A Quick and Effective Prototype Experimental Design and Analysis Tool

Dr. Richard A. Romano and Heather A. Stoner

Realtime Technologies, Inc.
1523 North Main Street
Royal Oak, MI 48067

Abstract

Experimental design and analysis is critical to any research laboratory. A semi- autonomous system that can assist the development and execution of an experiment can help provide a quick, accurate and cost-effective solution to many research laboratories. A prototype Simulator Monitoring and Control (SMAC) system was developed to help effectively run laboratory-based operator in the loop simulations. The SMAC prototype system was developed to support functionality required for each logical step of the experimental process. It includes an experimental process wizard that guides the user through the process of designing, configuring, running, analyzing, and reporting driving simulation studies. This user interface provides a common point of reference and indicates the status of the experiment as it progresses through various stages of development and implementation. This system was tested in TACOM's Ride Motion Simulator. It was found that the resulting prototype SMAC system allowed TACOM personnel to conduct safe, and accurate, laboratory-based operator-in-the-loop simulations. The paper also reports the researchers' evaluations of the advantages and disadvantages of this technique.

Résumé

Richard A. Romano is President and founder of Realtime Technologies, Inc. Dr. Romano earned his Ph. D. in Industrial Engineering from the University of Iowa in 1999.

Heather A. Stoner the Human Factors Engineer at Realtime Technologies, Inc. Ms. Stoner earned her M.S. in Industrial Engineering from the University of Iowa in 2004.

Introduction

Executing experimental design and analysis is a critical component in any research field. The focus of this paper is to describe the methodology and performance of a prototype experimental design and analysis software. A system that would allow researchers to design and execute experimental designs while performing the analysis quickly and effectively could reduce the time and cost of simulation research.

The experimental design and analysis module described in this paper allows the simulator experimenter to design a set of simulator configurations for use in an experiment. It also permits the testing and presentation of each configuration to each subject based on a predetermined experimental design and assists the analyst in reducing data from the experiment and then analyzing the results and preparing summary research reports. The paper also describes the deficiencies and problems with using an experiment control system and makes recommendations for further improvements.

The Simulator Monitor and Control (SMAC) System is intended for use by a variety of personnel involved in the implementation of driving simulation research studies. The principal investigator will likely use the system to generate the experimental design and to define the methods and measures used to collect data. The simulation developer will use the SMAC System to interpret the experimental design and to verify that all necessary components are available to conduct the experiment. The simulator operator will use the SMAC System to determine in what order to run subjects and which experimental conditions should be used for each run. Operators will also use the system to track which subjects have been run through the system and to verify the collected data. The data analyst will initiate the statistical data analysis and review the results. The data analyst will also have the necessary tools to perform ad hoc analyses as desired. Once the analyst is satisfied with the results, they are exported to a document along with other template report sections creating a final report.

The SMAC Experimentation Process

The SMAC system provides a wizard-like tool for managing the design, analysis, and conduct of human-in-the-loop driving simulation studies, providing a common focal point between all of these various steps. It is laid out in a linear structure that matches the logical progression of tasks that must be accomplished when conducting an experiment.

Figure 1 below shows the main SMAC user interface. This top level panel is a set of buttons that allow the user to launch into additional functionality to manage the experimental process. The functions are laid out onto the buttons in a top to bottom linear progression representing the steps required to complete a study from start to finish. Once the necessary steps for experimental development have been completed, a checkbox is marked with a red checkmark and the next function on the list is enabled.

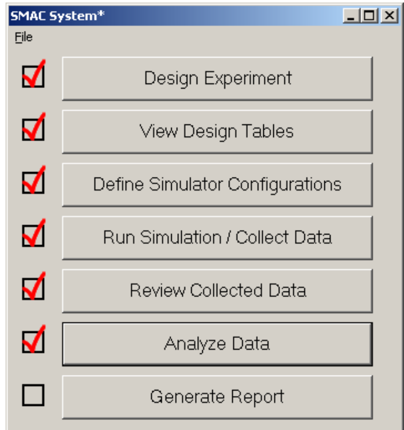


Figure 1: Main SMAC User Interface Panel

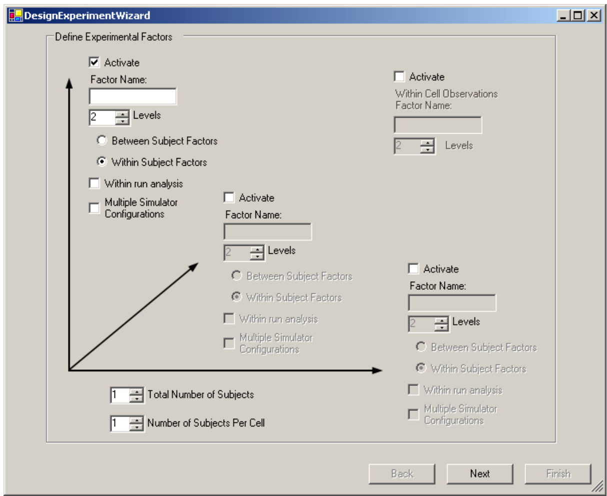
The main data structure behind the SMAC system is a multi-sheet MS Excel workbook. For purposes of common terminology, the workbook and all the data captured on its various worksheets will be called an experiment. Experiments are loaded into the SMAC system with the File main menu option at the top of the main user interface page.

Designing Experiments

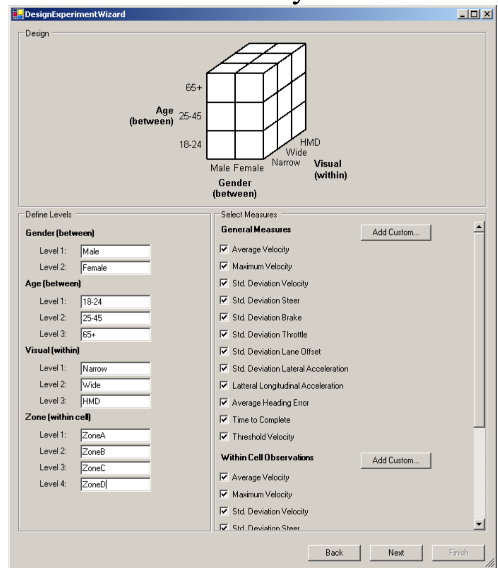
After reviewing experimental protocols from the driving simulator literature, the SMAC System was designed to handle a variety of common, block experimental design types (examples include: Devonshire &, Sayer, 2005; Horrey & Wickens, 2004; Mahlke, et. al., 2007; Marshall, et. al., 2007; Nunez et. al., 2001; Ranney et. al., 2005; Strayer & Drews, 2004). The current structure allows the definition of up to three dimensions of analysis or factors. Each of the factors has a number of characteristics that must be defined for the system in order to allow the SMAC system to create the most appropriate experimental design structure, experimental run order, and statistical analyses to be performed on the resulting data.

An interactive experimental design wizard was created that allows the user to define the various dimensions of the study. The results of the wizard provide the necessary inputs to create a data collection and analysis structure supported by the rest of the SMAC System. When you click on the Design Experiment button, the experimental design wizard page is presented (see Figure 2a). This is where the critical design factors are entered into the system that will shape the nature of the experiment and the resulting analysis. The three arrows on the screen represent the three potential dimensions (axis) of the experimental design. Each factor in the design represents one experimental dimension. SMAC currently supports up to three experimental dimensions plus additional within cell observations. Within cell observations allow the data to be collapsed across a set of observations such as along a set of horizontal geometric curves, or a set of straight road segments. A within run factor analysis may be used to compare two different observations such as straight versus curved road segments.

When setting up the experiment, each factor has several components to customize. Within each factor it is possible to indicate a within- or between-subject design, number of levels, and multiple simulator configurations. It could be very useful having one interface that lets one select multiple simulator configurations. For example, if a study required one condition to have motion and the other non-motion, the two different simulator configurations could be saved and referenced from the SMAC system interface.



(a)



(b)

Figure 2: SMAC Experimental Design Wizard (a); and SMAC Experimental Factor definition dialog (b).

Once the experimental factors have been defined for the experiment, names must be defined for the various levels they contain (see Figure 2b). In addition, experimental measurements of interest are defined and selected. Selecting the check box next to each measure ensures its inclusion in the experimental design. If a measurement is not predefined and provided in the list, it is possible to click on “Add Custom” to define a new measure. The measures defined are stored in the SMAC system experimental spreadsheet and gives the simulator developer an indication of additional measures that should be added into the simulation.

There are two different categories of measures that can be collected. The first is general measures. General measures are data collected over the entire simulated drive. These measures can be descriptive statistics for the variables of interest. The second category of measures are within cell measures. Within cell measures are collected in pre-determined data zones during the drive. For example, if an area of interest is located around a set of horizontal or vertical curves, data zones could be defined. The within cell measurements would then calculate descriptive statistics for just that specific zone. As for the general measures, that specific data zone plus the entire drive would be included in the descriptive statistics.

Once the experimental factors have been defined and measures selected for data collection, a review table of the experimental parameters are presented to the user of the SMAC system (see Figure 3). This allows the user to view the designed experiment and make any changes using the interface.

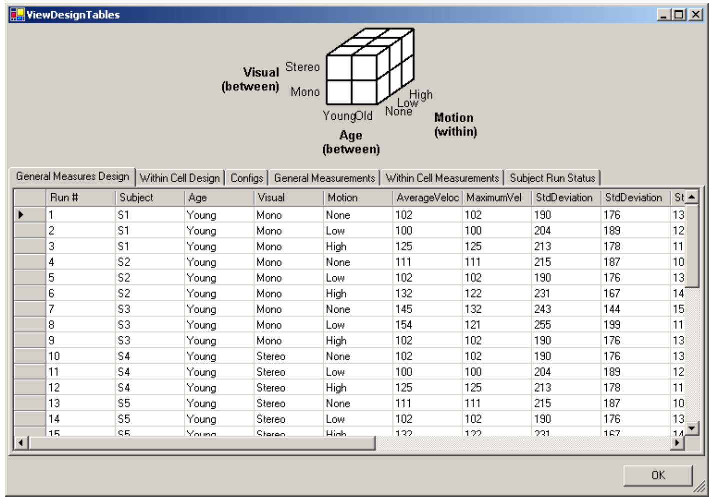


Figure 3: View Design Tables Dialog

Running the Experiment

The Run Simulation and Collect Data section of the SMAC interface provides the necessary controls to execute the data collection simulation in the appropriate configuration for each subject run included in the experiment. When the run simulation / collect data button from the SMAC user interface is pressed, the following dialog is presented. This dialog displays the entire list of experimental runs required to complete the experimental design that was previously defined. It also contains the necessary controls to select the current run of interest and a button to launch the simulation. The area at the top of the screen provides detailed information about the highlighted row in the spreadsheet box below.

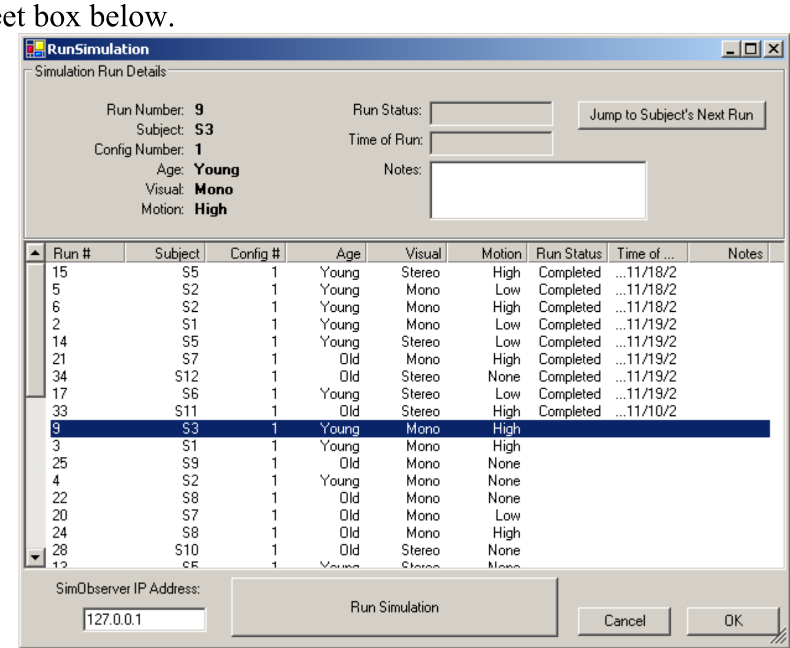


Figure 4: Run Simulation Dialog

The spreadsheet at the bottom half of the screen contains a listing of all the experimental runs. This shows the order of the block randomized experimental design with the specific factors that were specified earlier. The list has been randomized based on both the subject and run numbers. Ideally, the experimental plan would start at the top of the run list and complete data collection drives sequentially from top to bottom. This will ensure a complete randomization of subjects and experimental conditions. However, at times it is not feasible to complete one of the runs in the order that it is presented, so an option to jump to another experimental run is provided. For example, in Figure 4, notice that run 15 and 14 (far left column) use subject 5. However, if the original order for the runs is followed, subject 5 would need to return to participate. In most driving simulator laboratory environments this is not feasible, so using the "Jump to Subject's Next Run" will automatically go to the next condition where that particular subject is used.

When it is time to start data collection, the SMAC system offers several options to accomplish this task. First, a simulator could be directly connected to the SMAC system and allow for a seamless integration between the two. Or, the SMAC system could be used to guide the data collection process. Either way that this is accomplished, the collected data should ultimately be written to the excel data file the SMAC system reads.

Analyzing the Data

The Analyze Data portion of the SMAC user interface provides an ability to conduct the standard semi-automated data analysis. It is also possible to perform manual data analysis. The semi-automated data analysis may be used when there is a good understanding of the operational and statistical aspects of the designed scenarios. Otherwise, the manual data analysis capability may be used to explore statistical assumptions and distributions to verify the validity of statistical tests. The statistical software used in the SMAC system is JMP made by SAS (www.jmp.com). SMAC will perform an automated analysis procedure that matches the experimental design. SMAC will also automatically perform post hoc tests on any significant main effects. If an interaction is found significant, SMAC will instruct JMP to perform a test slice analysis but will not fully follow up with a simple effects analysis. There are many ways to pursue the analysis of significant interactions. The most appropriate method usually depends on the types of factors in the experiment and the questions to be answered regarding the experimental hypotheses. To facilitate exploring significant interactions, the JMP graphical user interface is left open with the data loaded so other analyses maybe pursued.

SMAC executes a JMP script that opens the corresponding data files, generates the appropriate statistical model given the experimental design, and runs an analysis of variance (ANOVA) on each of the measures selected for analysis. The JMP GUI will appear showing the data files used to do the analysis, the JMP dialogs showing the setup of the statistical analysis that resulted from the script, and the two results documents. The Fit Least Squares document shows the default JMP results output from the ANOVA. The Analysis Output document shows the ANOVA results pulled out of the otherwise long JMP ANOVA report. SMAC's custom JMP script retrieves the results from the ANOVA that would typically be included in an experimental report. SMAC formats them into the Analysis Output document. Results in the Analysis Output document are formatted for inclusion in the experimental report.

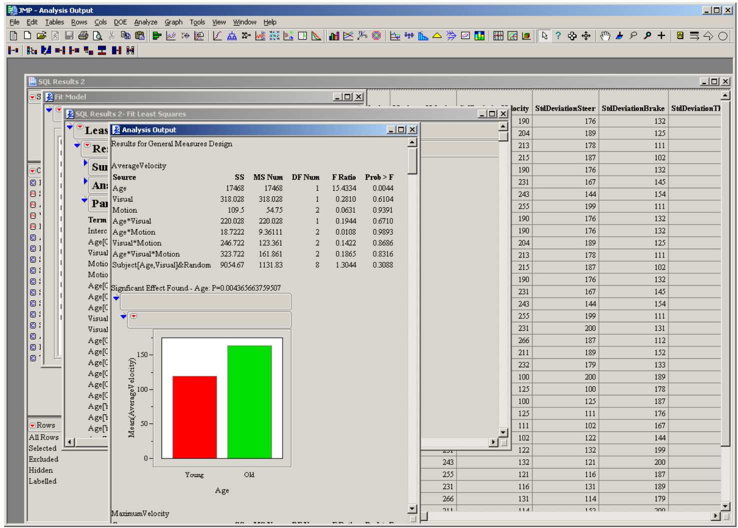


Figure 5. Results of Executing JMP Scripted Data Analysis

In the Analysis Output document (see Figure 5), ANOVA tables are generated for each measure showing the appropriate error terms and all possible effect tests. If the effect is significant it will also create a graph of the data. If the significant effect is a main effect, SMAC will generate a Tukey's post hoc test and insert it into the report. If the significant effect is an interaction, SMAC will still create the graph and insert it into the Analysis Output document. In addition, SMAC will generate a set of test slices within JMP to aid in the simple effects analysis.

Once the analyses processes complete successfully a Microsoft Word document can be created using the information from JMP.

Reporting the Results

The Generate Report portion of the SMAC System facilitates creating a structured report of the experimental results. The report generation function can be configured to compile a number of template report documents representing the various sections of an experimental report.

The generation of the report document represents the end of the experimentation process. The experimenter must still work through the report document to fill in the content that cannot be covered by the template. Additional statistical tests may also be warranted depending on which results are found significant and what interpretations are to be made from them.

Discussion

In order to assess the capabilities of the SMAC prototype system, a single experiment was done with TACOM's Ride Motion Simulation. The simulator features an electro-hydraulic 6 degree of freedom table on which a vehicle cab structure can be mounted. A re-configurable cab supports one occupant. The simulator can be outfitted with displays driven by a real-time image generator, driving controls, and an audio generation system. For a full description of the simulator see Nunez, Brudnak and Paul, (2001). TACOM's Ride Motion Simulator was configured with the simulator software SimCreator. The motion base was turned off to simplify and accelerate the test process.

Two measures were taken of driver performance: average vehicle speed, and number of steering reversals. The measures were calculated once a minute on the previous minute of data. Each subject drove the simulator for three minutes. Therefore each measure was calculated three times for each condition. The subjects drove two conditions: a narrow field of view condition and a wide field of view condition on a simulated version of the Churchville A test course at the Aberdeen Proving Grounds. Three subjects were used in the test case.

After each subject ran each condition, the SMAC system automatically saved the calculated measures for future analysis. Once all three subjects had driven each condition, the ANOVA was run on the two measures automatically by the SMAC interface. Reviewing the results of the average speed and using a probability P-value of 0.05, none of the results were significant. Reviewing the results of steering reversals and using a probability P-value of 0.05, it was found that the drivers had significantly more steering reversals using the narrow field of view, an average of 5.89, versus the wide field of view, with an average of 3.78. Based on interviews with the subjects it is hypothesized that the vehicle is harder to control especially at the exit from sharp corners using the narrow field of view resulting in an increase in steering reversals.

The prototype SMAC system was found to operate reliably and easily. The SMAC was used to select and run a simulator configuration, collect and store data, and finally to analyze the collected data. Several limitations were discovered when the TACOM personal used the system, based on the experimental design specifications and analysis. First, only three factors can be defined for the experiment, which can limit the interactions that may be of interest. Also, only a single within cell analysis can take place, again possibly limiting interactions of interest.

A downside to the experimental order is that only a completely randomized experimental order is allowed, thus a full block design does not result in a minimized number of participants. In some research environments executing a fully randomized block experimental design is not feasible, and the SMAC system does not account for this. This deficiency has been noted for future development of the system.

Several benefits were recognized with the prototype SMAC system. These benefits were pointed out by the TACOM personal after using the SMAC system. The first is that it facilitated the coordination and communication between the experimental design and simulator operator. They also appreciated the rapid experimental design production and that the designs were limited thus resulting in acceptable designs. They mentioned that it could help them avoid some design pitfalls in the future.

Conclusion

The high level SMAC prototype system user interface was developed to support functionality required for each logical step of the experimental process. It includes an experimental process wizard that guides the user through the process of designing, configuring, running, analyzing, and reporting driving simulation studies. This user interface provides a common point of reference and indicates the status of the experiment as it progresses through various stages of development and implementation. The resulting SMAC system allowed TACOM personnel to conduct safe, accurate, and cost-effective laboratory-based operator-in-the-loop simulations.

Acknowledgements

This research was financially supported under a Small Business and Innovative Research (SBIR) contract by the U. S. Army Tank & Automotive Command (TACOM) in Warren, Michigan (contract number DAAE07-03-C-L003 and DAAE07-02-C-L029). Those views expressed in this work are those of the authors and do not necessary reflect official U. S. Army policy and or opinions.

Reference

Devonshire, J. M., Sayer, J. R. (2005). Radiant Heat and Thermal Comfort in Vehicles. *Human Factors*, 47(4), 827-839.

Horrey, W. J., Wickens, C. D. (2004). Driving and Side Task Performance: The Effects of Display Clutter, Separation and Modality. *Human Factors*, 46(4), 611-624.

Mahlke, S., Rosler, D., Seifert, K., Krems, J. F., Thuring, M. (2007). Evaluation of six Night Vision Enhancement Systems: Qualitative and Quantitative Support for Intelligent Image Processing. *Human Factors*, 49(3), 518-531.

Marshall, D. C., Lee, J.D., Austria, P. A. (2007). Alerts for In-Vehicle Information Systems: Annoyance, Urgency and Appropriateness. *Human Factors*, 49(1), 145-157.

Nunez, P., Brudnak, M.J., Paul, V. (2001). "Warfighter/hardware in the Loop Simulation at TACOM-TARDEC's Ground Vehicle Simulation Laboratory (GVSL). In 1st Human Centered Transportation Simulation Conference, Iowa City, Iowa.

Ranney, T. A., Harbluk, J. L., Noy, Y. I. (2005). Effects of Voice Technology on Test Track Driving Performance: Implications for Driver Distraction. *Human Factors*, 47(2), 439-454.

Strayer, D. L., Drews, F. A. (2004). Profiles in Driver Distraction: Effects of Cell Phone Conversation on Younger and Older Drivers. *Human Factors*, 46(4), 640-649.