CONDUCTING EXPERIMENTS WITH EXPERIMENT MANAGER

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ABSTRACT

This tutorial demonstrates how to conduct experiments and perform analysis with Experiment Manager, CACI's tool for design and analysis of simulation experiments. Experiment Manager works in conjunction with SIMPROCESS and provides a quick and object-oriented approach to designing simulation experiments. The tutorial will describe how to conduct a full factorial experiment with 2 factors and 3 levels each. These experiments will be performed using a model constructed in SIMPROCESS and the results will be analyzed using such features of Experiment Manager as box plots, confidence intervals, and time series plots.

1 INTRODUCTION

Experiment Manager is a set of statistical software tools integrated with the SIMPROCESS modeling tool. SIMPROCESS is a hierarchical icon based simulation modeling tool designed specifically for business process re-engineering (BPR). Experiment Manager extends the analyst's ability to conduct statistical data analysis and experiments using SIMPROCESS. Experiment Manager:

• Provides statistical software tools tailored to the statistical simulation environment

• Provides statistical software tools for all phases of a statistical simulation experiment

• Increases the accuracy of conducting an experiment

• Decreases the time to find the solution to the problem under study

• Interacts with the user through a unique easy to use object-oriented graphical user interface

• Organizes experiments

• Archives experiments

• Automates tedious data collection and data entry tasks such as collecting and merging SIMPROCESS statistical output

Section 2 of this paper is an overview of the Experiment Manager. It describes the functions and features of the major components of the Experiment Manager as well as some high level architectural considerations. The rest of the paper primarily focuses on the design and analysis of an experiment using the Experiment Manager Tool (EMT) component of Experiment Manager. Section 3 describes the specification of an experiment. Section 4 describes the execution and analysis of the experiment.

2 OVERVIEW OF THE EXPERIMENT MANAGER

There are two integrated experiment components in the Experiment Manager tool set: the Data Analysis Tool (DAT) and the Experiment Manager Tool (EMT). Integrated with SIMPROCESS, these tools provide a tightly integrated end-to-end environment for conducting statistical simulation experiments.

DAT is used to analyze data and construct a data model of the random process that generated the data. DAT helps you find a probability distribution that approximates the true distribution by analyzing a data set of measurements obtained from the random process. The parameters of the probability distributions supported in SIMPROCESS are computed using the techniques of maximum likelihood estimation (MLE). The analyst selects a distribution based on

Table 1. SIMPROCESS and Experiment Manager Functionality

	SIMPROCESS	DAT	EMT
Model Development	• Graphical specification of logical processes • Interpretive specification of logical processes • Specification of data model for modeling elements • Specification of performance measures	• Data Analysis • Modeling of Random Processes	• Factor View of Model
Verification & Validation	• Animation • Trace Files	• Goodness of fit	• Statistical validation
Experimentation & Analysis	• Single scenario execution • Time Series analysis • Single scenario analysis	• Data analysis of statistical output • Residual analysis of statistical tests	• Design of experiments • Execution of experiments • Collection and merging of statistical output • Regression analysis • 2k analysis Statistical comparison of alternatives • Transformations • Confidence intervals
Results & Presentation	• Extensive reporting mechanism • Single run statistical output • Model archive	• Box Plot • Standard Error • Confidence Interval plot • Empirical and probability distributions • Numerical results	• Box plot comparisons of scenarios • Standard error comparisons • Confidence interval comparisons • Time series plot • ANOVA tables • Hypothesis tests • Numerical results • Experiment archive

goodness-of-fit ranking or prior knowledge of the process that produced the data set. The selected probability distribution is then used to model the random process in SIMPROCESS.

EMT is used to design, execute, and analyze statistical simulation experiments. EMT helps the analyst select the factors (variables) of interest for the experiment and specify the scenarios (values for the variables) for execution. EMT executes all of the specified scenarios automatically collecting the statistical output for each scenario. EMT provides

statistical tests for screening factors, developing quantitative relationships between important input variables and the performance of the system, and determining the best performing system of many.

The tightly integrated environment removes the drudgery of moving data from one tool to another and from the formats of one software tool to the formats of other software tools. This increases the accuracy of
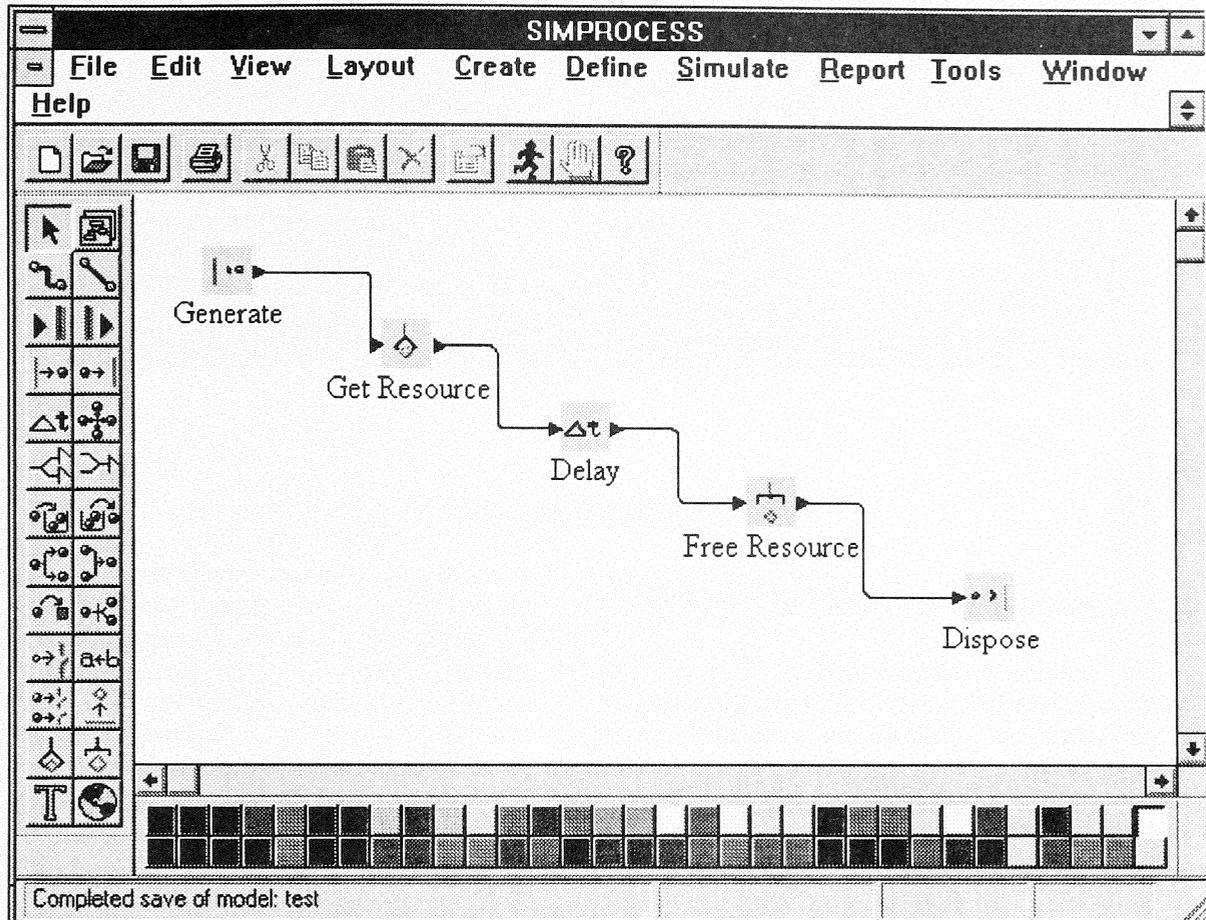
Figure 1. Simple Queuing Model

experimental information and decreases the time to find the solution to the problem under investigation. For example, data models constructed using DAT are automatically available to any SIMPROCESS modeling element that models some behavior as a random process.

Statistics collected during the execution of an experiment are automatically collected and even merged with existing data if necessary. Output graphs and reports automatically use the correct labels of SIMPROCESS modeling elements.

The end-to-end environment provides support for all of the major steps of a statistical simulation experiment including model development, verification & validation (v&v), experimentation, analysis and presentation of results. An end-to-end environment significantly shortens the turnaround time for obtaining statistically significant and presentable results. For the model development phase, SIMPROCESS provides graphical and interpretive specification of logical processes and DAT provides for data analysis and modeling of random processes. For the v&v phase, SIMPROCESS provides animation and trace files to verify the logical processes while EMT provides statistical procedures for validating a simulation model. For experimentation and analysis, SIMPROCESS provides single scenario execution and analysis capabilities and EMT provides multiple scenario execution and analysis capability. Finally, SIMPROCESS, DAT, and EMT all provide extensive graphing and reporting capabilities.

Table 1 shows the integrated capabilities of SIMPROCESS for all phases of the statistical experiment process. Each column of the table corresponds to a SIMPROCESS tool; each row to a phase of the statistical simulation experiment; and each cell to a set of capabilities provided by a tool for that phase of the statistical simulation experiment.
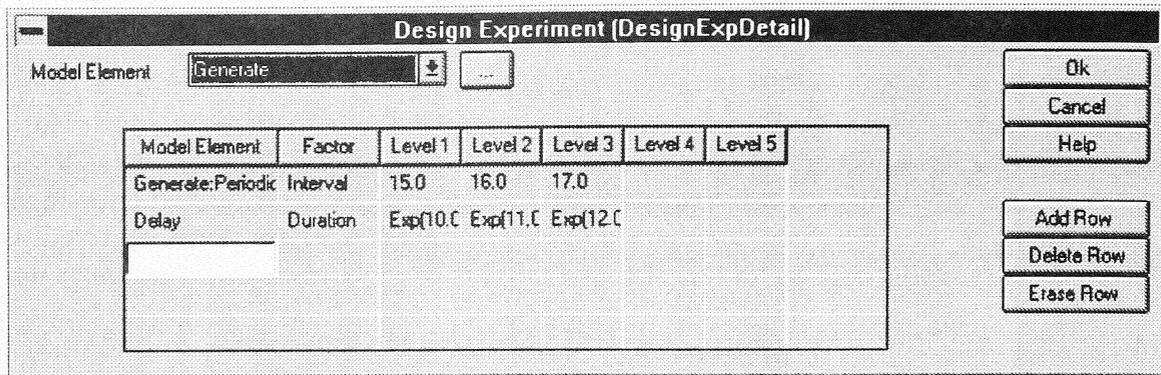
Figure 2: Specification of Factors and Levels

3 THE SPECIFICATION OF AN EXPERIMENT

EMT presents a different view of the model that makes experimentation easy. EMT views the model as a collection of factors for experimentation; SIMPROCESS views the model as a logical representation of the processes of a system. A factor is an input variable to the simulation model that could influence the output response. For example, the duration of a delay influences the total time required by an entity to move through a system whereas the particular bitmap used to represent the delay in the graphical view of the model does not. Note that although model elements are elementary from the SIMPROCESS perspective, they may have many behaviors from a Design of Experiment (DOE) point of view that affect the statistical output.

In SIMPROCESS, a simulation model is built by specifying the interactions between predefined model elements. Model elements include activities, resources, and entity types. Figure 1 shows the SIMPROCESS graphical representation of a simple queuing model used to demonstrate the design, execution, and analysis of an experiment using EMT. The interarrival times of entities is specified by the generate activity "Generate." Entities queue up for a single resource. The resource "Server" is made available to the first entity in the "Get Resource" queue. The use of the resource is a service that requires some length of time to occur. The service itself is modeled as a simple delay in the "Delay" activity. The server is freed for use by the next entity in the "Free Resource" activity. The entity exits the system in the "Dispose" activity. The statistical output of interest is the total time in the system. The total time in the system is the time an entity spends waiting in the queue plus the time it takes for service.

A statistical simulation experiment is initiated by creating an experiment object. An experiment object is a named object used as the organizational unit for managing experiments. The new experiment object manifests itself in the user interface as an experiment editor. The editor provides the interface for designing the experiment and performing analysis.

The design of the experiment is the specification of different input configurations of interest and the statistics used to measure their effect on performance. In EMT, the specification of different input configurations used to run a simulation is a two step process. The first step of the specification is the selection of factors and specification of levels - specific values for the factors. The second step of the specification is constructing the input configuration for individual simulation runs. The two-step specification of the input configuration is a deliberate design decision. Many types of statistical analysis of experimental results require a complete design i.e. a design that is executed at every combination of levels. A single combination of levels is a scenario or in DOE terminology a design point. Let's imagine an experiment that requires a complete design for four factors with each factor at four levels. There are 4*4*4*4 possible combinations of levels for the four factors. The complete design has 256 design points. In EMT, the user must specify four levels for each of the four factors. This is 4+4+4+4 or 16 level specifications in the first step of the process. The complete design is created simply by using the All Combinations option of the Scenarios command on the experiment editor. If the specification were a one step process, the user would be required to individually specify 256 scenarios rather than 16 levels to specify a complete design.
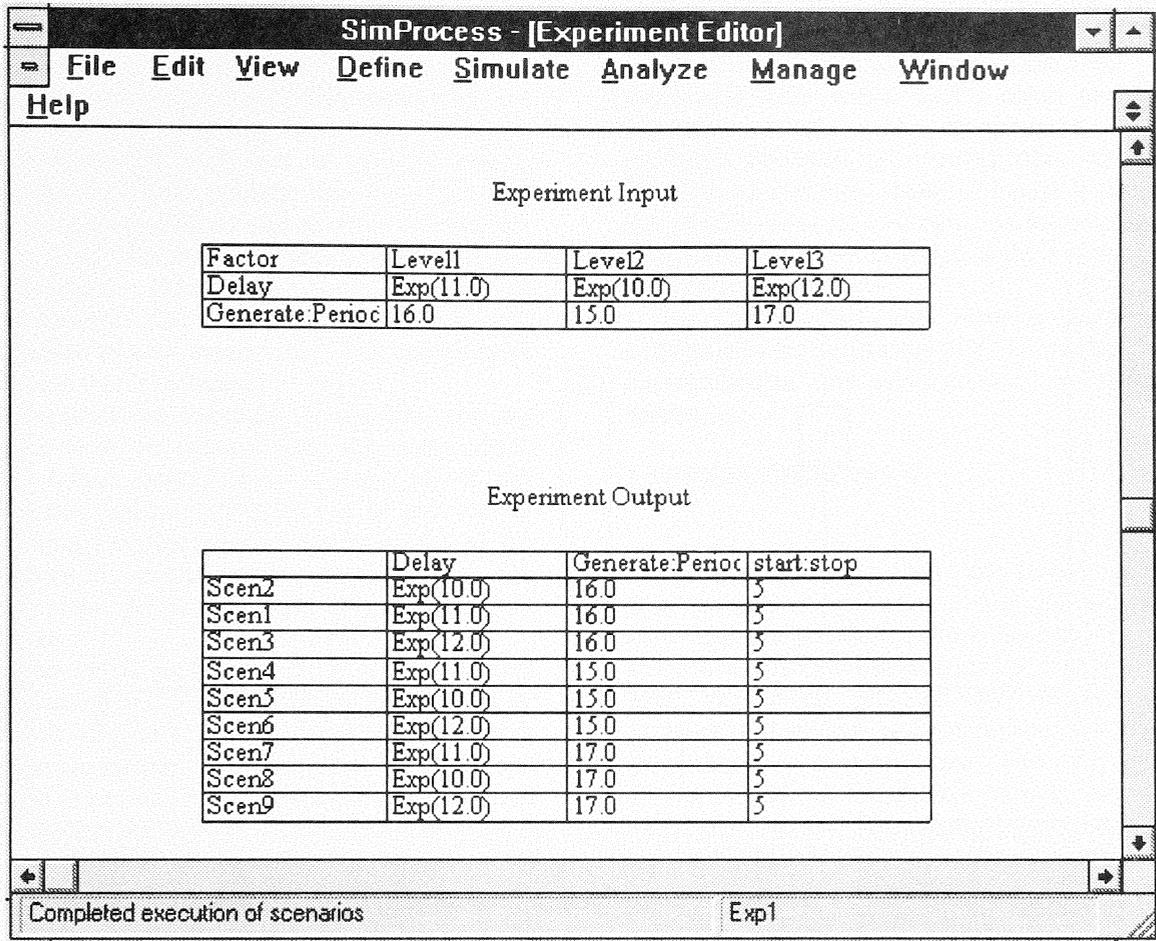
Figure 3: Experiment Input and Output Tables.

Figure 2 shows the spreadsheet-like user interface used to specify which factors to vary for a particular simulation experiment and what levels to use for the selected factors. Above the table is a context sensitive input selection list and text entry box. The first column of the table is used to specify the model element. Model elements are named objects in the simulation model that have at least one behavior designated as a factor. Selecting a cell in the model element column causes a list of selectable model elements to appear in the input selection list. The experimenter selects a model element for experimentation from the input selection list. Selecting the cell to the right of a selected model element in the factor column causes a list of factors to appear for the previously selected model element in the input selection list. Context sensitive spreadsheet data entry is used to correctly specify model elements and factors.

Each factor has a domain that is appropriate for the modeled behavior. Factors that model random processes have a sample domain. The sample domain is the set of supported distributions for SIMPROCESS.

EMT domains also include real, integer, and enumeration domains. Levels are specified by selecting the next available cell after the selection of a model element and factor. The domain of the factor defines appropriate values for levels of the factor. Valid level specification is ensured by context sensitive spreadsheet data entry.

Because SIMPROCESS is a hierarchical simulation tool, any hierarchical process in a model is a potential factor. The domain of the hierarchical process is the enumeration of named alternative subprocesses. A level of the hierarchical process is an individual subprocess. The enumeration can be used to create an experiment that compares alternate subprocesses or configurations of the model.

The end result of the first step of the specification is a completed experiment input table as shown in Figure 3. In this experiment, two factors have been selected: "Generate:Period1 Interval" and "Delay Duration". Factor "Generate:Period1 Interval" has levels 15.0, 16.0, and 17.0. Factor "Delay Duration" has levels Exp(15.0), Exp(16.0), and Exp(17.0).
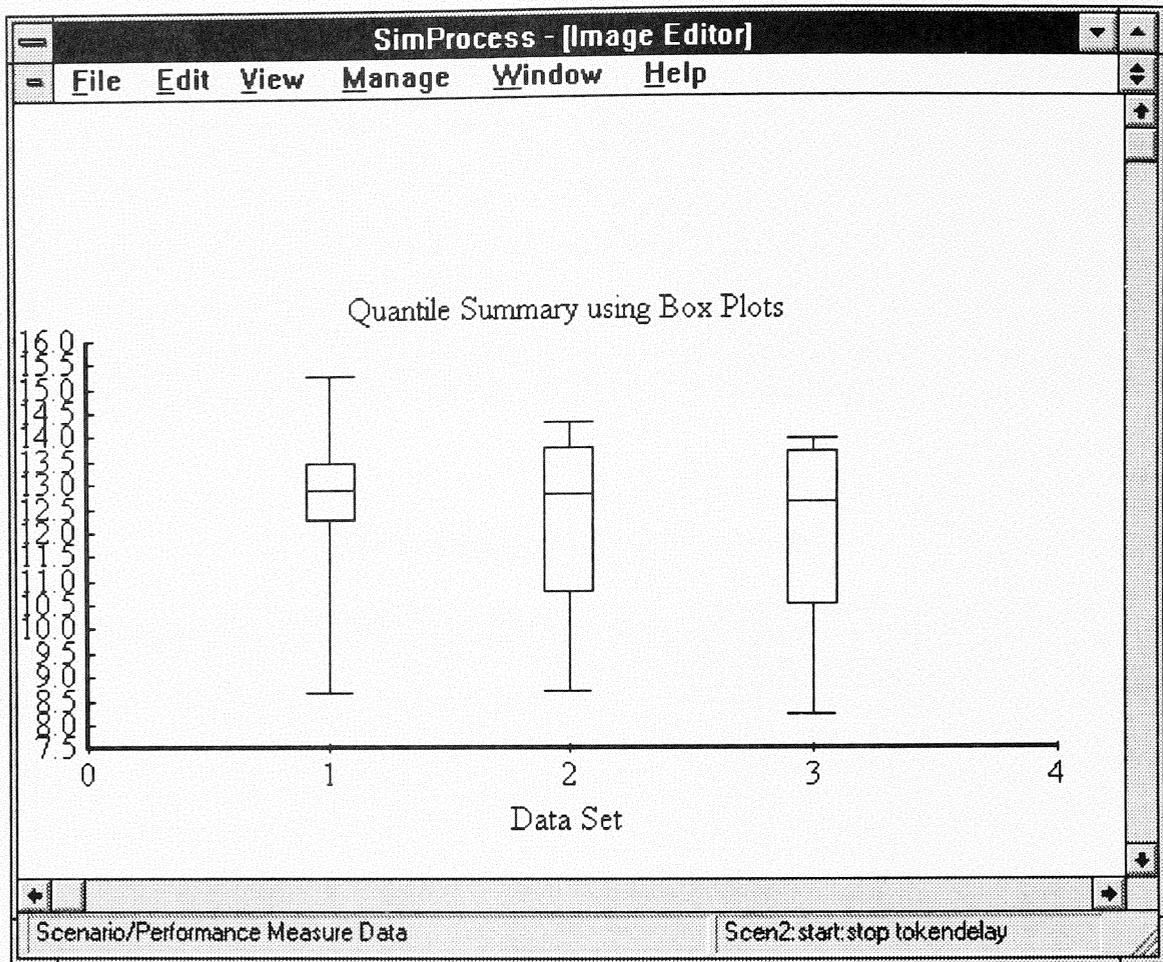
Figure 4: Box Plots of Selected Results

Exp is the standard abbreviation for an exponentional distribution. The parameter is the mean of the exponential distribution.

The second step in the design of the experiment is the specification of scenarios. There are nine possible scenarios to be executed as shown in Figure 3. If the design is complete all combinations are created by simply selecting the "scenario all" option from the experiment editor menu. If specific scenarios are necessary, they can be created by selecting an appropriate level for each factor in the experiment input table shown in Figure 3 and selecting the "scenario single" option from the experiment editor menu. Note the ability to select table entries on the user interface. The ability to select entries or "objects" is an inherent capability of the Experiment Manager object oriented user interface.

Figure 3 also shows the experiment output table. A named scenario has been created for each created scenario and a list of the levels that define the

scenario. The performance measure start:stop is also shown in the table. Experiment Manager determines which statistics and reports are enabled in the SIMPROCESS model. A performance measure entry is created for each enabled SIMPROCESS statistic. Note that the cell entries beneath the start:stop performance measure indicate if statistical information has been collected. Prior to the execution of an experiment, the number is set to 0 indicating that no data points have been collected.

4 EXECUTION AND ANALYSIS OF AN EXPERIMENT

The run parameters used to execute the scenarios are specified in the SIMPROCESS editor. The run parameters include the number of replications, the run length of each replication,

and the warm-up time. Either a terminating or batch-means experiment is specified. In the case of terminating simulations, EMT assumes that the specified warm-up period is long enough so that any bias is removed from the resulting observations. In the case of non-terminating simulations, EMT assumes that the replication lengths are of sufficient size to remove significant correlation from the observations. The number of replications determines the number of observations that will be recorded during execution of each scenario for each performance measure that is collected.

Scenarios are executed by selecting the run option from the menu of the experiment editor. The default action is to execute all of the scenarios. Specific scenarios can be executed by selecting the appropriate scenario entries in the experiment output table displayed by the experiment editor and then selecting the run option.

The initial seed values used for the random number streams for each scenario are identical by default. The current value of each random number stream is recorded with each scenario at the end of the execution. If more replications are required for the statistical analysis of an experiment, the experimenter can request that EMT merge results from subsequent executions of the scenario with already collected results. EMT will restart the experiment at the last value of each random number stream and automatically merge the new output results with existing data.

Figure 3 shows the experiment output table after execution of all nine scenarios. The cells beneath the performance measure column labeled "start:stop" indicate that 5 data points have been collected for each scenario. EMT uses the average value of a performance measure obtained at the end of each replication as a single estimate of the expected value of the performance measure. Statistical analysis of these estimates assume that the observations obtained from each replication are iid (independent and identically distributed).

Statistical output from multiple scenarios can be simultaneously viewed by selecting a

performance measure entry in the experiment output table or by selecting one or more data sets and then selecting the desired operation from the experiment editor menu. EMT's object oriented interface provides the experimenter with maximum flexibility in selecting data sets for viewing and statistical analysis. Figure 4 shows box plots of three selected data sets for graphical comparison of the performance of three scenarios for the start:stop statistic.

The EMT toolkit also includes statistical analysis tools for performing ANOVA, regression, transformations, time series analysis, and model validation.

5 FUTURE DIRECTIONS

The most interesting future direction for EMT is in the area of optimization. New advances in optimization algorithms, continuing improvement in hardware performance and greater expectations from commercial products are making the marriage of simulation and optimization not just a possibility but a requirement. Not only will SIMPROCESS and Experiment Manager provide "canned" optimization algorithms, but the environment can be extended to include custom algorithms. Other directions for growth include expanded statistical analysis particularly in the area of time series analysis. Time series analysis of simulation output can be used to determine appropriate warm-up times or replication lengths.

AUTHOR BIOGRAPHY

Michael Angel is a software developer for CACI's Advanced Simulation Laboratory in La Jolla, CA. His efforts at CACI have focused on developing simulation modeling tools including the Experiment Manager.