TESS can maintain multiple versions of simulation inputs, representing different scenarios to be evaluated, or multiple versions of simulation results, which are produced by simulating different scenarios. The analyst may define the data to be managed either explicitly in the TESS language or implicitly by telling TESS what data to collect during a simulation run. Data may be built from scratch or from other data or edited using the TESS forms procedures. Alternatively, data may be created by loading existing sequential files into the database.

In addition, TESS provides for linking data with simulation runs. Simulation programs may be coded to accept any version of data. Furthermore, TESS provides for the automatic collection of simulation results. These results may be summaries in the form of statistics or frequency distributions produced by SLAM. Furthermore, individual observations of SLAM variables can be collected. In addition, the analyst may collect values of variables not known by SLAM through the use of subroutine calls.

TESS provides data analysis capabilities that allow the analyst to compute summaries in the form of basic statistics and frequency distributions concerning data stored in the TESS database. Capabilities for producing summaries in ways commonly needed in simulation are provided. Typically, summaries disaggregated by time intervals, such as shift or day, or by entity attributes, such as type, are useful. In addition, aggregation of existing summaries is provided. Thus, if summaries are computed by shift, TESS allows the shifts to be aggregated into days. Furthermore, confidence intervals based on replicates of simulation runs can be computed by TESS.

TESS can display all data and summaries stored in the TESS database graphically. Standard business graphs such as bar charts, histograms and pie charts are used to show frequency distributions. A special TESS graph called a range chart is used to show minima, maxima and averages. Three types of plots for showing data values, spike, discrete and continuous, are provided. Capabilities for annotating each graph are included. Furthermore, text only graphs, called word charts, are available for preparing project presentation materials. Any graph may be drawn in a TESS supplied format. Alternatively, the analyst may specify parameters for drawing any graph. Graphs may be drawn on interactive graphics terminals or graphics hard copy devices such as plotters and printers.

Columnar line printer reports can be generated to supplement the graphics. Reports of data or statistics may be prepared. Reports may be displayed in a standard TESS format or in a user specified format. All formats are built using the TESS forms capabilities.

TESS animation shows the dynamics of a simulation run on a graphics terminal either concurrently with the simulation or after the simulation. The trace of the simulation, the list of event occurrences, drives the animation. The animation is shown on a schematic model of the system constructed by the user. A set of user specified statements relates the event occurrences on the trace to the actions of the animation.

TESS provides a subroutine library for use within user written simulation programs or other user written programs. Routines in this library provide for the retrieval of data and summaries from the TESS database. Other routines allow data and summaries to be stored in the TESS database. In addition, routines for deleting data or summaries or replacing existing data or summaries are provided.

The outer ring in Figure 3 indicates user interfaces to TESS. The TESS language gives the user access to the TESS subsystems which provide for network building, control building, data entry, format preparation and specifications needed to perform animations. In addition, the TESS language allows the user to directly specify operations such as data analysis, report generation and graphic generation. Shown at the bottom of the outer ring in Figure 3, the TESS library is accessed by calling FORTRAN subroutines in user written programs.

THE ESSENTIAL REQUIREMENTS FOR SIMULATION SOFTWARE

TESS embodies seven essential requirements which a simulation system must meet for maximum utility.

1. TESS supports all aspects of the simulation project. The comprehensive, integrated simulation framework of TESS reduces the amount of technical computer work simulation requires. So analysts with lesser computer skills will be able to use TESS. Analysts with computer sophistication will perform simulation projects more efficiently.

2. TESS tailors its simulation results to the needs of the decision makers. So decision makers can see the simulation, assist in its validation, and gain confidence in the results, TESS animates the model and provide graphical representations of all results, with supplementary reports. TESS can graph and report similar information from different scenarios to offer an easy means of comparing alternatives.

3. TESS takes a modular approach to simulation projects. Following the basic engineering strategy of "divide and conquer," TESS decomposes large problems into a series of smaller ones, or modules, which it solves one at

a time. TESS provides specific capabilities to handle each module--model building, simulation execution, results analysis, and presentation--along with a mechanism to link all together.

4. TESS minimizes the need for technical computer knowledge. TESS keeps database operations transparent as much as possible. Analysts may perform entire simulation projects with no direct reference to the database. Using forms techniques and graphical procedures for model building, TESS provides non-programming interfaces for building networks and controls, entering data, and specifying the presentation of results.

   Because TESS is a fourth generation non-procedural language, analysts need only specify which operations they want performed, and TESS will figure out how to do them. For example, to graph a given result from each of three scenarios, the analyst simply names the result and the scenarios. TESS locates the results and specifies the method of joining and displaying the information.

5. TESS recognizes the differences between model builders and model users. Model users often need to use a simulation model as a black box--changing inputs, rerunning simulations, obtaining standard reports and graphs--without having to concern themselves with the internal details of the model. Builders, though have concern for details of construction, the gathering of inputs and results, and the nature of the presentation mechanisms. TESS supports both.

6. TESS requires the analyst to concentrate on only one form of the model. Using SLAM network features as a modeling language, TESS allows analysts to build network models at an interactive graphics terminal and to update and change the model with the same mechanism. TESS creates and maintains all other forms transparently. TESS eliminates the need for analysts to translate models from symbolic to statement or textual form. This procedure eliminates discrepancies that rise over time from changing the statement model directly.

7. As simulation and computer technology advance, TESS will accommodate the changes. Machine and device independent, TESS can adapt to the new device drivers which will accompany advances in graphics technology and to new computers, especially the 32 bit microcomputers.

THE FUNCTION--DATA ELEMENT STRATEGY

TESS includes 3 functions which act on 10 data elements. Data elements encompass the entities which make-up a simulation project. The functions are manipulations of the entities required to perform the project. Figure 4 shows the TESS framework. Data elements are classified into three categories: modeling, simulation and analysis, and presentation.

MODELING DATA ELEMENTS

Modeling data elements are networks, definitions, ICONs and facilities. Networks are SLAM II networks. Networks are built and modified graphically using the TESS network builder. Plots of networks can be generated.

Definitions are specifications of the attributes of variables to be stored in the TESS database. Definitions are given implicitly when simulation results are automatically collected or explicitly in the TESS language.

A facility is a schematic model of a system. A facility is used in two ways: as an informal model of a system for discussion purposes and as a tool for displaying an animation of a simulation. TESS provides a facility builder for selecting, locating and specifying the parameters of a set of symbols to describe a system. To show different aspects or levels of detail in a system, there may be many facility diagrams for one system or one model of a system. This allows many different animations for one simulation run.

An ICON is a symbol used to build a facility. TESS provides a standard set of ICONs. In addition, the user can construct ICONs using the interactive, graphical ICON builder.

SIMULATION AND ANALYSIS DATA ELEMENTS

A control is a set of statements which tells how to run a simulation. Control statements specify results to be automatically collected, initial conditions and SLAM operational parameters. The TESS control builder is used to build or edit controls. Forms for each control statement are provided.

A scenario is a set of conditions under which data are generated. One such set of conditions is a simulation run, combining a network, control and user-defined input data. However, under this definition, no distinction is made between simulation results and other data. Thus, all data are processed by TESS in the same way.

Data are variable values. Data may be simulation input, simulation results or any other information of interest.

Summaries, derived from data, consist of basic statistics or frequency distributions. Summaries may be automatically collected during simulation runs, computed in user-written code, or computed using TESS language statements.

PRESENTATION DATA ELEMENTS

Two data elements assist the analyst in presenting simulation results. The first of these is format. A format specifies the parameters by which TESS should draw a graph or print a report. TESS supplies default parameters for all reports and graphs so that the analyst need not specify any formatting information. There is a type of format for each graph; range chart, histogram, bar chart, pie chart, spike plot, discrete plot, and continuous plot; for graphing networks; generating reports; placing annotation on graphs; and for text only graphs called word charts. Formats are created or modified using the TESS format builder. The format builder uses a series of forms to display parameters of the format. The analyst can change the parameters by inserting new values on the form. A particular format is associated with a particular graph or report only at the time the graph or report is generated.

The final TESS data element is a rule. A rule is a mapping between the events that can occur in a simulation run and actions to be taken on a facility to portray an animation. For example, in SLAM, events can be categorized as: 1. the beginning of an activity, 2. the completion of an activity, or 3. a time, discrete, or a state event. Actions taken during an animation that can correspond to events include: changing color of symbols to show changes in status, changes in counters to show changes in the number of entities grouped together, movement of ICONs to show movement of entities in a simulation, flows to show continuous movement of entities such as fluids, entry and exit of ICONs from queue, and tanks to show variable values by changing the length of colored bars. A rule is a set of statements that relates events during a simulation to actions to be taken during the animation. These statements are built using the TESS rule builder. In the rule builder, the analyst completes a form for each statement in the rule.

TESS FUNCTIONS

Three TESS functions manipulate the data elements in the database. The BUILD function is used to create or modify occurrences of data elements. The REPORT function displays occurrences on an alphanumeric device such as a line printer or alphanumeric terminal. The GRAPH function displays occurrences on a graphics device such as a interactive graphics terminal or a hard copy device such as a plotter or printer. The GRAPH function activates animations as well. Animations can be run either concurrently with the simulation or after the simulation is run.

Some combinations of functions and data elements are not allowed. The permissible combinations form 21 TESS statements which were indicated by an X in Figure 4. These 21 statements are the foundation of the TESS language.

SUMMARY

TESS initiates a fourth generation of simulation software. TESS contains a framework for organizing simulation projects and provides software support for all simulation project activities. TESS operationalizes its simulation project framework as a set of functions operating on a set of data elements. TESS is implemented with an integrated architecture combining database management and graphics capabilities with a simulation language.

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DATA ELEMENTS

FUNCTIONS	MODELING				SIMULATION & ANALYSIS				PRESENTATION	
	NETWORK	DEFINITION	FACILITY	ICON	CONTROL	SCENARIO	DATA	SUMMARY	FORMAT	RULE
BUILD	X	X	X	X	X	X	X	X	X	X
REPORT		X			X		X	X	X	X
GRAPH	X		X				X	X	X	

Figure 4: The Function - Data Element Strategy

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