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The Impact of the User Interface on Simulation Usability and Solution Quality

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by

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We hereby certify that this dissertation, submitted by Bruce Montgomery, conforms to acceptable standards and is fully adequate in scope and quality to fulfill the dissertation requirements for the degree of Doctor of Philosophy.

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An Abstract of a Dissertation Submitted to Nova Southeastern University
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This research outlines a study that was performed to determine the effects of user interface design variations on the usability and solution quality of complex, multivariate discrete-event simulations. Specifically, this study examined four key research questions: what are the user interface considerations for a given simulation model, what are the current best practices in user interface design for simulations, how is usability best evaluated for simulation interfaces, and specifically what are the measured effects of varying levels of usability of interface elements on simulation operations such as data entry and solution analysis. The overall goal of the study was to show the benefit of applied usability practices in simulation design, supported by experimental evidence from testing two alternative simulation user interfaces designed with varying usability.

The study employed directed research in usability and simulation design to support design of an experiment that addressed the core problem of interface effects on simulation. In keeping with the study goal of demonstrating usability practices, the experimental procedures were analogous to the development processes recommended in supporting literature for usability-based design lifecycles. Steps included user and task analysis, concept and use modeling, paper prototypes of user interfaces for initial usability assessment, interface development and assessment, and user-based testing of actual interfaces with an actual simulation model. The experimental tests employed two interfaces designed with selected usability variations, each interacting with the same core simulation model. The experimental steps were followed by an analysis of quantitative and qualitative data gathered, including data entry time, interaction errors, solution quality measures, and user acceptance data.

The study resulted in mixed support for the hypotheses that improvements in usability of simulation interface elements will improve data entry, solution quality, and overall simulation interactions. Evidence for data entry was mixed, for solution quality was positive to neutral, and for overall usability was very positive. As a secondary benefit, the study demonstrated application of usability-based interface design best practices and processes that could provide guidelines for increasing usability of future discrete-event simulation interface designs. Examination of the study results also provided suggestions for possible future research on the investigation topics.

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Chapter 1

Introduction

Problem Statement and Goal

Problem statement

The problem addressed by this study is to determine whether selected user interface design variations significantly affect the usability and solution quality of complex, multivariate discrete-event simulations. If usability design and test techniques can be demonstrated experimentally to improve simulation interaction and results, the argument for including such techniques in simulation development lifecycles will be strengthened. General benefits of usability methods are understood. Bias and Mayhew (2005) outline the general benefits of such efforts, including increases in user productivity, decreases in errors, and reduced cost of training and support. But the impact in simulation is potentially higher due to the complex nature of such applications, which employ complex mathematical models that evolve over time using variations of model inputs and examining their effect on output performance measures (Law, 2007). The creation of input data and models is generally held to be the most time consuming element of discrete-event simulations (Randell & Bolmsjo, 2001) and resulting output can be difficult to interpret, making it hard to recognize differences between system interrelationships and randomness (Banks, Carson, Nelson, & Nicol, 2010). The need for improved interface support is noted in some sources (Palaniappan, Sawhney, & Sarjoughian, 2006) with rare specific calls for usability in simulation development lifecycles (Ören & Yilmaz, 2005), yet many simulations that include interface design do not address usability (Heilala, Montonen, Salmela, and Pasi (2007) for example).

Problem background

While there is a nearly intuitive understanding that a lack of effective user-interfaces could inhibit simulation use, development, and analysis, many simulation packages, especially those targeted at complex modeling tasks, are developed with a minimal focus on the HCI aspects of the eventual product. As an example, one overview of a building energy simulation program, based on an extremely complex model, is intentionally designed with the barest of interfaces – simple text-based data file input and output (Crawley, Winkelmann, Lawrie, & Pedersen, 2001). The user interface is left to third-party developers. Papamichael (1998) points out that in such large building simulation models, "informed decisions require the management of vast amounts of information" about combinations of options and performance criteria. Yet, most building energy simulation programs are "developed by researchers, for research purposes, and are not easy to use" (Papamichael, 1998, p. 1-2).

Goals

The overall goal of this study was to determine the effects of user interface design variations on the usability and solution quality of complex, multivariate discrete-event simulations. Experimental interface designs varied the level of usability in data entry and validation, application flow and presentation, user feedback, error prevention and recovery, and help sub-systems. Specific effects impacted by these interface design variations included interaction time, error rates, and user satisfaction for common simulation interactions such as data input and model specification, parameter changes for simulation experiments, review of simulation results, and user support (Kuljis, 1996).

Demonstrating measurable effects through experimental assessment of interface usability on both simulation use and solution quality may bring more focus on including usability design in simulation development. Specifically, evaluating the solutions derived from alternate varied interfaces to a single core simulation provides a quantitative measure of usability importance not available in the current literature. Other beneficial aspects of the study includes identifying which HCI aspects contribute to effective simulation use, as well as identifying usability issues specific to those elements, through standard usability assessment. Finally, the study illustrates use of usability design and assessment methods in simulation development, providing some guidance for interested developers.

Research questions

The four key research questions for this study include:

- What are user interface considerations for discrete-event simulation models?
- What are best practices for designing an interface to a simulation application?
- How is usability best evaluated for simulation interfaces?
- What is the actual effect of increased usability for specific interface elements on simulation operations, such as data input and solution analysis?

For simulation applications, there are consistent sets of characteristic operations that must be considered, regardless of the simulation topic. In development of an assessment criteria for simulation environments, Tewoldeberhan and Bardonnet (2002) outline these operations, including model development, input modes, testing, execution, animation, output, and other user considerations. Design of the interface to address these common operations must also consider the user profile. As discussed in Galitz (2007), certain user groups, such as novice users, may have differing interface needs that may affect interface designs for these typical simulation operations, including aids to recognition memory, simplified tasks and vocabulary, and informative feedback.

Measures for evaluation were developed from prior simulation and usability research. Dumas and Redish (1999, p. 184) suggest a combination of quantitative performance measures, such as timed or counted tasks and observations, and qualitative subjective measures, such as ratings, preferences, and commentary. Gutwin and Greenberg (1999, p. 256) used selected measures such as task completion times, perception of effort, overall preference, and strategy evaluation in their study of usability of groupware. The Common Industry Format for Usability Test Reports (National Institute of Standards and Technology, 2001) also outlines accepted reporting formats and suggested metrics. In addition, these NIST guidelines suggest the use of pre-published and validated questionnaires for user satisfaction measurement, including the System Usability Scale (SUS), the After-Scenario Questionnaire (ASQ), or the Post-Study System Usability Questionnaire (PSSUQ) (Brooke, 1996; Lewis, 1993). Suggestions for use of standard questionnaires and related data analysis are also discussed in Tullis and Albert (2008).

Relevance and Significance

Problem scope

Simulation is a widely used technique for complex modeling tasks. Law (2007) lists simulation applications such as manufacturing, computer system design, military applications, inventory systems, and transportation networks. The improvement of simulation interfaces and interface customization are called for in discussions of future simulation systems (Banks, 1997). Banks (1999) asks for future simulation tools to provide end-user interfaces that are focused on the information and tasks the simulation user is responsible for. More recent simulation studies still maintain the need for rapid simulation and model development, through use of a effective user interface that provides for data entry and results analysis (Palaniappan, et al., 2006). Ease of use issues dominate a survey of simulation users regarding desired simulation software features (Hlupic, 2000). Yet characteristics of developed interfaces are often presented with no visible usability consideration (Robinson et al., 2001).

The published research discussing HCI aspects of simulation tends to use general discussions of usability benefits (Kuljis, 1996; Ören & Yilmaz, 2005; Pidd, 1996) or to review specific instances of interfaces designed for a selected task (P. Cohen et al., 1996; Herren, Fink, & Moehle, 1997). In particular, Ören and Yilmaz (2005) provides a rare recent focus on the elements of interactive simulation software, supported by usability quality principles from recognized sources (Mayhew, 1999; Shneiderman, 1998). They outline a set of 21 derived quality principles for simulation software grouped in four areas: usability, communicativeness, reliability, and evolvability. They further recommend application of the principles as a systematic approach for evaluation and design of simulation interfaces. This contrasts with the lack of usability support in many specific designs presented. In a less than rigorous approach to usability in simulation interface design Odhabi, Paul, and Macredie (1998) present development of a graphical user interface designed for simulation modeling. While the study recognizes the variety of front-ends used in simulation, from command line interfaces to direct manipulation, the selection of a graphical approach is made without support or experimentation, but simply because such interfaces are generally considered to better support novice users (Odhabi, et al., 1998).

The lack of integration of usability methods from discrete-event simulation development is not unique. A study of the relationship between usability methods and software engineering in general finds high levels of disconnect, claiming that most developers involved in user interface design do not use user-centered design approaches or tools (Seffah & Metzker, 2004). The study also suggests several obstacles that must be addressed in integrating HCI and software engineering, including clear and common definition of usability concepts; integration of usability methods into software development life cycles, address of gaps between specific usability and software engineering practices, development of computer-based usability tools, and provision for education on integrated approaches. In a similar discussion, Redish (2007) calls for expansion of usability testing to support complex systems, such as inventory analysis, resource allocation, health care, and intelligence analysis. Like simulation, such systems place a high burden on the user from the amount of information to consider, onerous data analysis and decision-making, difficulty in validation of results, lack of user domain knowledge, and interpretation of visualizations. Redish goes on to suggest expanded usability approaches and research, calling for usability practitioners to be more engaged in addressing such complex domains.

Prior examinations

There has been limited focused research directly tying HCI considerations to simulation design (Kuljis, 1996; Ören & Yilmaz, 2005; Pidd, 1996). Ören and Yilmaz (2005), the most recent study, is addressed in detail in Table 1 and the accompanying discussion. In a general examination of the interaction of HCI and simulation in several commercial discrete-event simulation systems, Kuljis (1996, p. 689) reviews how HCI aspects impact simulation development time, application consistency, ease of development, model completeness, and model validation. Kuljis, using a structured walkthrough of a typical user's tasks, found "usability defects" in simulation-specific areas such as data input, user support, and result analysis. Further, it is suggested that the benefits of addressing the usability issues could include reduced development time, increased application consistency, ease of simulation development, and increased model completeness and validation. Kuljis concludes with some suggestions for improvements in commercial simulation tools, including pre-defined problem domains, facilities to create new domains, facilities for graphical representations of elements, and methods to set defaults for values, statistical data collection, and presentation of results. It is also noted that there is a lack of published empirical evidence to support claims that interface improvements will lead to significant impact on simulation use and results.

Pidd (1996, p. 681) points out that development in discrete-event simulation software has generally moved forward "hand-in-hand" with computer software, and simulation packages from vendors have grown in user interface capabilities. However, the issue, as Pidd (p. 684) points out, is not the lack of interface tools, but rather a lack of understanding that the nature of the user interface provided can change the simulation task. Because simulation developers are often not versed in HCI and usability theory, this aspect of simulation design is often neglected. Pidd provides a framework of classification for studying HCI in simulation, including a breakdown of simulation tools, individuals involved (modelers, programmers, project managers, customers, and users), and system features. Finally, Pidd also argues that the tendency of simulation developers to focus on graphics and visualization may distract from the impact of simplification and application of an overall user-centered design approach. A later related article (Pidd & Carvalho, 2006) presents a view of the current state of simulation, arguing that simulation tools must move in the same direction as other computing developments, and suggests a need to focus on component based models for discrete-event simulation.

Barriers and Issues

Work elements

There are two major elements to this study – research-based development of a design process and experimentation to test study hypotheses. First, an extensive review of discrete-event simulation characteristics and appropriate usability methods was required. This research included applicable usability literature, such as examinations of usability assessment (Hollingsed & Novick, 2007; Nielsen, 1993), novice programming system usability (Galitz, 2007; Pane & Myers, 1996) or user interface elements (Myers, Hudson, & Pausch, 2000; Tidwell, 2011). This information is presented in this study to outline a process to allow simulation practitioners to use the information gathered and is summarized to guide their designs. Second, an experimental approach that both illustrates the application of usability methods and verifies the impact of these methods on simulation usage and solution sets was designed, developed, and deployed, with appropriate analysis of results. This study provided user-based tests with two alternate interfaces to a single simulation problem. A similar approach is used in two example studies, including an evaluation of three alternative interfaces to a database application from Medsker, Christensen, and Song (1995) and a usability evaluation of two alterative interfaces to a groupware application from Gutwin and Greenberg (1999). In this study, through application of a literature-supported user-centered design process with focus on simulation issues, the interfaces were developed to two expected usability levels (designated basic and improved). Live observed user testing of sample sizes appropriate to the study was conducted to ascertain both quantitative and qualitative measures of the impact of the varying interface usability levels on simulation interactions and solution quality.

Difficulty of problem

This study has two primary elements, a developmental task and an experimental task. The first developmental task required literature review, synthesis, and summary, which was not inherently difficult, but did require rigorous research and organization in order to develop a well-grounded, publishable guideline as well as to drive the design of the experimental portion of the study. The experimental task was more onerous, requiring identification and development of a complex simulation core, as well as design and development of the two alternative illustrative simulation interfaces using the process outlined in the prior task. Thorough and rigorous usability evaluations and extensive user-based testing to determine issues involving simulation use and solution determination followed the development. Finally, a comprehensive results analysis and suggestions for follow-on research concluded the study.

Hypotheses

As previously stated, there are four primary research questions in this study:

- What are user interface considerations for discrete-event simulation models?
- What are best practices for designing an interface to a simulation application?
- How is usability best evaluated for simulation interfaces?
- What is the actual effect of increased usability for specific interface elements on simulation operations, such as data input and solution analysis?

The first three research questions are answered through the development task of creating a literature-based process for usability design and evaluation targeted at simulation interfaces. The fourth research question was answered experimentally, to provide quantitative and qualitative evidence that the usability design and evaluation process actually results in the targeted effects of improvement in data input and solution analysis. This experiment also serves to confirm the focus and applicability of the development task results.

The following hypotheses were tested experimentally to provide answers to the fourth research question on actual effect of increased simulation operation usability (note that the hypothesis has been restated in terms of task failure rates instead of task success rates as appeared in the formal study proposal):

H(1) If a simulation-focused usability design process is applied to the data entry aspects of a simulation interface, there will be significant reduction in data entry time, interaction errors, and task failure rates.

H(2) If a simulation-focused usability design process is applied to the results analysis elements of a simulation interface, there will be significant reduction in analysis time, incorrect result reporting, and task failure rates.

H(3) If a simulation-focused usability design process is generally applied to a simulation interface, there will be significant increases in user satisfaction measures, including overall satisfaction, system usefulness, information quality, and interface quality.

The hypothesis discussion, related variables and methodology impact is further discussed in Chapter 3. (The format of the hypothesis discussion is drawn from a recent experimental study of social presence in asynchronous learning (M. S. Cohen & Ellis, 2007) and the previously discussed groupware usability assessment (Gutwin & Greenberg, 1999).)

Assumptions, Limitations, and Delimitations

Assumptions

- Sufficient computer-literate study participants are available for the simulation study.
- Sufficient skilled usability reviewers are available for usability reviews.
- All study participants will work to the best of their ability.

Limitations

- Study participants are not experts in the simulation subject matter.
- The study examines a single type of discrete-event simulation.
- Usability inspection methods are subjective measures.
- There is disagreement about sample sizes appropriate for some methods of usability design and review.
- The simulation experiments gather only selected usability measures: time on task, data entry time, error rates, graded solution outcomes, and user impressions of ease-of-use.

Delimitations

- Study participants needed to evidence basic computer literacy (word processing, e-mail use – etc.).
- Study participants had to prove capable of understanding the simulation problem.
- The simulation involved basic tasks, easily explained to novice users.
- Each simulation task experiment (introduction, data entry, solution review, and wrap-up) was limited to less than 30 minutes.
- Participants followed a script for data entry and solution exploration.
- The two simulation interfaces were deliberately designed with interface elements of differing usability levels; this is an artificial step in a normal design process, but was required for the study.

Definitions of Terms

- C# - A structured object-oriented programming language developed for the Microsoft .NET platform, sharing similarities with Java and C++ (Liberty & Xie, 2008).
- Class Diagram – Representations of static elements of a system, including structure and interrelationships; depicts logical and physical design of a system (Maksimchuk & Naiburg, 2005).
- Cognitive Dimensions Analysis – Usability evaluation method employing evaluators to assess an interface against a set of 13 defined cognitive interface aspects (Green & Petre, 1996).
- Cognitive Walkthrough – Task-oriented exploration of system functionalities through step-by-step simulation of user behavior and observation of selected cognitive issues (Holzinger, 2005).
- Decision Support – Model-based procedures for support and improvement of decision making; simulation is one form of a decision support tool (Turban, Aronson, Liang, & Sharda, 2007).
- Direct Manipulation – Interface interaction involving visible objects and actions, rapid and reversible incremental actions, and replacement of typed commands with pointing at objects of interest (Shneiderman, Plaisant, Cohen, & Jacobs, 2009).
- Discrete-Event Simulation (DES) – Simulation and modeling of systems where the state variable is changed at a set of points in time (Banks, et al., 2010).
- Heuristic Evaluation – Usability engineering method that employs a small set of evaluators to examine and judge the compliance of a given interface with selected recognized usability principals (Nielsen & Mack, 1994).
- Human-Computer Interaction (HCI) (Also Computer-Human Interaction, CHI) – Interdisciplinary design science that combines experimental psychology data-gathering methods and intellectual frameworks with tools developed from computer science (Shneiderman, et al., 2009).
- Mathematica – an interactive computer-based environment with a programming language providing for numerical, symbolic, procedural, and rule-based development; provides internal support for a wide range of graphics, mathematics, and statistical functions (Maeder, 2000).

- Simulation – Evaluation of a mathematical model of a system through numerical (vs. exact analytic) means that generates data to estimate model characteristics (Law, 2007).
- Unified Modeling Language (UML) – A standardized modeling language made up of graphical notations to express various levels of system designs (Fowler, 2004).
- Usability – The ease-of use and acceptability of systems for selected classes of users and specific tasks in a given environment (Holzinger, 2005).
- Use Case – Modeling approach for business process implemented in a system; describes who interacts with a system, and the ways the system will respond (Maksimchuk & Naiburg, 2005).

Summary

This study examined the effects of varying characteristics of user interface designs on the levels of usability and the solution quality of complex, multivariate discrete-event simulations. By selected variation of the usability of test application elements, and measurement of simulation interaction characteristics, the goal of demonstrating measurable effects of interface usability on both simulation use and solution quality was met. Ideally, this may bring more focus on including usability design in simulation development. Additional goals include identifying specific interface aspects that impact simulation, as well as providing an example of the use of usability design processes in a simulation development. For further support of the study, Chapter 2 outlines the literature support for the background, relevance, and approach for the study, followed by Chapter 3, which presents the steps for the methodology employed. The results of the study are presented in Chapter 4, followed by a discussion of conclusions, implications, recommendations, and a study summary in Chapter 5.

Chapter 2

Review of the Literature

Historical Overview

The two primary elements examined in this study are usability and simulation, both areas with a long history of research in computer science. Simulation, including specifically discrete-event simulation, has been a part of operations management in manufacturing for over 50 years (Lawrence, 2003). For a historical perspective on simulation, Nance and Sargent (2002) trace the origins of simulation as a methodology for problem analysis. The article states simulation use predates the arrival of computers, with initial uses of a manual method called "artificial sampling" being introduced in 1777 as a method of estimating π. (Known as Buffon's Needle Problem, the French naturalist Buffon first posed the problem in 1733, and proposed a solution in 1777 involving dropping needles on a grid of parallel lines and using the count of line and needle intersections as an estimator (Weisstein, 2005).)

Nance and Sargent describe computer-based methods of continuous and Monte Carlo simulation being introduced during World War II, with the first use of discrete-event simulation in the late 1940s. They further state that as simulation became more tied to computer-based implementations and languages, advances in the methodologies were driven by external and internal influences. Internal factors are those derived from simulation research, including advances in modeling, functions, verification and validation, analysis, and theory. External influences come from advances in computer hardware and software, including influences from computer graphics, networks, the World Wide Web. Nance and Sargent also mention HCI techniques and technologies as an external influence. The historical perspective is updated with additional details in a more recent presentation (Goldsman, Nance, & Wilson, 2010). Functional areas being extended in current tools include model re-use, collaborative methods, as well as visual, web-based, parallel and distributed simulation; improvements in the simulation modeling life cycle are seen as increase the overall return and acceptance of simulation as a business practice by reducing effort and increasing value of results (Diamond et al., 2002).

As with simulation, the research in usability and HCI technologies began in earnest after World War II, with the beginnings of human factors and ergonomics. Myers (1998) reviews the history of HCI technologies, with the earliest reference being the idea of linked document references, a precursor of the hypertext concept, as discussed by Vannevar Bush in 1945. Myers continues, discussing the introduction of enabling technologies, such as direct manipulation interfaces, the mouse, and the concept of windows in the 1960s. Usability engineering, and methodological approaches to its use, are introduced in the 1970s (Mayhew, 1999). Mayhew also notes an early reference to a specific usability engineering methodology in 1985, and that texts on usability engineering begin to proliferate in the late 1980s through the 1990s. Nielsen (1993) introduces the concept of discount usability engineering, with the goal of improving usability with a minimum of necessary tests or testers. Usability design and testing is more commonplace today in mainstream development. At Google, for instance, the focus on user experience is described as being “encoded” into the company’s culture, with usability staff on hand to consult on designs, perform various tests, gather and analyze data, and help with product localization (Au et al., 2008).

One recent study (Wania, Atwood, & McCain, 2006) has attempted to identify the focus of current usability research from analysis of the literature. The study maps current research showing how HCI authors cover topics from theory development to specific application to build usable systems, and from collaboration and group work to specific users and cognition issues. It is further suggested that research is trending toward design and evaluation methods in the context of use. Looking forward for HCI, Shneiderman (2007) discusses the need to expand interaction design and usability methods to enable creativity and exploration. In examples of such tools, mathematical and simulation tools are included. Shneiderman reviews many design aspects of such systems; aid in managing and comparing multiple designs, integration of search engines, and easier backtracking and historical comparison. Shneiderman also looks for an expansion of usability methods, including observation, long term case studies, data logging, and integration of multiple analysis methods to understand usage patterns, as well as continuing research in HCI to refine methods, theories, and study techniques that enable breakthrough designs for discovery and innovation.

Literature Specific to Topic

Major focus areas for research

The goals of an effective literature review are to understand what is known about a given subject area, to provide a foundation for intended research, to confirm the need for the research, to justify the contribution of the research, and to provide support for the goals and methodologies of the study (Levy & Ellis, 2006). To provide this research-based foundation for this study, the review is divided into two main areas; relevance of the subjects involved to address confirmation and justification, and support for the design of the experiment and assessment methods employed in the study. The areas of relevance to review include the importance of discrete-event simulation and of usability methods, the need for usability focus in simulation, and examples of simulation studies that call for improved interfaces but do not employ usability design or assessment methods. To support the design of the study, the following areas are subject to review: general experimental design guidelines, similar experimental studies, usability design and assessment methods, appropriate visual and user interface elements, interface needs in simulation, simulation development guidelines, and support for selected development tools.

Importance of Discrete-Event Simulation

There is ample literature to support the widespread use of discrete-event simulation in various academic, industrial, and other applications. Simulation is presented among other approaches to decision support alongside various static, dynamic, and risk models, heuristic programs, and visual and data modeling methods, where it is recommended for problems too complex for more precise numerical optimization approaches (Turban, et al., 2007). Turban et al. also review advantages and disadvantages of simulation. Advantages include well-understood theories and approaches, time compression, ability to pose what-if questions, ability to handle a wide variety of problem types, and the ability to include real complexity through statistical modeling. Disadvantages include the lack of a guaranteed optimal solution, the overhead of the process, and the special skills required to develop.

Standard texts outline simulation methods, the design of models, data distributions, sensitivity analysis and reporting formats (Banks, et al., 2010; Fishman, 2001; Fishwick, 1995; Law, 2007; Ross, 2006). Law (2007) provides an overview of discrete-event simulation and steps for simulation studies, examples of modeling complex systems such as banks and job-shops, reviews of simulation software features, and probability and statistics that apply to simulation. Law also provides details for modeling systems and analyzing results, comparing alternatives and reducing variation, applying experimental designs, and simulating manufacturing systems.

Simulation can be applied to a wide range of problem domains. Specific industrial applications of simulation may include modeling automotive production lines, new manufacturing plant layouts, baggage handling systems, and communications networks (Lawrence, 2003). Fishman (2001) describes inventory systems, distribution systems, transportation networks, and health-care delivery systems as being amenable to discrete-event system modeling. Business process models are identified as particularly suitable subjects for discrete-event simulation, for a number of reasons: ease of modification, modeling complete processes, ease of modeling information flow, testing new process designs, capturing human and technical elements, showing dynamic change, and allowing for stochastic elements in designs (Hlupic, 2001).

Introductions to and tutorials on simulation, tools, and applications are regularly presented at simulation conferences (Ingalls, 2002; Sanchez, 2006; Schriber & Brunner, 2007, 2010). Schriber and Brunner provide recent tutorials on discrete-event simulation software, where such simulations are described in a "transaction-flow world view", that envisions simulations tracking discrete traffic elements (transactions) moving through a system from one point to another (flow) requesting and using resources. This describes the concept most common to discrete-event simulations, that of a collection of queuing systems. The Schriber and Brunner presentations go on to discuss the objects that make up a simulation, as well an overview of typical model execution, and how simulation is implemented specifically in three typical simulation tools.

Simulation has been an active area of research since the 1960s, but was inhibited by storage limitations, costly processor time, slow development iterations, and lack of textbooks (Nance & Sargent, 2002). Today simulation is widely used in military applications, where a high level architecture (HLA) has been developed to support reuse and interoperation of simulations (Dahmann & Morse, 1998). Simulation tools in industry have been shown to provide growth benefits to organizations employing the methods, including increased project completion, reduced cycle times, and earlier identification of wrong initiatives (Miller, Pulgar-Vidal, & Ferrin, 2002). Benefits and barriers to application of simulation in industry are also discussed in McLean and Leong (2001), who also point out that the benefits of simulation are offset by the costs, which include hardware, software, salaries, training, development and maintenance. Statistical support for simulation design can be found in general simulation texts discussed above, as well as in focused statistical distribution modeling guides (Dovich, 1990).

Relevance of Usability Methods

Usability is an active research field, with HCI literature and research across several focus areas in usability design and evaluation, looking at theory and applications, as well as group, individual, and cognitive models of usability (Wania, et al., 2006). Standard texts, such as Shneiderman, Plaisant, Cohen and Jacobs (2009), present the wide variety of usability elements, such as theory, process, assessment, testing, tools, graphical environments, and multimedia. Schneiderman et. al. also present four “pillars of design” that outlines the key elements in successful interface development, which include use of user interface requirements, usability guideline documents and processes, user interface software tools, and expert reviews and usability tests all based on a foundation of academic research. There are also a number of usability motivations presented, including the need for usable interfaces to ensure effective life safety systems, to respond to entertainment applications, to enable creative and collaborative tools, to facilitate effective socio-technical systems for large numbers of people, and to reduce cost and increase performance of commercial and industrial tools (Shneiderman, et al., 2009). Significant literature focus is also placed on direct cost-justification of usability in the design process (Bias & Mayhew, 2005; Marcus, 2002). Marcus breaks this down into internal return on investment (ROI) such as increased productivity, less errors, and reduced training and support needs as well as external ROI factors such as increased sales, lower cost of customer-side support and training, and making changes to products earlier in design cycles through usability focus.

There are also more practical or applied views of the value of usability practices. In a recent essay, Brooks (2010) makes an argument for the need for explicit user and use models. He argues the need for such models as support for conceptual integrity in developing systems, becoming even more important as complexity increases. Brooks also states even wrong explicit assumptions about use models are better than none, because at least the wrong model will be questioned and examined, as opposed to one that is vague or missing. Krug (2010) also argues that even minimal usability focus has value. In application of his discount assessment methods for web usability, he states the processes work because all interfaces have usability issues, most serious issues are easily found, and directly involving and watching users makes interface developers stronger, as they are no longer designing for an abstract concept of their target user.

Lowgren (1995) looks at various perspectives on usability, including general theory and usability engineering, as well as subjective, flexible, and social aspects. In terms of general theory, Lowgren talks about a causal framework for usability in which the user's motivation and knowledge combine with the ease of use of the system, the match between the system and the tasks, and the frequency of tasks, to produce a user reaction, which may be positive, resulting in continued use and learning, or negative, resulting in reduced or no use. This framework is posited as an approach to experimental definition focused on the user's reaction. Usability engineering is the general approach for interface development, which Lowgren describes as a three step process, including user and task analysis, development of a usability specification, and iterative prototyping to develop the final interface. The subjective perspective looks at usability as a property of the interaction between a user and the system at a given time, which requires an iterative user-based process of contextual and participatory design. Flexibility in usability refers to extending the participatory design into a long term continuing design effort with tools that responds to changing situations the user may experience. Finally, Lowgren describes a social form of usability, sociality, which encompasses the design of systems for cooperative and collaborative environments. Lowgren suggests these perspectives as a framework for usability research, and also suggests maintaining a view of these different perspectives supports evolution and development of usability approaches.

Need for Usability in Simulation Design

Because of the significant human-computer interaction components in simulation data entry, modeling, and analysis, there are regular calls for usability improvements and increased focus on ease-of-use in tools in panel discussions (Banks, 1997, 1999), industry reviews (Umeda & Jones, 1997), and surveys of simulation users (Hlupic, 2000). Hlupic's survey results of academic and industrial users provide some support for usability enhancement for simulation tools. Significant number of academic respondents (55 total) found their simulation tools lacked flexibility (44%) or were difficult to learn (22%) yet, as Hlupic points out, only 6% cited a poor user interface. Some 59% of academic respondents cited software limitations that impeded simulation work. Industrial users also reported flexibility (22%) and learning difficulty (11%) issues, although only 25% reported issues completing simulation work. Hlupic draws the conclusion from the survey as a whole that increased flexibility, ease of use and learning, and features for experimental design and output analysis are key features. More recently, the SIMCHI 2005 (2005 International Conference on Human-Computer Interface Advances for Modeling and Simulation) conference was dedicated to the examination of a variety of topics in how simulation and HCI considerations interact (Ören & Yilmaz, 2005). In practice, extensive simulation is often performed without attention to interface design (Crawley, et al., 2001), yet this is recognized as a deficiency that should be addressed (Clarke, 2001; Papamichael, 1998).

As with simulation, integration of usability into general software development is also recognized as an area of concern; a recent tutorial outlined the challenges of integrating HCI and software development in both terminology and required design approaches (Juristo & Ferre, 2006). Similar to the challenge for a simulation developer, the tutorial states that because software engineering methodologies do not generally include usability concerns, a software developer that wants to integrate usability must consult several HCI books to investigate available methods, and then select a subset of the techniques described that fit the project in question. Holzinger (2005) echoes this need for software developers to be aware of usability methods, and to be able to decide which approaches best fit a given project. Holzinger calls for each software project to consider usability related requirements for learnability, efficiency, memorability (or prevention of re-learning), low error rates, and satisfaction, and presents a review of common usability inspection and test methods for design and development.

In applying usability practices to simulation design, it is important to balance usability design methods with other aspects of the overall design process. One recent study found a potential for usability methods to be misapplied, in that novice designers regularly (in approximately 70% of cases) disregarded usability fact-based measures in favor of other pseudo-evidence developed in design activities (Friess, 2008). Friess suggests that documentation of design decisions that include support for why design choices are made would help offset this effect. Friess also suggests that designer intuition may be undervalued in comparison to some formal methods. A similar concern is voiced in Greenberg and Buxton (2008) which suggests that usability tests and designs must be applied carefully, so as not to damage the design process and inhibit creativity and innovation. They suggest several approaches to ensure usability is applied appropriately, including using usability design only when appropriate, using scientific methods that can be replicated, and looking to other disciplines for additional design measures. Buxton (2007) focuses enabling early and iterative exploratory design by using sketch-based designs as a path to usability prototypes. Sketches are suggested to propose and suggest tentative early concepts, vs. prototypes that are intended to depict specific refined interface descriptions for early assessment.

Simulation Interface Aspects and Designs

Numerous texts and studies look at the nature of simulations and their interfaces. Interfaces must provide access to core performance measures common to discrete-event models. Fishman (2001) outlines four measures: delay, buffer occupancy, throughput, and resource utilization. Delay is the time spent waiting for resources or events. Buffer occupancy describes the queuing of jobs, objects, or individuals as they wait for processing. The number of objects processed in a given amount of time is the achieved throughput, and the amount of time resources are in use describes utilization.

In addition to books and studies on discrete-event system mechanics, there are some discussions focused on simulation interface characteristics, some general (Diamond, et al., 2002), some with examples of applications developed to address specific domain-related interaction needs (P. Cohen, 1991; P. Cohen, et al., 1996). Cohen (1991) addresses the potential for well designed user interfaces to provide new levels of ease of use for simulation systems. Cohen, using an early graphical user interface combined with natural language processing, attempted to provide ways for simulation-based decision makers to ask general what-if questions about the simulations and data available.

Even today, only a few papers present simulation interface requirements in relation to HCI and usability, either in how HCI concepts might be applied (Pidd, 1996), or in the specific usability concerns of different simulation tasks (Dawson, 2008; Kuljis, 1996; Kuljis & Paul, 2000; Ören & Yilmaz, 2005; Tabachneck-Schijf & Geenen, 2006). Ören and Yilmaz provide one of the most thorough published considerations of usability considerations for simulation. By reviewing key usability principles and applying those to simulation characteristics they propose a set of 21 recommended quality principles for simulation interface design, summarized in Table 1.

Table 1. Usability Principles for Simulation Software from Ören and Yilmaz (2005)

Principle area	Principles	Notes
Usability	Least training	As little training required as possible
	Minimum memory load	Users should not have to remember information from one interface part to another
	Simplicity	Interface should not be distractive; should be uniform, unambiguous, and allow easy navigation
	Familiarity	Language, terminology, metaphor, and inputs should be familiar
	Separation of concerns	Interface should allow for focusing on simulation tasks
	Functionality	Interface should be able to specify, process, analyze, and present results of problems
Communicativeness	Restrained realitionship with users	Do not use patronizing or insulting tone
	Informativeness	Provide current system knowledge
	Perceptiveness	Observe user actions and suggest actions
	Explanation ability	Interface should justify decisions and explain results
	Aesthetic and cultural acceptance	Information displays consistent with universal and local cultural and aesthetic norms
Reliability	Access reliability	Control access by authorized users
	Predictability	Interface should do what users expect
	Consistency	Consistent reaction to user action in different contexts
	Safety	Interface supports error tolerance, caution, and robustness
	Built-in quality assurance	Filter and prevent (when possible) input and output errors

Principle area	Principles	Notes
Evolvability	Adaptability	Adapt to users with differing skills and preferences
	Customizability	Easily tailored interfaces
	Learning ability	System should remember usage and enhance user problem solving
	Maintainability	System should be easily updated
	Portability	Should be portable to different platforms

Another article looks at attempting to prevent knowledge transfer errors in probabilistic decision support systems, such as a discrete-event simulation (Tabachneck-Schijf & Geenen, 2006). In examining the information transfers in such systems, the following representations are presented: knowledge for expert interaction (the development of models), model evaluation (mapping the model to user language), data entry (by the user), dissemination of outcomes (into a user-compatible form), and explanation of outcomes (in user language). They evolve this into a set of heuristics for user-centered representations: preserving precision, user compatibility, natural language, invisible technology, and an efficient application or system. These considerations should shape other simulation interface and interaction heuristics.

More recently, a study looked at what the author termed a holistic usability framework for distributed simulation (Dawson, 2008). Dawson's investigation has similar goals to this study, but takes a much different approach to simulation usability improvement. Dawson develops a usability framework for distributed simulation development that involves a set of measures for various dimensions of distributed simulation characteristics

– interfaces, visualization, installation, training, etc. The approach does not measure usability directly from the system, but rather from assessing the attributes that can affect usability measures. The result is a survey that provides input on usability concerns for distributed simulation systems.

It is very common in the simulation literature for studies to recognize a need for usability or to claim the presence of user-friendly interactions, but to then provide interfaces and designs with no application of usability design, test or assessment (Bendre & Sarjoughian, 2005; Chen, Olson, & Morrison, 2002; Hastbacka, Westerlund, & Westerlund, 2007; Heilala, et al., 2007; Herren, et al., 1997; Hewitt & Herrmann, 2003; Kim, Halpin, & Abraham, 2001; Martens & Himmelspach, 2005; Odhabi, et al., 1998; Randell, 2002; Randell & Bolmsjo, 2001; Tebo, Mukherjee, & Onder, 2010; Valentin & Verbraeck, 2002; Verbraeck & Valentin, 2008; Wood & Harger, 2003). Similarly, specific reviews of simulation tools often speak obliquely of usability needs; Gray (2007) provides a review of an object-based discrete-event tool using a list of desirable system features that includes ease-of-use concerns with no reference to usability design or assessment. Another study looks at a template-based discrete-event tool, and discusses issues found during use of the system, including recommended changes, with no reference to formal usability reviews or methods (Grigorov, 2007). There is also an comparison of simulation tools for protein cell signaling that includes usability reviews by the authors, with no formal usability assessment or references (Manninen et al., 2006).

The concept of using objects, templates, or "plugins" (Himmelspach & Uhrmacher, 2007) to build discrete-event systems is largely an attempt to reduce complexity through abstraction, and could also be supported by applied usability techniques. A similar approach with goals of flexibility and reuse is considered in articles regarding a project describing a building block approach to simulation (Valentin & Verbraeck, 2002; Verbraeck & Valentin, 2008), in which one article (Verbraeck & Valentin, 2008) includes significant discussion of user interface characteristics without addressing the usability of the individual blocks or of the assembled systems.

One parallel area that may help in both justifying and structuring usability processes for simulation is the examination of usability issues with medical decision support systems (Graham et al., 2008; Kushniruk, Borycki, Anderson, & Anderson, 2008). In these studies systems were assessed using think aloud subject-based tests for usability errors that could cause life threatening mistakes (Graham, et al., 2008). The authors suggest usability engineering approaches be used to identify issues early in design cycles to eliminate these serious consequences, including the development of simulated human interaction with the systems to further explore the problem space (Kushniruk, et al., 2008).

Experimental Design and Similar Studies

There are a variety of support materials for research guidelines, experimental design, and other appropriate documentation that helped structure this study. General texts on research methodologies (Bock, 2001; Leedy & Ormrod, 2010) provide suggestions for structuring research problems. Bock provides support for modern scientific studies, including discussion of the scientific method and its components – analysis, hypothesis, synthesis, and validation. The preliminary proposal for this study developed the analysis and hypothesis steps, the execution of the study itself provided synthesis, and the final analysis and report presented here comprises the validation step. Bock also provides guidelines for the design of experiment protocols that outline considerations for laboratory based testing and related test instruments. Leedy and Ormrod provide a more academic focus, including support for planning research study designs, including methods for ensuring internal and external validity. Internal validity refers to eliminating other possible explanations for observed results, where external validity refers to the ability to generalize the results of a study. Leedy and Ormrod highlight the Hawthorne effect as one element of concern in internal validity. A recent study (Macefield, 2007) specifically looks at the Hawthorne effect in usability testing, which suggests that participants in a human-centric study may perform at higher levels because they are aware they are being studied. Macefield reviews the effect and its origins in detail, and suggests ways for usability studies to defend against such issues, including application of verbal protocols, semi-structured interviewing, and elimination (or minimization) of extrinsic performance feedback.

There are also studies similar to the proposed project that lend credence to the approach presented (Gutwin & Greenberg, 1999; Medsker, et al., 1995). Gutwin and Greenberg provided an example of a very thorough study that tested two alternative interfaces to determine the effect of enhancing awareness of other user's activities for a distributed groupware system. The study employed a complex design where individuals were asked to perform three tasks using first one interface, and then alternate with an interface enhancement. Half of the participants started with the advanced interface, half with the basic interface. The hypothesis was expressed for both the between-participants and within-participants studies. Measures included completion time, perceived effort, verbal efficiency (working in the group), preference, and strategy use. Participants were drawn from a student population, all had used e-mail and web browsers at least once per week, and all had no experience with the problem domain or the system being used. Stopwatches, videotape, and questionnaires were used for data gathering.

Finally, the study uses standard documentation approaches wherever possible. There is significant support for documenting software designs using UML (Unified Modeling Language) notation (Fowler, 2004; Maksimchuk & Naiburg, 2005; Phillips, Kemp, & Kek, 2001), allowing software designs to follow a common graphical representation. There are also standard formats for usability test reports (National Institute of Standards and Technology, 2001) that were reviewed and applied or adapted to support completeness in result reporting.

Usability Design and Assessment Methods

There are numerous usability design and assessment methods available that were considered for use in the project and documented in the literature. These include standard usability testing guides for user-based tests (Dumas & Redish, 1999; National Institute of Standards and Technology, 2001; Rubin & Chisnell, 2008) as well as studies employing such usability tests (Weaver et al., 2002). Carter (2007) focuses on user-based testing, and discusses specific approaches to improve the talk aloud method, as well as the proper relationships between the tester and the user that will garner the best results. This is also examined in Molich and Wilson (2008) which discusses the most common issues in preparing, conducting, and concluding a usability test scenario. Among the many problems identified are over-direction by the facilitator, interference by third parties, lack of clear guidelines for facilitator intervention, and lack of post-test debriefing.

Hornebaek and Law (2007) discuss concerns over the correlations between measures gathered in standard usability tests, such as task completion time, error rates, satisfaction, perceived workload, product quality, are reviewed in a study of over 70 usability tests, which concludes there is medium to low correlation between usability measures, but encourages researchers to use standard instruments where possible and to consider possible correlation issues. Another suggested set of metrics, specific to assessment of visual analytics, is also available, which outlines specific measures to answer different types of hypotheses for testing visual systems (Scholtz, 2006). Tullis and Albert (2008) also present standard approaches for gathering, analyzing, and presenting performance metrics such as time-on-task, task success, errors, efficiency, and learnability as well as usability issue metrics that involve assessment of severity, frequency of use, business impact, and persistence. Extending this is a proposal for an automated framework for collecting summary statistics and visualization of mouse click events, which is intended to allow instrumentation for gathering usability data without directly programming the application to do so (Bateman, Gutwin, Osgood, & McCalla, 2009). A similar proposed effort at automating user logs for usability assessment, based on a data model that relates components, inputs, and tasks, has also been presented (Babaian, Lucas, & Topi, 2007).

There are also discussions of specific usability evaluation methods such as heuristic evaluations (Chattratichart & Lindgaard, 2008; Mankoff et al., 2003; Nielsen, 1993; Nielsen & Mack, 1994), cognitive dimensions assessments (Green & Petre, 1996), and cognitive walkthrough-based approaches (Green et al., 2000; Karoulis, Demetriades, & Pombortsis, 2000). Each source on evaluation generally weighs the strengths and weaknesses of the usability assessment technique presented, and this is supplemented by overall reviews and surveys (Ivory & Hearst, 2001; John & Marks, 1996) as well as specific comparison studies (Englefield, 2003), method summaries (Axup, 2002), and best practice discussions (Holzinger, 2005). Hollingsed and Novick (2007) review literature for usability inspection methods over 15 years of use, and evaluate the effectiveness of heuristic evaluations, cognitive walkthroughs, pluralistic usability walkthroughs, and formal usability inspections. Heuristic evaluations and cognitive walkthroughs are found to be in common use as inspection methods, with developers using the method appropriate to a given project. The conclusion is that inspection alone cannot provide a full assessment, and must be used with user-based tests to provide full defect exposure. Another study of variations in heuristics models presents a framework for comparison of heuristics including reliability, validity, effectiveness, and reliability, and also looks at performance of the heuristics when used by novices vs. experts (Chattratichart & Lindgaard, 2008).

An experimental application of the evaluation methods also reviews strengths and weaknesses of the approaches (Karoulis, Valsamidou, Demetriadis, & Timcenko, 2005). Karoulis et al. (2005) discusses the advantages and disadvantages of evaluation vs. user-based testing. Evaluation advantages include early application, easy preparation and performance, good assessment of problem severity, and high effectiveness for low cost; disadvantages include not finding all problems, requiring experienced evaluators, losing sight of user concerns, and difficulty in proposing solutions. User-based testing can find problems real users encounter, can find most issues, and is efficient for complex interfaces; it is however expensive and difficult, requires numerous representative users, subject bias is a concern, and it requires some level of product completion. (It should be noted that other literature suggests a combination of these approaches for an overall usability assessment (Holzinger, 2005; Usability Professionals' Association, 2000)) Karoulis et al. also includes an experimental application of cognitive walkthrough and heuristic evaluation; both methods provided good results, but the heuristic evaluation was more easily applied.

Significant portions of these sources and others (Krug, 2006, 2010; Medlock, Wixon, Terrano, Romero, & Fulton, 2002) discuss the effects of testing with low numbers of users, known as discount assessments. Medlock et al. provides a review of the literature related to sample size in usability evaluations, stating that 4 to 5 participants will uncover approximately 80% of detectable issues (a likelihood of detection greater than .31). If problems have a higher likelihood of detection (5 or greater), three participants will find 87.5% of issues. Krug (2006) suggests that the addition of more test subjects has significantly diminishing returns after the 4^{th} or 5^{th} participant. In all cases, where discount methods with low numbers of participants are used, it is recommended to iterate tests to ensure coverage.

There is also a range of literature sources that discuss whole usability-focused design methodologies, from gathering requirements through product deployment. Moggridge (2007) presents a series of studies of and interviews with interaction designers, and then describes a suggested process for prototyping “screen-based experiences”; three steps that includes low fidelity paper prototypes, high fidelity computer-based prototypes, and user testing with final prototypes. The approach in this three stage process is echoed in other process methodology studies (Hackos & Redish, 1998; Usability Professionals' Association, 2000). Other studies of similar overall process methodologies are provided in some sources (Constantine & Lockwood, 1999; Cooper, Reimann, & Cronin, 2007; Mayhew, 1999), in others there is more specific focus parts of the process: use case development (Ambler, 2005), sketch-based designs (Buxton, 2007), paper prototyping (Snyder, 2003), or process best practices (Bailey, 2005). Given the wide range of suggested processes, a study of user-centered design processes found that not all aspects of system development are covered by each approach in the literature, and that evaluation of the applicability of individual usability design practices is needed for individual projects (Iivari & Iivari, 2006). There are also efforts to automate some of these practices, such as a proposed automation of the paper prototyping process (Li, Cao, Everitt, Dixon, & Landay, 2010).

Mirel (2004) provides a discussion of interaction modeling and usability design approaches focused on complex problem solving applications. Mirel describes the contextual influences in understanding the problem solving work space, which has four components: the problem, the work domain, technology and data, and subjective elements. The problem describes the severity and nature of the task – its type, trigger events, and inquiry patterns. The work domain looks at the surrounding influences of roles, environment, and external pressures. The technology and data describe the infrastructure for the work, such as databases, software tools, and information sources. Finally the subjective elements include the cognitive abilities of the users and their preferences, skills, and motivation. Mirel states that interaction designers must address this full context space for a successful outcome. Further, in looking at the actions complex problem solving must address, Mirel identifies three core activities – data ordeals, using large volumes of multidimensional data; wayfinding, working through complex analysis and exploration; and sensemaking, processing data to draw relationships and develop meaning. In addition, for a complete address of a complex problem, the designer must consider what Mirel calls mainline and enabling tasks, the basic procedures involved in the work, as well as the patterns of inquiry that are used to solve problems.

The Mirel text is also expanded on in Redish (2007) which agrees with the need for focus on usability for complex systems. Redish states that the main point of the Mirel text is that usefulness is as important as usability in complex systems, and that the product developed must match the actual work and requirements. Redish looks at the aspects of complex systems that differ from normal subjects of usability tests, special considerations, and what should be and has been done to support complex system usability development. To facilitate usability tests for complex systems, Redish suggests a number of approaches, including use of usability studies outside of laboratories, possibly at conferences where developers and domain experts are present; building simulations of tasks; development of situational awareness assessment; and automating long-term use data capture. Hilbert and Redmiles (2000) describes in detail the theory and application of automated extraction of usability information from user interface events. Suggested metrics for capture include performance time, mouse travel, command frequency, command pair frequency, cancel and undo use, and physical device swapping.

Inspired by the Mirel text, Albers (2004) also looks at complex system issues, and concludes that the focus is presenting the right information in the right way at the right time, and that complex system designers must ensure content is communicated to users in a way that justifies the cost of complex system development, ensuring users understand where information can be found and when it is needed. In an article in a follow on volume of related papers (Albers & Still, 2011), Albers suggests that as complexity scaling issues increase, risk of usability failures increases, and that for anything other than the most simple system, it is impossible to test the entire interaction tree. Albers presents a set of defined layers of complex systems: conceptual, semantic, syntactical, lexical, and pragmatic, to structure addressing design aspects in an on-going iterative process (Albers, 2011). A related study (Chilana, Wobbrock, & Ko, 2010) interviewed usability experts regarding complex system issues. They found that usability experts often suffer from not having a complete understanding of the domain, and must either extensively study the domain or partner with domain experts in the assessment process. Otherwise, usability experts can be excluded from domain-specific development if an understanding of the domain is not evidenced. Chilana et. al. also found that the uniqueness of a complex system, the domain-specific terminology, and the limited access to domain experts were barriers to usability improvement.

User Interface and Visual Elements

Sources providing reviews of Windows-style user interface elements were of particular interest in designing GUI front-ends for the PC-based simulation used in the experimental interfaces for this study, as are more theoretical references dealing with considerations of visual presentation. A series of books by Edward Tufte look at visual aspects of information display, including display of numeric, dynamic, and static information. In a 2004 lecture, Tufte described his books as presenting approaches for pictures of numbers (Tufte, 2002a), nouns (Tufte, 1990), and verbs (Tufte, 2002b). His latest book outlines a set of principles for analysis and presentation of data (Tufte, 2006). These principles include: show comparisons, contrasts, and differences; show causality, mechanism, explanation, and systematic structure; show multivariate data, more than 1 or 2 variables; integrate words, numbers, images, and diagrams; thoroughly describe evidence (include title, authors, sources, scales, and relevant issues); provide quality content with relevance and integrity. Sells (2004) observed additional focus areas from Tufte's lectures and texts, including the need for annotation and use of proven design templates. Sells also discusses the use of Tufte's sparklines, small in-line graphics to present data, and the need for displays to be high content and high resolution. Another reviewer of Tufte's works discusses the impact on designs, where less clutter and a reduction of unnecessary choices can provide significant interface improvements (Jenson, 2008). Other texts also focus on aspects of visual design effectiveness (Mullet & Sano, 1995).

For more focused Windows-style design issues, a number of texts and papers outline general approaches (Myers, et al., 2000), specific research-based guidelines (Bailey, Koyani, & Nall, 2006), suggested standards (Apple Inc., 2008; Microsoft Corporation, 2007), and commentary on individual Windows form elements (Cooper, et al., 2007; Galitz, 2007; Johnson, 2008). Tidwell (2011) uses a pattern language approach to provide effective interaction design elements for user interfaces. The patterns (descriptions of best practices presented in a standard format within a given design domain) cover most aspects of interface design, including content organization, navigation, screen layouts, actions and commands, display of complex data, form and control designs, editors, and visual aesthetics. There is also thorough discussion of special considerations for novice users in interface design (Pane & Myers, 1996), which essentially is a pattern set for novice usability concerns, organized to match the heuristic usability principles set out in Nielsen (1994). The guidelines are broken down into eight topic areas: visibility of system status, match between system and real world, user control and freedom, consistency and standards, recognition rather than recall, aesthetic and minimalist design, help users recover from errors, and help and documentation. Each guideline is presented with context of use, justification, examples, exceptions, cross references, and literature references. Although it is targeted at web design, Bailey et al. (2006) is also an exhaustive set of usability recommendations presented in a pattern-like format. The guidelines are presented in subsets, including design process and evaluation, optimizing user experience, accessibility, screen-based controls, and many others. Each guideline includes its description, comments, sources, examples, and on a one to five scale, the relative importance and strength of evidence of the guideline. In his preface to Bailey et al., Shneiderman states that the collection of such guidelines serves novices by providing a roadmap, and experienced developers by providing an overview and a reminder of the wide range of usability issues.

Simulation Development Guidelines

Several sources are available for consideration in development of the simulation itself. Some studies present simulations designed with separate front-end interfaces (Johansson & Kaiser, 2002; Robinson, et al., 2001), another describes a multi-tiered simulation structure (Kumara et al., 2002), while others focus on evaluation and verification of the simulation (Balci, 1994; Tewoldeberhan & Bardonnet, 2002). More generally, Law (2006) presents a seven step process for building a valid, credible simulation, including formulation of the problem, collecting information and data to produce an assumptions document, validation of assumptions, programming the model, validating the model, conducting experiments, and documenting results. Key supporting steps are also provided including, interviews of subject matter experts, regular interaction with decision-makers, structured walkthroughs of assumptions documents, sensitivity analysis of key factors, and comparison against existing systems. Similarly, a life cycle of simulation development, related to traditional systems engineering, has also been suggested (Ören & Yilmaz, 2006). More complex than the practical Law approach, their life cycle is broken into problem domain and solution domain elements which intersect at a formulated problem definition. Problem domain tasks include experimenting, abstracting, and formulation of the problem from available data, theories, and problem descriptions. The solution domain tasks include analysis, specifications, designs, experiments, and implementation to gather data, concepts, objectives, and specifications into a model. All such sources will add to effective development of the simulation to be tested and its interface to the various GUIs provided. Balci (1994) presents another life cycle model, including problem investigations, objective definitions, and a series of models that lead into results and integrated decision support. The same paper also present a series of 15 principles for testing that should be used during model validation, verification, and test. Another approach to apply standard software architecture patterns, such as the Model-View-Control pattern, to simulation development in order to improve development approaches and outcomes, has also been proposed (Sarjoughian & Singh, 2004). In presenting three classes of simulation models: disposable models (where problems are unknown at the start), software engineered models (where the system being modeled is well understood), and investigative models (where the problem space is only partially understood), another article warns of increasing complexity of simulation models without proper validation and calls for research into experimental cycles and methods to update and validate models (Paul & Kuljis, 2010).

Support for Selected Development Tools

The final category of literature support is for the tools used in the study. In a typical simulation development project, a formal selection and evaluation process may be employed that compares the tool capabilities with the requirements of the project (Rincon & Perez, 2004). For this study, Mathematica and C# were selected for their capabilities and their familiarity to the developer. There are a variety of sources that discuss general use of Mathematica (Blachman, 1992; J. W. Gray, 1992, 1998; Maeder, 2000; Wolfram, 1996), use of Mathematica as a programming language (Maeder, 1991; Trott, 2004; Wellin, Gaylord, & Kamin, 2005), use of Mathematica as a simulation engine (Bergstrom, 1999; D'Apice, D'Auria, Gargiulo, & Salerno, 2000; Gaylord & Wellin, 1995; Savory, 1995), and interfacing Mathematica to other languages for development of external interfaces (Abudiab, 2002; Abudiab & Starek, 2003). Another article looks at simulation development using Microsoft .NET languages, such as C#, the target GUI development environment for this study (Kilgore, 2002). The clear similarities between C# and Java, as outlined in Obasanjo (2001), makes a source on Java for simulation development of interest as well (Pidd & Cassel, 2000). Architectural guides for constructing .NET-based systems are common (Microsoft Corporation, 2009), as are programming and user interface development guides for C# (Albahari & Albahari, 2007; Hilyard & Teilhet, 2008; Liberty & Xie, 2008; Maiani, Still, Kastroulis, Bellinaso, & Darie, 2002; Sells & Weinhardt, 2006; Troelsen, 2007; Wagner, 2010).

Summary

Research in earnest, for both simulation and usability methods, originated in the 1940s from wartime needs. Both areas benefited from increases in computing capability and new developments such as direct manipulation interfaces. Today, discrete-event and other simulation forms are regularly used in military, industrial, and research applications. Usability is a common element of computer science disciplines today as well, with significant research in a broad range of areas. There are many statements of the importance of usability in simulation, but little focused research. Literature examining the interfaces aspects of simulations is available, as are discussions of experimental usability studies and assessment methods, and best practices for both elements of simulations and for general user interfaces. One area not evident in the literature is a study showing specific experimental support for usability considerations in simulation applications, which is the goal of this study, as outlined in the methodology discussion in Chapter 3.

Chapter 3

Methodology

Research Questions

From Chapter 1, the four key research questions for this study included:

- What are user interface considerations for discrete-event simulation models?
- What are best practices for designing an interface to a simulation application?
- How is usability best evaluated for simulation interfaces?
- What is the actual effect of increased usability for specific interface elements on simulation operations, such as data input and solution analysis?

Also from Chapter 1, the following hypotheses were tested experimentally to provide answers to the research questions on actual effects of increased simulation operation usability:

H(1) If a simulation-focused usability design process is applied to the data entry aspects of a simulation interface, there will be significant reduction in data entry time, interaction errors, and task failure rates.

H(2) If a simulation-focused usability design process is applied to the results analysis elements of a simulation interface, there will be significant reduction in analysis time, incorrect result reporting, and task failure rates.

H(3) If a simulation-focused usability design process is generally applied to a simulation interface, there will be increases in user satisfaction measures, including overall satisfaction, system usefulness, information quality, and interface quality.

The experiment encompassed the following independent and dependent variables:

IV(1) Simulation interface data entry element design. Data entry will have two levels – basic and improved.

IV(2) Simulation interface results analysis element design. Results analysis will have two levels – basic and improved.

IV(3) Simulation interface support element design. Support elements will have two levels – basic and improved.

DV(1) Data entry performance. Measures will include data entry time, interaction errors, and task failure counts.

DV(2) Results analysis performance. Measures will include analysis time, result errors, and task failure counts.

DV(3) Overall user satisfaction. Measures will include scores for overall satisfaction, system usefulness, information quality, and interface quality.

In a discussion of experimental design (Leedy & Ormrod, 2010), the importance of maintaining constants wherever possible is stressed. In this experiment, the task instructions, contents of the simulation problem, assessment methods, test environment and testing conditions were all held constant. Also, the use of a within-subjects design, as applied in this study, reduced variation due to individual subject differences. The user demographics were also controlled. Subjects were required to be computer literate individuals, defined by use of e-mail and web browsers a minimum of once per week. This is similar to typical industrial simulation customers, who use computers at a variety of levels for other job tasks.

Research Methods

Research studies take many forms; Leedy and Ormrod (2010) suggest several types: historical, descriptive, developmental, qualitative, correlational, causal-comparative, and experimental. This study was based on two tasks, a developmental approach to create a simulation-focused usability design process, and an experimental approach intended to answer the question of how the usability of the user interface for a discrete event simulation affects its usefulness and solution quality. The core element of the study was an experiment designed to determine the effect of usability by examining alternate interfaces to a single simulation. Given the guidelines for usability-based development, the experimental portion can be easily reproduced. This experimental design followed the standard scientific method; a flow from analysis and hypothesis, through synthesis, experimentation, and validation in an accepted research approach (Bock, 2001, p. 168).

Study Procedures

In order to perform this experimental research, a number of staged tasks were required before, during, and after the study. Because the goal of the study was to show the benefit of usability practices in simulation design, the study tasks were analogous to the development process used in usability-based design lifecycles. Several such models are available (Constantine & Lockwood, 1999; Cooper, et al., 2007; Hackos & Redish, 1998;

Mayhew, 1999). The relationship of the study stages to a typical usability design process is illustrated in Figure 1, which shows the study procedures in contrast with the design process presented in an appropriate source (Hackos & Redish, Figure 1-3). Similar prototype and test processes are presented in other sources (Moggridge, 2007; Usability Professionals' Association, 2000)

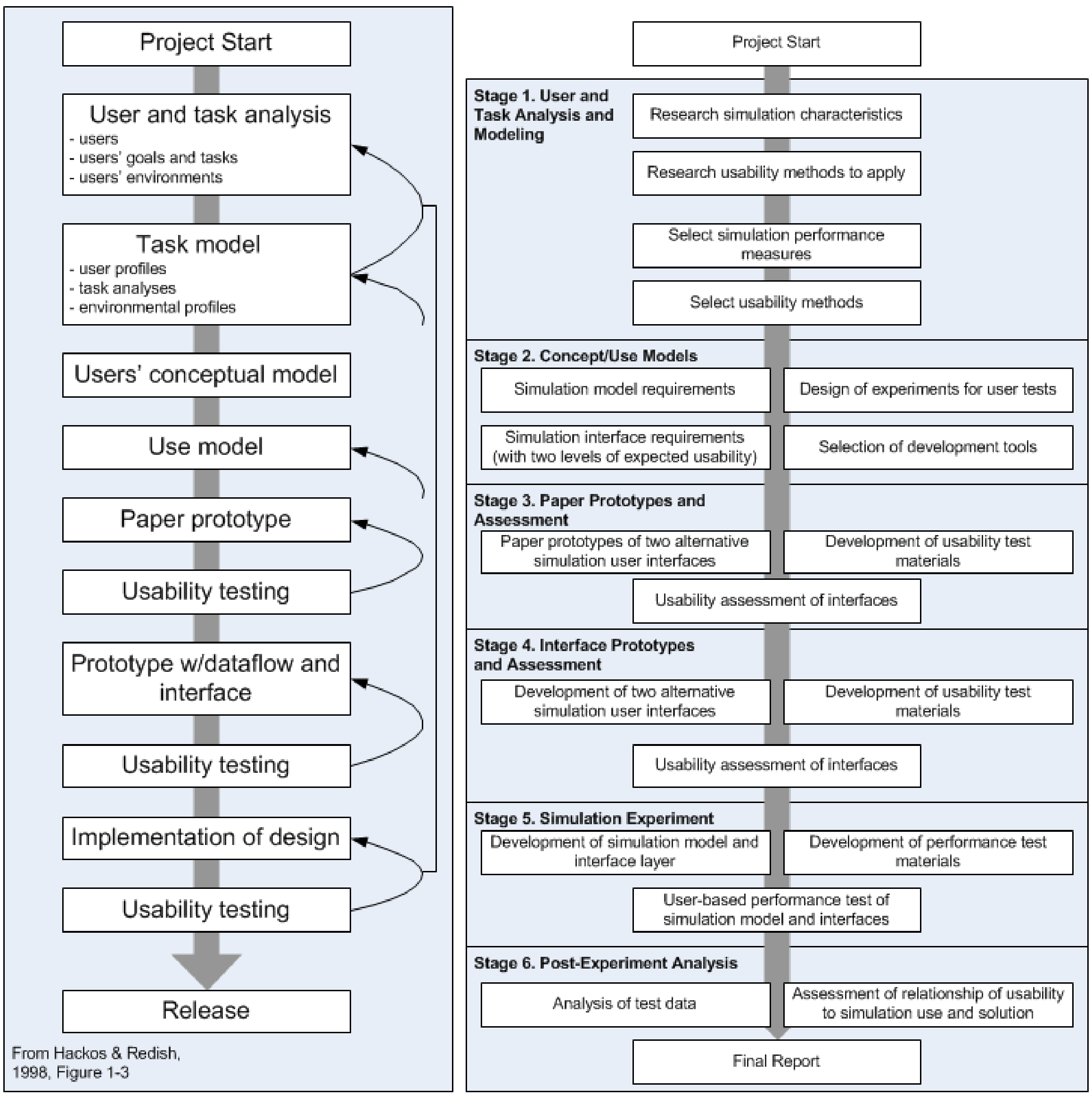

Figure 1. Comparison of typical usability-based design cycle vs. process for study.

The study tasks were divided into six stages: user and task analysis and modeling, concept/use models, paper prototypes and assessment, interface prototypes and assessment, the simulation experiment, and post-experiment analysis. A summary of the stages with associated tasks is presented below, followed by a detailed discussion and a summary of deliverables.

Study Activities Summary by Stages

Stage 1. User and Task Analysis and Modeling

1. Research and summary of discrete-event simulation characteristics.
2. Research and summary of usability methods, as applicable to simulation characteristics.
3. Selection of appropriate simulation performance measures for experimental use.
4. Selection of usability design, evaluation, and test methods appropriate to simulation interface development and assessment.

Stage 2. Concept/Use Models

1. Definition and requirements of simulation user interfaces.
2. Definition and requirements of a general multivariate discrete-event simulation problem for testing illustrating essential simulation characteristics.
3. Design of experiments for testing simulations with alternative interfaces, including user profiles, sample sizes.
4. Selection of development tools for simulation model and user interfaces.

Stage 3. Paper Prototypes and Assessment

1. Design and development of paper prototypes for alternative simulation user interfaces using selected usability design practices.
2. Development of usability assessment and test procedures and materials.
3. Perform usability assessment and tests of prototypes to determine relative usability of interfaces. Measures are specific to usability assessments methods applied.

Stage 4. Interface Prototypes and Assessment

1. Design and development of two computer-based alternative simulation user interfaces using selected usability design practices (similar testing of alternative interfaces suggested by Medsker et al. (1995) and Gutwin and Greenberg (1999)).
2. Development of usability assessment and test procedures and materials
3. Perform usability assessment and tests to determine relative usability of interfaces. Measures are specific to usability assessments methods applied.

Stage 5. Simulation Experiment

1. Development of the simulation model and definition of a programming interface to allow connection from simulation to three separate GUI designs.
2. Development of experimental procedures and test materials.
3. Perform testing of each interface with actual simulation model, using appropriate sample population, and recording selected experimental simulation performance measures. Measures to include time on tasks, error rates, solution quality, and user satisfaction.

Stage 6. Post-experiment Analysis

1. Analyze and compare the relative usability measures of each simulation interface with the experimental performance measures gathered from testing.
2. Assess the study's bearing on general relationship of usability to simulation use and solution quality.
3. Complete final review, including follow-on research directions.

Study Activities – Content and Support

Stage 1. User and Task Analysis and Modeling

In a traditional user-centered design process, these initial steps would be focused on the understanding of user and task characteristics. This can involve extensive user interviews and workplace observations, to develop an understanding of users, including their goals and tasks, profiles and work environment (Hackos & Redish, 1998). Gathering this information can be done using a number of approaches. Use case modeling is often suggested, resulting in use cases (at a user or system level), user stories, or feature lists (Ambler, 2005). Alternate approaches used for similar purposes include user profiles and conceptual task analysis, resulting in models of work flows and common tasks (Mayhew, 1999).

For this study in particular, the preliminary study tasks were designed to develop an understanding of the characteristics of discrete-event simulations that could be affected by usability. It was also necessary to review usability design and test methods that should be demonstrated as applicable to simulation applications. Rather than perform user or task analysis directly to gain this understanding, prior studies in the literature focused on the interface requirements or usability aspects of simulations were used as references (Diamond, et al., 2002; Kuljis & Paul, 2000; Kumara, et al., 2002; Odhabi, et al., 1998; Ören & Yilmaz, 2005; Pidd, 1996; Pidd & Cassel, 2000). At this point, other reviewed references for visual and interface design elements were also consulted to capture key issues for specific interactive requirements of the interfaces (Apple Inc., 2008; Bailey, et al., 2006; Constantine & Lockwood, 1999; Cooper, et al., 2007; Galitz, 2007; Microsoft Corporation, 2007; Mullet & Sano, 1995; Tidwell, 2011; Tufte, 1990, 2002a, 2002b, 2006). Special considerations around novice users (Pane & Myers, 1996) and complex problem solving (Mirel, 2004) were also considered. Based on analysis of these sources, simulation performance measures and the usability design, evaluation, and test methods to be applied in the study were selected. These methods and measures enabled the study's required evaluation of user acceptance, data entry time, interaction errors, and solution quality for the two interfaces to the simulation model, and also helped define data that had to be collected in the test environment (through automation, survey, or observation). Deliverable elements for this stage included feature lists and UML-based use case, sequence, and activity diagrams as needed to outline the user and task elements from this stage. Support sources for the approaches to UML diagramming have been reviewed (Ambler, 2005; Fowler, 2004; Hackos & Redish, 1998; Maksimchuk & Naiburg, 2005; Phillips, et al., 2001). Figure 2 illustrates an initial basic use case for the simulation interface.

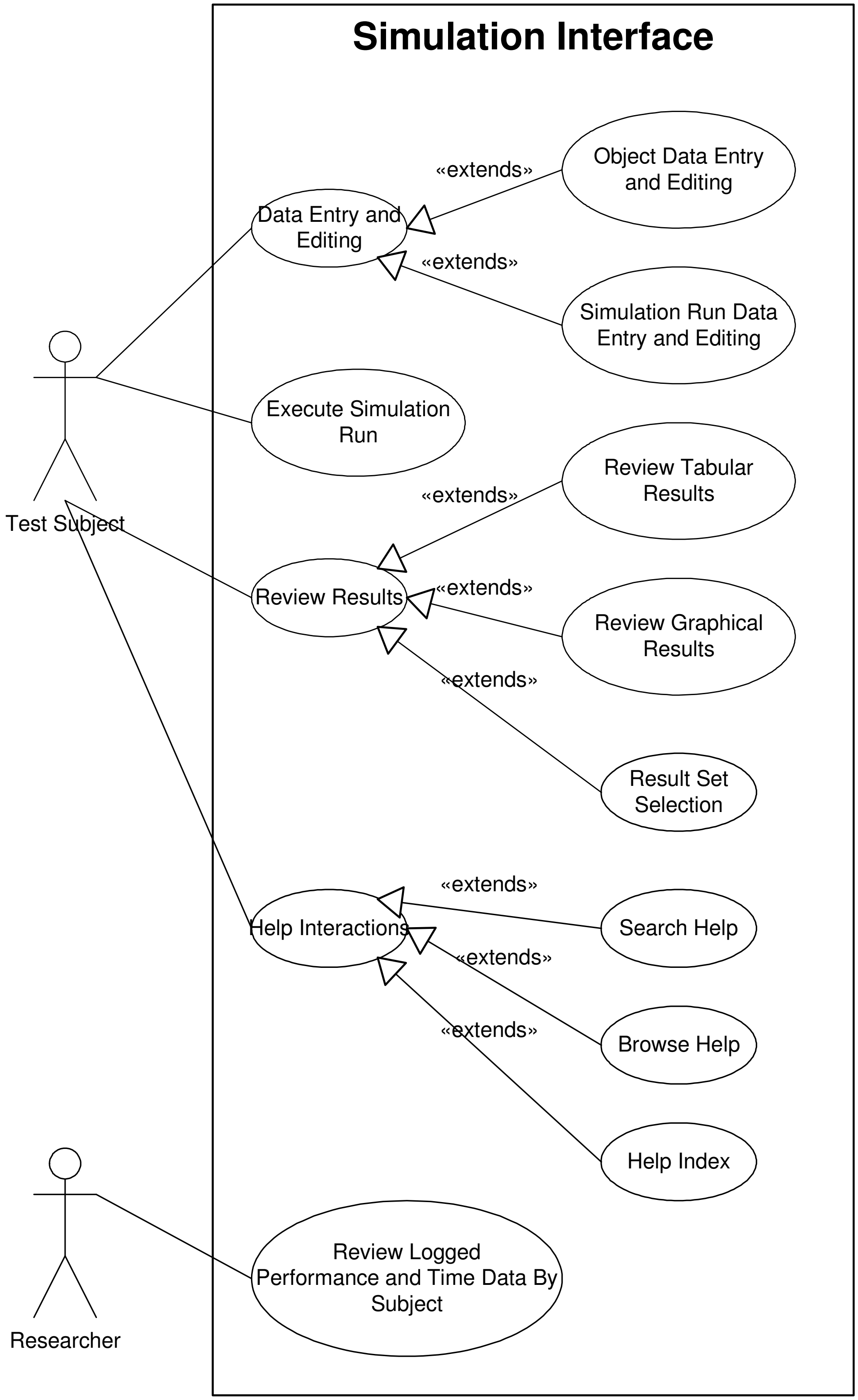

Figure 2. High-level use case for simulation interface (based on Maksimchuk & Naiburg, 2005).

Stage 2. Concept/Use Models

The goal of this stage was to ensure understanding of the user and the tasks to be performed, and translate that knowledge into a set of concepts and requirements for later development. This stage is analogous to conceptual model design (Mayhew, 1999), sketching to support iteration toward prototypes (Buxton, 2007), the later stages of goal-directed design (Cooper, et al., 2007), conceptual domain modeling (Ambler, 2005), or the interface content modeling step in usage-centered design (Constantine & Lockwood, 1999). These processes recognize common artifacts at this stage, including concept sketches and models, content models, flow diagrams, system-level specifications, and class and data diagrams.

Specifically for this study, the first task in this stage was to define a general multivariate discrete-event simulation problem with consideration of the simulation features and measures identified previously. The simulation engine was designed and developed with a layered or tiered application programming interface (API) (Kumara, et al., 2002) to facilitate interconnection to the alternative user interfaces. Figure 3 is a UML activity diagram outlining a typical cycle for the discrete-event simulation of a part repair/recall model, which allows exercise of input variance and output alternatives needed for the experimental tasks. Similar simulations for inventory or distribution models are common in simulation literature – e.g. a more detailed simulation of interactions between inventory and transportation strategies in a logistics network (Lee & Farahmand, 2010).

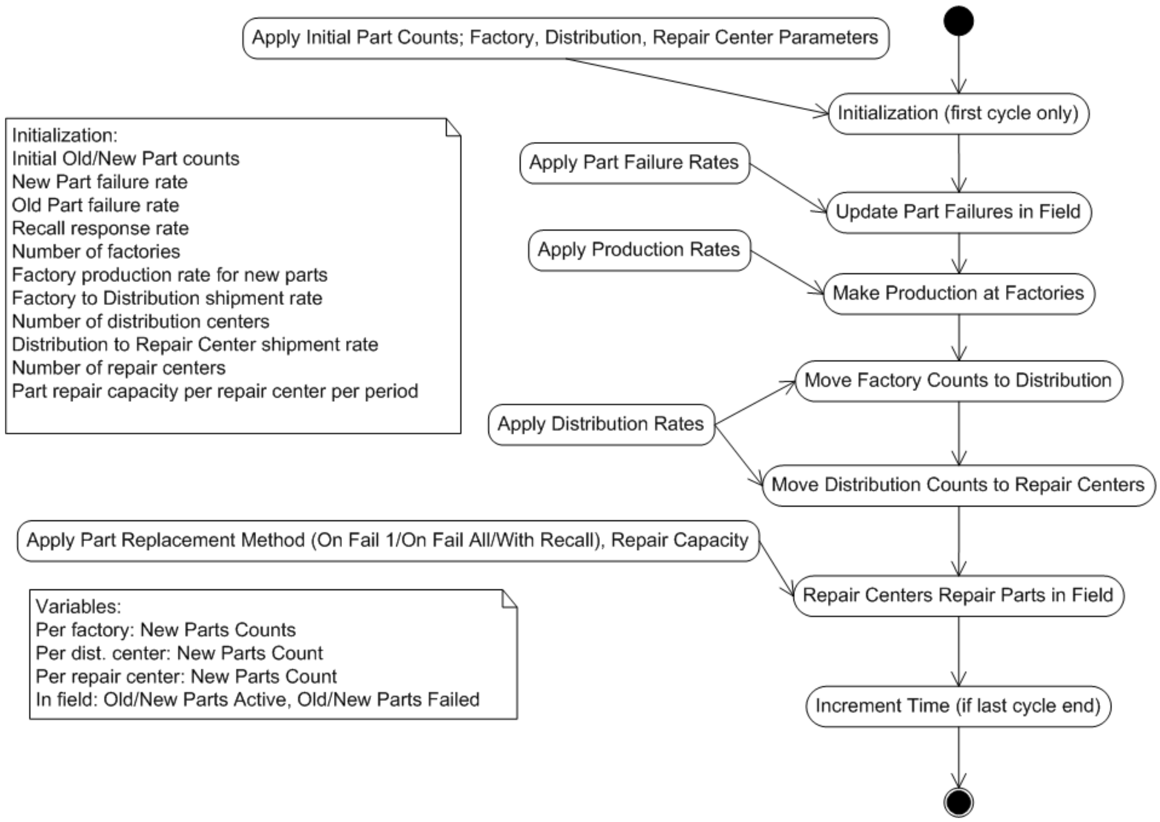

Figure 3. Discrete-Event Simulation Problem modeled as a UML Activity Diagram (Fowler, 2004).

The prior stage's user and task analysis of interface and usability considerations also allowed definition and requirements of user interfaces that met study goals. Per the study approach, two alternative interfaces (Gutwin & Greenberg, 1999; Medsker, et al., 1995) were designed and developed per usability guidelines. The two interfaces, designated basic and improved, mirrored the level of intended usability in selected interaction elements. These elements included model representation and navigation, graphical elements, data entry and validation, user feedback and interaction methods, error prevention and recovery, and help support (Kuljis, 1996). Consideration was given during design to automation of usability and performance measure collection as possible (Hilbert & Redmiles, 2000).

Table 2. Typical Alternative Interface Design Differences from Interaction Elements and Usability Heuristics

Elements/Heuristics	Basic interface	Improved interface
Interaction elements[a]		
Model representation	Represented in help	Combined with graphics of data entry forms
Navigation	Menu-based	Global static navigation bar[b], Sequence maps or breadcrumbs[b], responsive enabling[b]
Graphical elements	None	Icon-based displays[d]
Data entry and validation	Basic form based entry by object type	Model based entry by object (use two-panel selector[b], graphical window drilldown[b]), also datatip displays for objects[b], input hint[b], versioning[d]
User feedback and interaction methods	Log file provided	Graphical progress indicators[b] and command history[b]
Error prevention and recovery	Fields in error identified when form submitted	Default values[b], entry auditing[d], same page error messages[b]
Help support	Help text display only	Context-based, multi-level help[b], with search and index

Elements/Heuristics	Basic interface	Improved interface
Usability heuristics[*]		
Simple and natural dialog and aesthetic and minimalistic design	Standard forms-based dialogs	Custom application, color-coded sections[b], consistent visual framework, row striping and sorting for tabular displays, consistent label alignment and labeling[c]
Speak the users' language: match between system and real world	Limited support	Consistent, clear terminology, avoid developer-centric text[c]
Minimize the users' cognitive load: recognition rather than recall	Minimal support for between run comparisons	Graphical progress indicators[b] and command history[b]
Consistency and standards	May use different formats for command layouts in sections	Consistent content placement[e], standardize task sequences[e]
Flexibility and efficiency of use – provide shortcuts	None	Multiple navigation options – sequence map[b], breadcrumbs[b], escape hatch[b]
Support users' control and freedom	Fixed flow No undo/redo	Full support, single or multi-level undo[b], cancelability[b]
Help users recognize, diagnose and recover from errors with constructive error messages	Minimal messages, log file	Full integrated messages, multi-level help[b], datatip displays[b], same page error messages[b]

[a] Kuljis(1996) [b]Tidwell (2011) [c]Johnson (2008) [d]Cooper et al. (2007)
[e]Bailey et al.(2006) [*]from Appendix A

Table 2 presents a preliminary view of differing factors between the two simulation interfaces (the eventual designs were shaped by the design process in the study).

For both the simulation model and the interfaces, the result of this step provided sufficient requirement detail to allow development of prototypes. The UML element cluster method presented in Phillips et al. (2001) was of particular use in this stage, as the UML diagrams flow well into the paper interface prototypes of stage 3. Given an understanding of the development requirements, it was also possible to confirm the choices of development tools for both the simulation model and user interfaces, and their ability to provide for required functionalities and interface elements. Deliverables at this stage included selected UML cluster, component, activity, class, or state chart diagrams, as needed to outline the conceptual application based on the earlier user analysis, as supported in reviewed literature (Ambler, 2005; Fowler, 2004; Hackos & Redish, 1998; Maksimchuk & Naiburg, 2005). An example of a basic UML component diagram is shown in Figure 4.

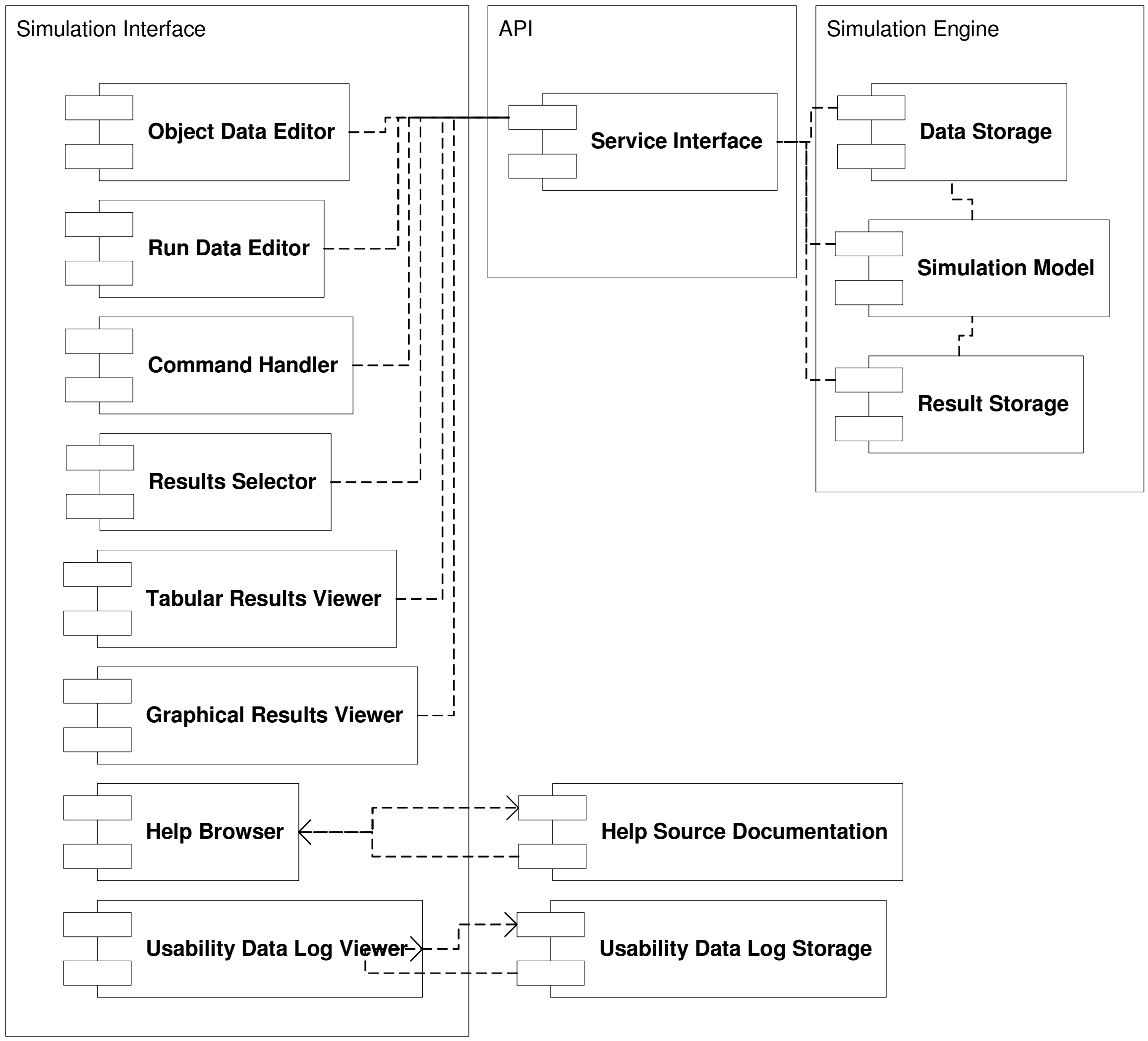

Figure 4. Preliminary UML system component diagram (based on Maksimchuk & Naiburg, 2005).

Also at this stage of the study, it was appropriate to detail a plan for the design of the experiment for testing the simulations with alternative interfaces, including needed detail of user profiles and requirements, sample sizes, or other experimental bounds. Care was taken in the experimental design to prevent adverse effects from bias introduced in subject group assignment, pre-testing, or lack of control groups (Leedy & Ormrod, 2010). Providing an appropriate environment for testing was another consideration. Testing was performed across a selected sample population, and pre-selected experimental measures were selected and recorded. The test was treated as an usability assessment test based on standard guidelines (Rubin & Chisnell, 2008) and example applications of testing procedures (Weaver, et al., 2002).

Current committee guidelines indicated a target of 45 test subjects were required for testing (minimum of 30, maximum of 60). In the experiment, each subject tested one of the interfaces, waited at least seven days, and then returned to test against the other interface. The one week delay between test sessions was intended to reduce any learning effects. Further, half the subjects were randomly assigned to test first with the basic interface, while the other half used the improved interface first. This experimental design provided for a within-subjects or repeated measures design, which was intended to reduce the effect of individual differences in subject capabilities (Leedy & Ormrod, 2010).

Subjects were required to sign a participation agreement, per IRB (Institutional Review Board) guidelines. Subjects were given a preliminary screening and an introduction, performed the usability test task (approximately 15 to 20 minutes), and completed a concluding questionnaire, requiring another 10 minutes to respond to. The total test cycle for each subject was approximately 30 minutes. The deliverable for this stage was a test plan, based on standard test approaches (Dumas & Loring, 2008; Dumas & Redish, 1999; National Institute of Standards and Technology, 2001; Rubin & Chisnell, 2008; Weaver, et al., 2002) detailing the test protocols and practices.

Stage 3. Paper Prototypes and Assessment

The development and assessment of paper prototypes is a common approach to moving from concept designs to tangible representations of what user interaction will be. In most cases, the paper prototype stage is an iterative process, allowing users or usability designers to quickly assess and modify designs (Snyder, 2003). This step is found in several development processes under various names: essential user-interface prototyping (Ambler, 2005), low-fidelity passive prototyping (Constantine & Lockwood, 1999), or conceptual model mock-ups (Mayhew, 1999).

For the study, the tasks for this stage included the development of several low-resolution paper prototypes of the two alternative simulation user interfaces based on the concept models in earlier stages. Prior to assessment of these prototypes, it was necessary to develop required usability test materials for the test method to be applied. In particular, Snyder (2003) calls for preparing paper prototypes and task outlines to discuss with respect to the prototypes. Finally, paper prototypes were assessed for usability in an iterative process with a small group of experienced designers, per the process outlined in Snyder (Chap. 5), with a process that took several passes. Each review session was targeted for approximately 90 minutes with some variation. The deliverables for this stage were the consent forms for participants (Appendix B), initial paper prototypes, test plan handouts and task outlines (see Appendix C), and the final revised prototypes.

Stage 4. Interface Prototypes and Assessment

Development of working computer-based prototypes, and usability assessment of those prototypes, was another step in ensuring usability and functional goals are represented in user-based design processes. Again, this is usually an iterative process, applying a variety of assessment methods, including formal usability testing and usability inspection, to provide evaluations and recommended design changes (Mayhew, 1999). This step is found in most usability engineering processes under a variety of names: iterative screen design evaluation (Mayhew, 1999), prototype reviews and walkthroughs (Ambler, 2005), implementation modeling and usability inspection of dynamic high-fidelity prototypes (Constantine & Lockwood, 1999). A common approach at this stage is to apply discount usability engineering inspection approaches to limit time and resources while still providing sufficient interface assessment (Nielsen, 1993). Recommended inspection approaches include heuristic evaluations, cognitive walkthroughs, and action analyses (Holzinger, 2005).

This study included the development of two high-resolution computer-based prototypes of the alternative simulation user interfaces designed in earlier concept models and prototypes. As above, any necessary artifacts for the usability test process were developed in this stage. The prototypes were assessed using inspection techniques to determine the relative usability levels of the two interfaces, and to identify other selected usability measures. This stage was performed using heuristic evaluation (Nielsen & Mack, 1994). Modified versions of the base heuristic evaluation approach are often used in assessment (Karoulis, et al., 2005; Mankoff, et al., 2003), and similar modifications were made in the final evaluation criteria, including integration of applicable elements from the cognitive dimensions assessment method (Green & Petre, 1996). Per discount methods, a group of between three to five interface designers performed the assessment. This was expected to complete in a single session, with additional sessions held if needed. Again, these sessions were planned for 90 minute durations, with some variation expected. Deliverables from this phase included the consent forms for participants (Appendix B), interactive interface prototypes, test plan handouts and heuristic evaluation forms (Appendix A), and the quantitative and qualitative measures from the usability assessment.

Stage 5. Simulation Experiment

In a usability engineering process, this next stage represents both final application construction and live user testing. This development stage is referred to in several processes under different names: iterative detailed interface design (Mayhew, 1999), concentric construction with usability inspection (Constantine & Lockwood, 1999), or simply the implementation phase (Usability Professionals' Association, 2000). In this stage, as elements of the software are implemented, they undergo further inspection and user test to ensure acceptance and confirm that the implementation continues to match the user’s conceptual model (Rubin & Chisnell, 2008). Output from this phase included test reports, videotapes and recordings of test sessions, and recommendations for changes.

In a typical development process, the goal at this point would be to verify and improve the system's usability. For this study, there was a specific goal of assessing user performance levels against each of the two alternate interfaces. Prior to the experimental tests, any remaining development for the simulation model designed in earlier stages was completed, and then integrated with final versions of the two user interfaces to be tested. Any required instruments for the simulation tests were also developed in this stage. The primary user input came from a post-test questionnaire, based on validated designs suggested by standard usability test sources (Dumas & Redish, 1999; National Institute of Standards and Technology, 2001; Rubin & Chisnell, 2008; Tullis & Albert, 2008). Rather than develop and validate a custom questionnaire (which is a significant experimental effort, as demonstrated in studies such as Davis (1989)), this study applied the Post-Study System Usability Questionnaire (PSSUQ). The PSSUQ questionnaire takes approximately 10 minutes to apply, and provides four measures – overall satisfaction, system usefulness, information quality, and interface quality (Lewis, 1993).

The primary experimental task of the study, testing the two user interfaces with a sample subject population, was performed per the prior experimental design with appropriate recording of selected experimental simulation performance measures (to include time on task, error rates, and user satisfaction). The task used the experiment designed in the second stage of the overall project. Output deliverables included consent forms (Appendix B), test plan handouts including entry and analysis tasks (dependent on simulation and interface designs), the test systems, and resultant data gathering, including automated data gathered during the test session, observed data during the test, and input from subject post-test questionnaires (Appendix D). Formats for these instruments are suggested in a variety of sources (Dumas & Loring, 2008; Dumas & Redish, 1999; National Institute of Standards and Technology, 2001; Rubin & Chisnell, 2008) and selected sources are cited on the instruments.

Stage 6. Post-experiment Analysis

It is common in many usability engineering design tasks to include a post-development deployment phase, where the product release and process are examined, sometimes through user surveys or field studies (Usability Professionals' Association, 2000). For this study, this stage consisted primarily of data analysis. Analysis tasks began by comparing the relationship between the relative usability measures of each simulation interface with the experimental performance measures gathered from testing. Given the analysis of experimental data, the next step was to assess the study's general bearing on the relationship of usability to simulation use and solution quality. The final task was to complete the final report for the study, including a discussion of issues seen in the study process and follow-on research directions suggested by the study conduct and results.

The primary deliverable of the final stage is this final study report, which answers the research questions posed for the study. In its presentation, the report provides the user interface considerations specific to simulation models, which speaks to specific interface characteristics reviewed and applied, and those are drawn from the experimental designs supported by literature. The best practices for simulation interface design question also focuses on the development process or life cycle, and is taken from the applied process in the study as well as supporting literature. The presentation in Law (2006) provides a good example of a life cycle discussion that blends practical application with literature support. The report also recommends how to evaluate usability of simulation interfaces, and looks at the evaluation and user-based test methods applied in the study, along with support from related sources. This discussion is similar to that found in Holzinger (2005), which outlines suggested usability tools for software engineers.

Finally, the experimental part of the study is presented here, to provide the validation for the improvements in use and solution quality from implementing the suggested design elements, development life cycle, and assessment methods. This provides a comprehensive discussion of the topic supported by experimental proof, which further provides a unique perspective on the issues involved. The experimental design is presented in a form that would be easily reproducible by other researchers. The organization and presentation of the similar experiment in the Gutwin and Greenburg (1999) study provides an excellent guideline for organizing the presentation of the experiment and its support, as well as an approach for eventual publication. Tullis and Albert (2008) also provides extensive guidelines on metric assessment and analysis.

Deliverables

Table 3 summarizes the specific deliverables, by stage, for the study. Also included in table 3 is the deliverable format, the intended timing of the activity and the responsible individual(s).

Table 3. Deliverables for the Overall Study Effort

Deliverable	Format	Study phase	Responsible
	Stage 1. User and Task Analysis and Modeling		
Research of discrete-event simulation characteristics	Literature review	Proposal	Researcher
Research of usability methods applicable to simulation characteristics	Literature review	Proposal	Researcher
Selection of simulation performance measures	Methodology	Proposal	Researcher
Selection of usability design, evaluation, and test methods appropriate to simulation interface development and assessment	Methodology	Proposal	Researcher
	Stage 2. Concept/Use Models		
Design of experiments for testing simulations with alternative interfaces, including user profiles, sample sizes	Methodology	Proposal	Researcher
Selection of development tools for simulation model and user interfaces	Methodology	Proposal	Researcher

Deliverable	Format	Study phase	Responsible
Definition and requirements of two simulation user interfaces (basic and improved)	UML model	Main study	Researcher
Definition and requirements of general multivariate discrete-event simulation problem for experiment	UML model	Main study	Researcher
	Stage 3. Paper Prototypes and Assessment		
Design and development of paper prototypes for two alternative simulation user interfaces using selected usability design practices	Paper prototypes	Main study	Researcher
Development of usability assessment and test procedures and materials for stage 3	Test plan and instruments (initial designs)	Proposal	Researcher
Pre-test to validate test plan and instruments	Test plan and instruments (reviewed designs)	Main study	Researcher, pre-test subject
Perform usability assessment of paper prototypes to determine relative usability of interfaces	Testing sessions and results (completed reviews) – note that this will likely take several sessions to complete.	Main study	Researcher, Interface Designers (3 to 5)

Deliverable	Format	Study phase	Responsible
	Stage 4. Interface Prototypes and Assessment		
Design and development of two alternative simulation user interfaces using selected usability design practices	C#-based interface prototypes	Main study	Researcher
Development of usability assessment and test procedures and materials for stage 4	Test plan and instruments (initial designs)	Proposal	Researcher
Pre-test to validate test plan and instruments	Test plan and instruments (reviewed designs)	Main Study	Researcher, pre-test subject
Perform usability assessment and tests to determine relative usability of interfaces	Testing sessions and results (completed reviews)	Main Study	Researcher, Interface Designers (3 to 5)
	Stage 5. Simulation Experiment		
Development of the simulation model and interface layer to two GUI designs	Mathematica-based simulation and interface to GUIs	Main Study	Researcher
Development of experimental procedures and test materials for stage 5	Test plan and instruments (initial designs)	Proposal	Researcher
Pre-test to validate test plan and instruments	Test plan and instruments (reviewed designs)	Main Study	Researcher, pre-test subjects (3)

Deliverable	Format	Study phase	Responsible
Perform testing of two interfaces with actual simulation model	Testing sessions and results (completed reviews, videotapes)	Main Study	Researcher, test subjects (target 45 – min. 30, max. 60, each subject tests both interfaces)
	Stage 6. Post-experiment Analysis		
Analyze and compare the relative usability measures of each simulation interface with the experimental performance measures gathered from testing	Statistical analysis and final report	Final Report	Researcher
Assess the study's bearing on research questions	Final report	Final Report	Researcher
Complete final review including follow-on research directions	Final report	Final Report	Researcher

Formats for Results

Design documentation was largely based on UML diagramming procedures and other literature suggested formats. Usability data was recorded in standard formats designed for individual testing goals and saved for later consideration. Sample forms for various usability tests and reports are found in several sources (Constantine & Lockwood, 1999; Dumas & Loring, 2008; Dumas & Redish, 1999; Hackos & Redish, 1998; Mayhew, 1999; National Institute of Standards and Technology, 2001; Rubin & Chisnell, 2008; Tullis & Albert, 2008).

Required Resources

Particular resources were required for both development and test. Development required software tools for simulation and interface development. The design of the user interfaces to be tested, as well as the design of the simulation example, influenced the final decision on which development tools to use. Resources were also required for user testing (as discussed in Dumas and Redish (1999)). In addition to a plan and design for the tests, other physical elements were required, such as handouts and recording materials, screen recording software, a test system, participants that fit required user profiles, and a properly prepared testing location. Per university guidelines, all user-based testing was performed based on the review and approval of the testing procedures by the Institutional Review Board (IRB), which oversees all research with human subjects. Videotaping is recommended for single-person test administration (Dumas & Redish, 1999), but in this study – to limit personal privacy concerns for subjects – recording of sessions is limited to automated data collection, screen recordings, and notes by the researcher. It may be necessary for such studies to make much of the test environment portable, in order to engage as many test participants as required – this was not a particular requirement in this study.

Final decisions on configuration of the test environment and number of participants required were shaped by the designs of experiments that resulted from the prerequisite research. For instance, Dumas and Redish (1999) suggest 6 to 12 participants grouped in two or three subgroups are sufficient for typical usability tests, but desired statistical strength of quantitative test measures discussed with the committee suggested greater numbers, with approximately 45 subjects in a within-subjects or repeated measures design. Because of concern in obtaining qualified participants as a limiting factor for the study, alternative sources of participants, such as various places of employment, academic environments, or related conferences, were identified and explored. Possible incentives (drawings for prizes) and other recruitment strategies for participants were also considered as needed for the particular population of participants.

Summary

The methodology applied used standard usability design processes to simulation development, with the allowances needed specific to the experimental study and to finding the answers to the research questions posed. The study began by examining the interface considerations for simulations, through user and task analysis. Then best practices in interface design and usability evaluation were brought into the interface design and development cycle, examining paper and computer-based prototypes with heuristic evaluations and other methods. Finally the specific effects of the varying levels of usability in the simulation interfaces were subjected to user-based testing, to gather data examining relative usability of the two alternative approaches. The resulting data, along with the prior literature reviews, provided support for the final report on the study results.

Chapter 4

Results

Overview

The study was structured to be performed in six stages as outlined in Chapter 3, Methodology. The following sections discuss the results and deliverables from each of the study stages, the details of the experimental data analysis performed on data collected from the subject-based simulation experiment stage, the findings from the overall study, and a summary of the results. The results of the three stages that involved subjects and usability testing procedures are presented using the basic outline presented in the Common Industry Format for Usability Test Reports, Version 2.0 (National Institute of Standards and Technology, 2001).

Results and Deliverables of Study Stages

Stage 1. User and Task Analysis and Modeling

The goal of this stage was to develop an understanding of the discrete-event simulation characteristics that could be impacted by usability design and assessment. The deliverables initially proposed for this stage included the following: literature reviews of discrete-event simulation characteristics and usability methods applicable to such simulations, the selection of the simulation performance measures, and the selection of usability design, evaluation, and test methods appropriate to simulation interface development and assessment. Other expected deliverable elements expected included feature lists and UML-based analysis (use case, sequence, activity diagrams) as needed to support the initial designs.

The results of the first stage of work are primarily seen in the literature reviews supporting the study, which were first presented in the formal study proposal, and have been updated regularly throughout the study process. New literature support is included in this report as warranted. The basic methodology for the study, in terms of performance measures and usability methods, was also provided in the formal study proposal, and was followed for the follow-on stages. UML diagrams and other support used for development of the simulation interfaces or the simulation are extended as part of the stage 2 deliverables.

Stage 2. Concept/Use Models

The goal of the second project stage was to present an analog of the conceptual design that a simulation developer would perform to develop concepts and specifications. The proposed deliverables for this stage included the design of the experiments needed for testing two alterative interfaces to a discrete-event simulation, as well as the selection of development tools to be used in the development. These deliverables, the experimental design and the development tools, were provided and detailed in the formal study proposal. The other required deliverables for this stage included the definition and requirements for a general multivariate simulation design that could be used to demonstrate the study approaches, as well as the definition and requirements for two alternative simulation user interfaces (a basic interface and an improved interface). A limited set of UML use case, component, and activity diagram models were used for the initial system specifications; final models can be found in Appendixes E, F, G, H & I. The initial UML models, starting from the examples in the formal study proposal, were updated and expanded to capture results of early design activities, especially those in the stage 3 paper prototyping exercises with interface designers. The initial UML models were used to develop the task templates (Appendix J) employed in the initial and follow-on sessions of the stage 3 paper prototyping and assessment.

Prior to stage 3 testing with human subjects, the researcher completed all required Institutional Review Board (IRB) submissions, resulting in a letter granting permission to perform subject testing under IRB guidelines (the IRB permission letter is included in Appendix K). Also, as part of the IRB process, a facility use permission letter (see Appendix L) was obtained from representatives for the testing facility.

Stage 3. Paper Prototypes and Assessment

The stage 3 tasks were the first involving test subjects, and the goal was to demonstrate a process for paper prototyping and assessment of the simulation interface designs. The formal study proposal outlined the deliverables for this process, including a test plan and test instruments, paper prototypes, and the execution of the design and usability assessment. The results of this usability test are presented using a format similar to that suggested in the Common Industry Format for Usability Test Reports, Version 2.0 (National Institute of Standards and Technology, 2001).

Summary: Three 90 minute sessions were held to develop and assess paper prototypes of the user interfaces for the simulation system. An iterative process, each session resulted in updates to paper prototypes and designs, which cycled into the follow-on session. A structured process adapted from Snyder (2003, Chap. 5) was used to guide task design and review, prototype creation, and usability testing for iterative refinement.

Product Description: The evaluation focused on development and assessment of designs for two user interfaces, designated basic and advanced, for a discrete-event simulation of an inventory and distribution system. The user population for the application as proposed is adult test subjects (over age 18) who are computer-literate users (defined by use of e-mail and web browsers a minimum of once per week). The users must be able to follow instructions for use, but are not required to have a background in the simulation problem area. While the interfaces represent a typical simulation application, the focus of use is on selected tasks performed in testing the interfaces.

Test Objectives: Objectives include review and updates of initial task outlines, review and updates of paper prototypes and their interface elements in terms of the application and task outlines, and structured usability testing of the paper prototypes to task outlines.

Participants: Test participants were interface designers from the researcher's workplace, each with more than 10 years experience in development. There were three participants for each session; each participant signed a consent form (Appendix B) prior to the test sessions.

Tasks: Tasks used for assessments of prototypes were selected based on typical simulation use cases. Each task to be assessed on paper prototypes was included in a handout of formal task templates (Snyder, 2003). (See handout in Appendix J.)

Facility: Testing was held in a private conference room. No computer equipment was used. Participants were provided with handouts, paper, pens or pencils, flip chart, and markers. The initial set of paper prototypes resulting from the first session were made with a combination of Microsoft Visio as a drawing tool and hand drawn elements. The second set of paper prototypes was created almost entirely in Visio.

Procedure: There were two primary types of sessions – the initial creation of the paper prototypes, and two sessions of paper prototype refinement through a structured usability test. The procedures followed a series of steps to iteratively develop the paper prototypes, as follows:

- Prior to the first session, the researcher prepared an initial set of handouts, including the initial UML diagrams of the system, the proposed list of interaction elements and usability heuristics (see Table 2), and a document showing typical tasks and formal task templates (Snyder, 2003) for use in assessing the interface designs (Appendix J), as well as a test plan outline (Appendix M).

- In addition, during the first session, the participants asked to see examples of other simulation interfaces, so an additional handout was prepared with examples from several published tools (Chen, et al., 2002; Heilala, et al., 2007; Herren, et al., 1997).
- In the first of three sessions, the researcher and participants reviewed the input materials and developed a rough flip-chart based outline similar to a tabular alignment of use case elements to interface elements (Phillips, et al., 2001).
- Prior to each of the next sessions, a paper prototype (Appendixes N and O) was developed, based on the notes from the prior session.
- The second and third sessions used a desktop usability test (Snyder, 2003) in which participants applied the task outlines to the paper prototype forms. Participants were selected to assume the role of the computer, the user, an observer, and the researcher acted as the facilitator.
- The participant acting as the user then performed each task on the paper prototypes, the computer participant stated what the computer would have done, and the observer added comments. The facilitator captured notes which were used to drive further prototyping.

Participant General Instructions: The test sessions were conducted according to a provided test plan (Appendix M). After consent was provided, participants discussed the test plan, the application, and the handouts with the researcher. Participants were instructed to consider the interface being developed by a technical simulation expert, but not an experienced interface designer. All materials were to be returned to the instructor at the end of the session.

Participant Task Instructions: For the initial session, participants were asked to consider the design handouts and list the interface elements needed to support the tasks outlined. This was performed primarily on a flip chart, using a rough version of a tabular representation of interface elements (Phillips, et al., 2001). For the second and third sessions, participants followed the process for paper prototype assessment (Snyder, 2003): taking the role of computer, user, observer, and facilitator to assess the interfaces against the task profiles (Appendix J).

Usability Metrics: The usability assessment was qualitative in nature; participants were instructed to consider typical design choices for the basic application, and to consider the proposed list of interaction elements and usability heuristics for the advanced application. Prototypes were marked up directly and notes were captured from sessions.

Data Analysis: Qualitative results gathered were fed back into the next set of paper prototypes in an iterative basis.

Results: The initial session allowed the interface designers to provide input on what the basic and improved interfaces would likely consist of. There was considerable discussion on the form the interface should take – forms vs. a spreadsheet vs. a purely graphical representation. In consideration of the expected low experience level that simulation developers would have, it was decided that a forms based approach was most likely, particularly given the use of C# as front-end, which is form oriented by default. There is supporting evidence of form-based approaches for simulations as well (Kim, et al., 2001).

The two follow-on sessions generated changes to task outlines, UML designs, and paper prototypes in a cycle of iterative refinement, which (in addition to demonstrating the process) was the goal of the exercise. The structured role-based assessment worked well to provide a process to working through interface design issues. The final paper prototype developed during the sessions was used to create higher fidelity computer-based interface prototypes for the stage 4 interface assessment.

Stage 4. Interface Prototypes and Assessment

The goals of the stage 4 testing were to identify any unaddressed usability issues in the two alternative simulation user interfaces, to ensure appropriate levels of usability for the basic and improved interfaces, and to demonstrate the potential impact of the heuristic evaluation approach to simulation interface developers. Again, this stage involves a subject-based usability test, so the results will be discussed using the NIST usability test report (National Institute of Standards and Technology, 2001) categories.

Summary: Two 90-minute sessions were held to perform a usability test on high-fidelity prototypes of the two alternative user interfaces. The test, similar to the approach in Karoulis et al. (2005), consisted of a structured usability heuristic evaluation of each interface set by four experienced interface developers. One of the interfaces was assessed in each session by walking through the forms that make up the application while considering a set of provided usability heuristics. Observations of each participant were collected, compiled, and used to complete the development of the user interfaces to full working applications.

Product Description: The evaluation focused on development and assessment of designs for two user interfaces, designated basic and advanced, for a discrete-event simulation of an inventory and distribution system. The user population for the application as proposed is adult test subjects (over age 18) who are computer-literate users (defined by use of e-mail and web browsers a minimum of once per week). The users must be able to follow instructions for use, but are not required to have a background in the simulation problem area. While the interfaces represent a typical simulation application, the focus of use is on selected tasks performed in testing the interfaces.

Test Objectives: Using the basic structure of the heuristic assessment method (Nielsen, 1993), collect usability concerns about each interface, to use in further development. The assessment also serves to validate the difference in expected usability between the basic and improved applications, as well as to illustrate the assessment methodology.

Participants: Test participants were interface designers from the researcher's workplace, each with more than 10 years experience in development. There were four participants for each session; each signed a consent form (Appendix B) prior to the test sessions.

Tasks: This was not performed as a task-based exercise, but rather as a general assessment of each form in the application. The researcher provided guidance as to what operations would be performed on forms, and answered questions about specific operations. The assessment criteria were very specific, and were provided on the heuristic assessment forms (see Appendix A) the participants used during their review.

Facility: Testing was held in a private conference room. A computer with overhead projector was used to display the forms under consideration (participants had paper copies as well). Participants were provided with handouts, paper, and pens or pencils.

Procedure: The testing followed a similar process to that in Karoulis et al. (2005). The focus was on collection of issues per heuristic area and any corresponding design changes. Unlike other heuristic approaches (Mankoff, et al., 2003), the ranking of issues was not seen as necessary at this stage and was not used.

- Participants reviewed the test plan (Appendix M), the usability heuristic assessment forms (Appendix A), the heuristics themselves, and the application approach with the researcher.
- This was followed by stepping through a heuristic-based assessment of each form in the interface set (basic interface for the first session, improved interface for the

second). Forms were numbered for ease of reference (see Appendix P).

- Participants were given time to write down observations about each of the heuristic categories for each form before proceeding. Results and the general designs were discussed after assessments were made.

Participant General Instructions: Per the test plan (Appendix M) participants were encouraged to ask questions and make observations at any point during the process, including during evaluation. However, the researcher encouraged a few moments of quiet private assessment of each form, to allow the participants to find the issues that may be unique to their observation, prior to being led to other directions by discussion. All materials were to be returned to the instructor at the end of the session.

Participant Task Instructions: Participants were provided with heuristic worksheets (Appendix A) and images of the interface forms. (Forms were assigned numbers to allow easier reference.) During the assessment of a given form, participants were encouraged to consider what types of issues were evident in the design for each heuristic category.

Usability Metrics: Unlike some studies using heuristic evaluation (Mankoff, et al., 2003), this assessment was not targeted at a quantitative result, such as number of issues found or duplications across evaluators. Instead, the heuristics were simply to structure qualitative assessment of usability issues the participants found in each heuristic category. The findings of the participants for the two interfaces are summarized in Appendix P.

Results: The heuristic assessments were very successful in identifying usability issues in the interface forms. The list of observations was used in the development of the final interfaces which were presented to subjects for testing in stage 5. The review team also suggested design changes to the interfaces that would potentially provide improved usability. These changes were implemented in the interfaces used in the stage 5 testing.

Stage 5. Simulation Experiment

The primary experimental task in the study, stage 5 was focused on conducting subject-based testing to prove the effectiveness of the usability design methods and their impact on users performing data entry and analysis tasks for a typical discrete-event simulation. This study stage represents the application development and user-based test process that would be performed in an actual implementation. Deliverables for this stage included the final deployable versions of the Mathematica-based simulation and the two C#-based alternative simulation user interfaces, the test plan and supporting instruments, and other tools required to conduct the testing. As with previous stages, the subject-based usability test is presented using the outline of the NIST usability test report (National Institute of Standards and Technology, 2001).

Summary: The subject-based assessment of the alternative user interfaces consisted of 97 thirty-minute test sessions over a two-month period, during which each subject performed a series of prescribed data entry and data analysis tasks, followed by filling out a pre-validated survey, the Post-Study System Usability Questionnaire or PSSUQ (Lewis, 1993). Each subject that completed the sessions participated in two half-hour sessions, one for each of the alternative interfaces. Half the subjects held their first session using the basic interface; the others used the alternative improved interface first. Their second session consisted of the same test cycle using the interface they had not yet tested. Three tests were invalidated during the study, data from the remaining 94 was collected through screen capture of the session, the researcher's observation log sheet, and though log files of the subject's interactions with the applications. The approach for the testing was drawn from standardized user-based test procedures (Dumas & Loring, 2008; Dumas & Redish, 1999; Rubin & Chisnell, 2008). Generally, the testing showed the improved interface to be more usable based on quantitative data analysis. These findings are discussed in detail in following sections.

Product Description: The evaluation focused on assessment of specific interactions with two user interfaces, designated basic and advanced, for a discrete-event simulation of an inventory and distribution system. The user population for the application as proposed is adult test subjects (over age 18) who are computer-literate users (defined by use of e-mail and web browsers a minimum of once per week). The users must be able to follow instructions for use, but are not required to have a background in the simulation problem area. While the interfaces represent a typical simulation application, the focus of use is on selected tasks performed in testing the interfaces.

Test Objectives: The objective of the test was to develop qualitative and quantitative measures of the effects of the usability differences between the two interfaces. These measures can support the assessment of the process used to develop the interfaces, and the impact of usability issues on the data entry and solution analysis from a typical discrete-event simulations.

Participants: Test participants consisted of 49 adult workers from the researcher's workplace, each expected to meet the minimum requirements for computer literacy (weekly use of e-mail and web browsers) and ability to follow directions. Each participated voluntarily, and each signed a consent form (Appendix B) in order to participate in the test sessions. Two participants were dropped from the study, one after the first session due to language difficulties in following instructions, one after the second session due to visual difficulties in using the simulation interface. In all, 47 subjects contributed 94 trial data sets. (The target participant count based on the formal study proposal was 30 to 60 subjects.)

Tasks: Tasks used for interface testing were selected based on the simulation use cases used throughout the study. Subjects were provided with task sheets outlining specific tasks to perform, including values to enter or analysis data to find. Each trial consisted of an initialization task where the subject number was entered, five data entry tasks comprised of a total of 18 data entries or modifications, and two analysis tasks comprised of six results data analysis questions. The task sheet provided to the users are in Appendix Q. The task sheet between the two interfaces differed slightly in the distribution center task due to a difference in program flow (distribution network connections were made on the distribution center form in the basic interface and on the main form in the improved interface). There were no differences in the content of the tasks being performed from interface to interface. Informal testing with pre-test subjects was performed to ensure the flow of the test, clarity of instructions, and the timing of each test section. The goal was to perform each part of the test - data entry, analysis, and survey completion – in ten minutes or less for each part.

Facility: A test schedule was provided for subjects, with testing slots available weekdays at 7:00 AM, 7:30 AM, noon, 12:30 PM, 5 PM, and 5:30 PM. Subjects were asked to sign up for two sessions, with a minimum of a one-week separation in trials per the formal study proposal experimental design. Testing was conducted in a private office. A single Microsoft Vista-based testing computer was set up on a small desk with a standard PC monitor, keyboard and mouse. Two chairs were available, one for the subject, one for the researcher acting as facilitator and observer. Participants were provided with handouts, paper, and pens or pencils. No video or audio recording was performed, but the screen interactions of each test were captured using the open source RenderSoft CamStudio version 2.0 screen recorder. The simulation runs and graphic output were generated through Wolfram Mathematica Version 7 (source code for the simulation is provided in Appendix R). The C#-based user interfaces were generated using Microsoft Visual Studio 2008, including a flowcharting component called MindFusion FlowChart.NET used for the graphical simulation network. All non-open source tools are used under appropriate license agreements.

Procedure: Each session was held using the same test procedure, as follows:

- The researcher prepared a data packet for each session consisting of a test plan outline (Appendix M), two sheets of task instructions (Appendix Q), the four sheet PSSUQ (Lewis, 1993) usability questionnaire (Appendix D), and a session notes form for the researcher to track session steps and results (Appendix S).
- Subject was greeted, consent forms were confirmed to be signed and witnessed, and the subject was asked to sit at the testing workstation.
- Subjects were provided with test plan outlines, and these were reviewed. Subjects were reminded that the session was timed, but they should work at a normal pace. Subjects were also encouraged to think aloud during the testing to provide their input to the researcher. Subjects were also informed that the researcher would not provide directions for use of the tool unless they declared they could not continue.
- The CamStudio screen recorder was initialized, and the entry screen to the selected simulation interface was started.
- When the subject stated they were ready to begin, they were handed the task instructions form and instructed to begin. In early testing, a stopwatch was used to control the entry periods. This was later abandoned in favor of using the clock on the Windows interface for the majority of testing, as the task timing was not proving to be an issue for participants, and specific measures of task times were being captured through automated time-stamped log entries.
- The subject entered their subject number; this action was used by the interface program to initialize a log file for the subject and session to collect timing,

tracking of element entry and exit, and values of data entries.

- The subject performed data entry tasks per the task instruction sheet. This process generally took place in less than ten minutes. The researcher generally limited interaction to the question "What are you thinking?" if it appeared the subject was not progressing and was not providing feedback. In cases where the user declared they were unable to continue, the task was marked as incomplete on the session notes form, and the user was instructed on how to proceed to the next task.
- The final task in the data entry was to "run" the simulation. However, to ensure that each subject used the same data set for the analysis tasks (rather than variations that may be introduced due to data entry errors), a pre-validated set of simulation results from an earlier run of the application was loaded at this point for the subject's analysis tasks.
- The subject then performed the analysis tasks per the task instruction sheet. Again, the process generally took ten minutes or less. The same interaction guidelines were followed as in the prior step. Answers to the analysis questions were provided verbally to the researcher and recorded on the session notes form.
- The subject completed their computer-based trial by closing the application. The researcher stopped and stored the recorded CamStudio file with the subject name and date.
- The subject then completed the PSSUQ questionnaire. Subjects were encouraged to provide comments in addition to ratings. Note: In a few early cases, subjects did not read the questionnaire closely, and reversed the 1 to 7 scale for answers (which has 1 as strong agree or best answer, 7 as strong disagree). Three

questionnaires were completed in this way, and subjects initialed their questionnaires to indicate that their entries should be reversed in data assessment. After this, the researcher reminded the subjects that a rating of 1 was a strongly agree rating and a rating of 7 was a strong disagree rating prior to their filling out the instrument.

- The researcher thanked the subject for their participation, recovered all forms from the subject, and then released the subject.

Participant General Instructions: As presented above, all subjects received a similar introduction to the test and guidance to use of the questionnaire. Subjects were reminded about task timing, speaking aloud regarding their observations or issues, and they were asked not to discuss the test content with anyone who was planning to participate in the two test sessions. All materials from the test were to be returned to the instructor at the end of the session.

Participant Task Instructions: Tasks were presented via a task instruction sheet – participants had no prior knowledge of the tasks unless it was from their initial test session. The tasks represent the use cases the system was designed for, and also a mix of inter actions. In data entry, users were asked and modify integer, real, percentage, and string data. They were also asked to make connections between simulation network items and to delete network items, as well as naming the output data set from the simulation. In analysis, the users worked with both tabular and graphic displays. In tabular data they were asked for a mean, a minimum, and a specific value from one of the several data categories and summary statistics presented. From the graphic data displays they were asked to find values on both the x and y axis from graphical displays, as well as comparing two graphs for the highest y value at a given x value.

Usability Metrics: A series of usability metrics were collected, both qualitative and quantitative for the study tasks performed. For data entry, the quantitative measures include:

- Seconds for all tasks
- Seconds for factory entry task
- Seconds for distribution center entry task
- Seconds for run set modification task
- Errors in data entry for all tasks (includes incorrect numeric entries, or completely incorrect text entry - spelling or capitalization misses were not considered errors)
- Errors in the factory entry task
- Errors in the distribution center entry task
- Errors in the run set modification task
- Data entry task failures (tasks not completed or requiring researcher intervention)

For analysis tasks, the quantitative metrics include:

- Seconds for all analysis tasks
- Seconds for tabular data analysis
- Seconds for graphical data analysis
- Errors in values provided from analysis (rounding or small estimation errors from

reading data from graphs were not counted as errors if it was evident the correct value was intended, based on the researcher's judgment.)

- Analysis task failures

Finally, the PSSUQ questionnaire (see Appendix D) provides 19 quantitative specific usability measures, as well as 4 summary measures (overall usability, system usefulness, information quality, and interface quality). Qualitative measures include the comments from participants written on their PSSUQ forms and observations and notes taken by the researcher during testing. The raw data, organized for analysis, is presented in Appendix T for review.

Data Analysis: Details of the data analysis process are discussed in the following Experimental Data Analysis section.

Results: The results of the test cycle will be discussed in detail in the Experimental Data Analysis, Findings, and Conclusions sections of this document. In summary, for data entry, of the nine measures used, six had significantly different means at a 90% confidence level or better – four showing the improved interface to be more effective, two showing the basic interface was more usable. Additionally, one of the nine measures found the improved interface more effective at an 84% confidence level. For analysis, of the five measures taken, two measures found the improved interface had better usability at a 90% confidence level or more. Another found the improved interface more effective at an 89% level, and a fourth at an 83% level. All the questionnaire measures, including the 19 individual measures and the four summary measures found the improved interface more usable at a 97% confidence level or better. Most mean differences between measures were at least 1 point different on the 1 to 7 scale from the PSSUQ.

In addition, the data analysis looked at data values paired by participant to determine if there was any effect on measures if a participant used the basic or improved interface first in the testing series. Seven measures showed a 90% or better significance of difference in mean score due to the order of testing. Four of these were in data entry and analysis, where using the first interface and then the second resulted in lower (better) mean measures (i.e. better performance) than the reverse order. Also, users of the second interface before the first rated mean scores for three usability questionnaire measures lower (better) at a 95% confidence level. Comments on qualitative measures and other findings will be discussed in sections to follow.

Stage 6. Post Experiment Analysis

The intent of the final stage is to assess the results of the experimental testing. In this case, the final study report includes an analysis with the study's results, findings, and conclusions. Specific deliverables include the statistical analysis of the quantitative experimental data, discussion of qualitative measures and observations, the assessment of the study's bearing on the original research questions and hypotheses, and a discussion of follow-on research suggested by what was learned.

Experimental Data Analysis

Quantitative Measures

In total, 37 quantitative measures were collected in the stage 5 subject-based usability testing – nine for data entry, five for analysis, and 23 for the usability questionnaire (19 individual values and four aggregate summary values). The data counts range between 94 observations (two trials per subject, 47 trials for each interface) down to 70 observations (some individual questionnaire values were marked as n/a or no answer).

The analysis began by collecting all quantitative measures in a Microsoft Excel data file. This was a two step process, consisting of automated data extraction and manual data extraction. Utility C# programs were written to pull quantitative measures out of the 94 subject log files and extract them into comma separated lists to bring the data into Excel. Then the researcher analyzed each of the 94 session notes forms by hand to check for task completions and analysis values, which were also entered into Excel. As well, each of the 94 completed PSSQC forms was entered into Excel by hand. The data is categorized by trial number, subject number, interface tested, and first interface tested. The raw data, as imported into Mathematica, is presented in Appendix T.

Using Mathematica 7 as a statistical analysis tool, the initial analysis process began by importing the Excel data and generating summary statistics and basic graphical data analysis. Summary statistics included count, minimum, 25% quartile, median, 75% quartile, and maximum as well as mean, standard deviation, and variance. This was initially performed for all data and then for the data binned by interface (basic = 1 or improved = 2). An online statistical analysis handbook (National Institute of Standards and Technology, 2010) suggested a number of Exploratory Data Analysis (EDA) graphical methods, including box-whisker plots, sorted list plots, histograms, and quantitative methods.

From this view of the data and the desired hypothesis tests, it was clear there needed to be hypothesis testing on the difference in means between the two interfaces for each of the measures. Also, the experimental design applied was a within-subjects model (Leedy & Ormrod, 2010) that tested half the subjects with one interface first, and the others with the remaining interface. There was an attempt to reduce any “learning” effect by keeping the interface tests at least a week apart. It seemed important to look for any issues with the within-subjects approach by examining the effect of the first interface tested on the means for each measure.

At this point, with the permission of the committee, the researcher consulted a practicing statistician for additional guidance. After some discussion and trial analyses, the following tests were finalized and performed - for each data set, descriptive statistics were calculated, a box-whisker plot was generated, and an ANOVA (analysis of variance) was performed to find a p-value significance level for the difference in the means in question.

The box-whisker plot was chosen as the primary graphic display due to its clarity in showing differences in the shape of distributions as well as outliers. The plot method provides a useful way to compare locality, spread, and symmetry for data sets with the same units (du Toit, Steyn, & Stumpf, 1986). In addition to the descriptive statistics and graphics, an ANOVA (or Analysis of Variance) was run for each data set. The ANOVA, recommended as a hypothesis test (Leedy & Ormrod, 2010), is a general technique to test the hypothesis that two means are equal (assuming a normal distribution). The ANOVA includes an F-test statistic to test the equality of means, and the Mathematica ANOVA implementation also provides a p-value for significance; the p-value can be interpreted as the significance of the F-test statistic, providing a confidence level for the difference in means (National Institute of Standards and Technology, 2010).

For each data measure, four data sets were prepared for the combined summary, graphical, and ANOVA analyses:

- All data – includes all data, using factors interface (with levels 1 – basic, and 2 – improved) and first interface (also with levels 1 – basic and 2 – improved).
- Paired data – subtracts the measure for interface 2 from that of interface 1, using only first interface as a factor.
- Trimmed all data – drops the largest three and smallest three values from the “all data” data set in order to look at the possible effect of outliers.
- Trimmed paired data – drops the largest three and smallest three values from the “paired data” data set in order to look at the possible effect of outliers.

As described above, as an outlier control measure, data analysis was performed on so-called trimmed data, defined as data with the highest three and lowest three values of observations dropped from the data set. Generally, this had little positive change in significance of mean differences, so the trimmed data values are not being considered for the overall analysis assessment. Detailed views of the data analysis performed are found in Appendixes U1, U2, and U3. In addition, summary tables of significance values and means are provided in Appendix V. Mathematica code for the data analysis is in Appendix W. Findings from review of the data analysis will be discussed below and in the study conclusions.

Qualitative Measures and Observations

There are several sources of qualitative measures and observations. There are notes and materials from the stage 3 paper prototyping sessions, notes and materials from the stage 4 heuristic analysis sessions, and the researcher's notes and participant's comments from the stage 5 usability tests. Of these, the heuristic notes are collected in Appendix P and the participant comments are collected in Appendix X. All the qualitative data collected contributes directly to develop the following findings and conclusions.

Findings

One respected guide to usability tests describes results as documenting the data that is collected and analyzed and findings as inferences drawn from observations along with data analysis (Rubin & Chisnell, 2008). The prior sections have discussed the results of the testing stages of the study, while this section will focus on inferences drawn from the quantitative and qualitative data analysis, particularly in terms of how they answer the four primary research questions addressed by this study:

- What are user interface considerations for discrete-event simulation models?
- What are best practices for designing an interface to a simulation application?
- How is usability best evaluated for simulation interfaces?
- What is the actual effect of increased usability for specific interface elements on simulation operations, such as data entry and solution analysis?

The stage 1 and 2 activities were centered on exploring the literature space around usability and discrete-event simulation and for developing an understanding of the user requirements for the example simulation system. The literature examination was enlightening, exposing many supportive references and studies around both discrete-event simulation development and usability assessment. This included the review of several standard sources on discrete-event simulation development methodologies reviewed (Banks, et al., 2010; Fishwick, 1995; Law, 2006, 2007; Ross, 2006) and assessment of a numerous individual simulation studies. This assessment, discussed in the study justification, found that although interface development was a key aspect of many simulation studies, usability design or assessment methods were rarely applied. This paralleled prior studies calling for usability process improvement in general software development of interfaces (Redish, 2007; Seffah & Metzker, 2004).

From the usability literature, there were many supportive references that provided potential answers to the first three research questions around simulation considerations, design best practices, and assessment methods. Many studies are discussed in the literature review, but the following references are of particular interest for key topics:

- Challenges of integrating usability into software development (Friess, 2008; Greenberg & Buxton, 2008; Holzinger, 2005; Juristo & Ferre, 2006)
- Justification for usability improvement efforts (Bias & Mayhew, 2005; Marcus, 2002)
- Usability considerations for simulation (Kuljis, 1996; Ören & Yilmaz, 2005; Pidd, 1996)
- UML-based interface and application design (Fowler, 2004; Maksimchuk & Naiburg, 2005; Phillips, et al., 2001)
- Information presentation and visual design (Mullet & Sano, 1995; Tufte, 1990, 2002a, 2002b, 2006)
- Interface design practices and guidelines(Apple Inc., 2008; Bailey, et al., 2006; Cooper, et al., 2007; Galitz, 2007; Microsoft Corporation, 2007; Tidwell, 2011)
- Usability design processes and life cycles (Constantine & Lockwood, 1999; Cooper, et al., 2007; Hackos & Redish, 1998; Mayhew, 1999; Shneiderman, et al., 2009; Usability Professionals' Association, 2000)
- Prototype design and assessment (Buxton, 2007; Snyder, 2003)
- Heuristic evaluation and related assessment methods (Hollingsed & Novick, 2007; Holzinger, 2005; Mankoff, et al., 2003; Nielsen, 1993; Nielsen & Mack, 1994)

- Usability test measures, procedures, and reports (Carter, 2007; Dumas & Loring, 2008; Dumas & Redish, 1999; Molich & Wilson, 2008; National Institute of Standards and Technology, 2001; Rubin & Chisnell, 2008; Tullis & Albert, 2008)
- Usability surveys and questionnaires (Dumas & Redish, 1999; Lewis, 1993; Rubin & Chisnell, 2008; Tullis & Albert, 2008)
- Mathematica-based development and use (Blachman, 1992; J. W. Gray, 1998; Maeder, 1991, 2000; Trott, 2004; Wellin, et al., 2005; Wolfram, 1996)
- Mathematica-based simulation development and interfaces (Abudiab, 2002; Abudiab & Starek, 2003; Bergstrom, 1999; D'Apice, et al., 2000; Gaylord & Wellin, 1995; Savory, 1995)
- C#-based development (Albahari & Albahari, 2007; Hilyard & Teilhet, 2008; Liberty & Xie, 2008; Maiani, et al., 2002; Microsoft Corporation, 2009; Sells & Weinhardt, 2006; Troelsen, 2007; Wagner, 2010)

In these early stages, the demonstrated use of UML for modeling interfaces and simulations proved to be both natural and effective. Visual UML models provide a concise format for documenting and sharing information with other designers. Maksimchuk and Naiburg (2005) was a particular influential guide for this work, with extremely practical guidelines for effective modeling. As an example, the guidelines for developing use cases are particularly thorough and practical: they present an acronym, WAVE, for summing up use case best practices – what (not how) is the system doing, actor’s point of view, value provided to actor through the use case, and entire scenario described by case or cases (Maksimchuk & Naiburg, 2005).

The suggested UML extensions for user interface design (Phillips, et al., 2001), such as tabular representations leading to UML cluster diagram, were not employed directly in stage 2, as the initial UML models and task templates seemed sufficient to initiate the stage 3 work. However, an approach similar to the tabular model in Phillips et al. was used interactively on paper designs produced during the initial stage 3 paper prototyping session. The UML UI models were captured more formally following the session, and their use is believed to have resulted in a more direct and effective translation from the models to the user interface prototypes. This supports the statements that such use models are more necessary for complex designs, and that early detailed assumptions from use models support finding issues in the design process sooner (Brooks, 2010).

The paper prototyping activities in stage 3 of the study illustrated the benefits of a process-based iteration toward a prototype. Beginning the first session with only basic UML descriptions and task details (Appendix J), four participants were able to develop a fairly detailed set of paper prototypes (see Appendixes N and O) and perform basic usability validation of the designs against the expected tasks in three 90-minute sessions (with outside work to capture and clarify the design decisions made in the meetings. The exercise was deemed practical and productive by the participants, and could be easily implemented by brief study of the published process guidelines (Snyder, 2003).

Because of the study goals, it was necessary to include a somewhat artificial step to develop two interface designs in the stage 3 prototyping, a basic interface that would be expected from someone with development skills but limited usability or interface design experience, and an improved interface that took into account all usability considerations and experiences available. Looking at examples of actual simulation projects (Chen, et al., 2002; Heilala, et al., 2007; Herren, et al., 1997), there was debate over the use of a spreadsheet, visual programming, or form basis for the interfaces. The team decided forms were the most likely decision for a less experienced designer, and then debated whether a tabbed interface or a menu-based interface to multiple forms would be selected. Again, it was decided that a tabbed interface might be more challenging for a developer of less experience, so the basic interface became a collection of forms.

While the resulting designs were agreed upon by the participant designers and the researcher, one particular comment made by a participant would turn out to have usability implications later. The comment was that the basic interface, with its simple forms and single flow of control through the tasks, may act as a "wizard" style interface, and prove to be easier to use than expected. At the time, this was seen as unlikely due to some of the obvious usability issues seen (or allowed) in the basic form designs, and the high level of usability improvement focus on updates for the improved interface. In the stage 5 testing of the applications with actual users, these comments would be further borne out, and were echoed in some data and comments on subject questionnaires.

The stage 4 heuristic assessment was also seen to be an effective exercise by the researcher and participants, both in terms of the effectiveness and thoroughness of the process, the applicability of the heuristics used, and in the resulting positive design changes. The evaluation process was applied in turn to a high-fidelity computer-based prototype of both the basic interface and the improved interface. There was a significant volume of findings (documented in Appendix P) from the sessions, although many of the usability issues identified in the basic interface were not adjusted per the study parameters.

The process of the heuristic assessment and the related discussions resulted in some fairly significant design change for the improved interface. As presented in the assessment, the improved design included a main form with a simulation browser, breadcrumb navigation, simulation status, and a command history (see Appendix Y). A secondary form for run set included a graphical view of the simulation network and an input form for run set parameters. The participants in the second session reviewing the design felt that the status and history provided little value, and that the network display would be more effective as part of the main form that users had open continuously during their interactions. They agreed that the visual depiction of the network, and the ability to access each network element from that screen, provided the best paradigm for interacting with the simulation network, and other supporting functions could potentially be eliminated. The changes based on their suggestions were implemented in the final working version of the improved interface (Appendix Z).

A note on implementation of the interfaces, at this stage and in follow on stages, there was a need to consider many guidelines in the development of the operating application – UML models and tasks descriptions, several supporting design and style texts, reviewer observations, summaries of key simulation characteristics, and other notes and sources. The interfaces developed earnestly used these guidelines to the fullest extent possible, but as would later be seen, issues were missed that impacted later usability. One suggestion for further research would be a single source for user interface elements focused on usability concerns for a simulation environment (or even generally), perhaps developed in a form similar to an interface patterns book (Tidwell, 2011) or a guideline approach (Bailey, et al., 2006), or perhaps in a version of a heuristic analysis of specific interaction elements. Having a more concentrated (or possibly automated) review approach for specific user controls would be a great benefit to ensuring issues are addressed.

The resulting designs changes for the improved interface from the heuristic assessment session certainly provided a more useable and focused interface approach than the initial proposed prototype. However, in hindsight, it would likely have been beneficial to iterate back through the heuristic assessment of the updated displays from the initial stage 4 heuristic assessment. At the time, the staged process flow directing study activities did not call specifically for this iteration. This is discussed later as a weakness in the study methodology, as these design changes resulted in introduction of some unexpected usability issues that were observed during the stage 5 subject-based testing. In practice, such iteration is seen as a key contributor to usability growth (Bailey, 2005).

The goal of the multi-stage approach put in practice in this study was to allow each process to provide its maximum impact on discovering usability issues. The supporting literature discusses the need for multi-stage application of different methods in order to ensure such issue discovery (Hollingsed & Novick, 2007; Holzinger, 2005). The stage 5 subject-based assessments supported this approach by uncovering numerous issues not previously exposed with each interface. However, this also exposed a weakness of the study protocol, discussed in the study conclusions to follow, in that the stage 5 testing was to be run against all subjects to assess usability improvements but did not allow for iteration to both expose and correct any issues found. In essence, the usability comparison of the basic and improved interfaces would be based on usability improvements and design from only the first four design stages, but the designs, particularly the improved design, would not benefit from correction of issues found during subject-based testing.

Regardless of this process error, the stage 5 usability tests were effective in several ways. First, the tests did generate significant amounts of qualitative and quantitative data to show the impact of the usability improvements on simulation operations. The testing also illustrated the effectiveness of user-based testing. Several characteristics of user-based testing noted in the literature were demonstrated in this cycle, including the value of pre-testing (Rubin & Chisnell, 2008), the early discovery of primary usability issues with few users, and the challenges and impact of the think aloud mechanism for subjects.

The pre-testing performed by the researcher and pre-test subjects allowed for modification to test instrument correctness, tuning of test timing, identification of defects in the operation of the interfaces, and development of confidence in application of the test procedure. It was suggested that the pre-test (or pilot testing) be done with subjects at the lower end of the expertise scale to ensure that time allowed for interactions was sufficient (Rubin & Chisnell, 2008). This was a valuable suggestion: tasks were adjusted so the relatively inexperienced pre-test subjects were working at approximately ten minutes per phase, in practice, the more computer-literate population of testers varied between five and ten minutes per phase, so testing could complete on time.

As predicted by literature (Krug, 2006; Nielsen, 1993), within the first few test cycles of three to four users, most of the major interface usability issues remaining were evident. For the basic interface, this included many intentional issues, such as lack of units or data authentication in data entry, or cut-off labels for tabular displays. But other unexpected issues were also found – a combination pull-down and text entry box control was used in the basic interface to provide a name for the run set. This particular control confused many users, to the point of their being unable to continue without being told to type a label into the box.

In the improved interface, there were many unexpected usability issues discovered fairly quickly. (Images from the interfaces are included in Appendix Z.) The issues discovered included:

- Lack of design consistency – many of the functions that were menu based on the basic interface were now only accessible via right-click menus on a tree control or visual network objects. While this was an intentional simplification, some subjects had difficulty finding selected interactions.

- Mode-switching – the user might begin working with the visual network objects, but not all functions could be accessed from there, requiring the user to move to the tree control or to menus. A stronger usability design would allow the user to stay within a selected interaction mode for all operations.
- Tree control – this control was not as obvious to all the subjects as it was to the form designers. In retrospect, there is mention that this control can be problematic when the information presented does not naturally fall into a tree representation, and that the control, although becoming more familiar, can be problematic for some users (Cooper, et al., 2007).
- Direct manipulation of the graphical simulation network vs. checklists – the basic interface allowed adding and dropping objects from the simulation network via checklists – in the improved interface, the checklists were removed in favor of direct manipulation of links between visual network objects. Even with on-screen help text, this operation was not clear to some users, and proved to be a slower operation than the checklist-based selections. This was responsible for a difference of approximately 50 seconds in mean completion rates between the basic and improved interfaces, one of only two significant measures where the basic interface proved superior.
- Misreading similar labels/poor field positions – the second issue where the improved interface performed significantly worse than the basic was in data entry for the run set form. The form consists of a single column of data entry fields, and the subject's task was to update some, but not all, of the fields. The four fields were, in order, "Old Part Count", "New Part Count", "Old Fail Rate", and

"New Fail Rate", and the user was to update "Old Part Count" and "New Fail Rate" with new values. In many cases, users updated the "Old Fail Rate" field rather than the "New Fail Rate" field. While these fields were designed per guidelines (Jarrett & Gaffney, 2009), there are likely alternate arrangements and labeling that would provide better results.

- Error indicators – unlike the basic interface, the improved interface placed a red error indication icon next to any field whose entered value was out of bounds or otherwise incorrect. The indicator (a C# errorProvider control) automatically flashed a few times when first shown, and then stayed on next to the field. Moving the mouse over the icon would display the error message. Unfortunately, the design decision was made to allow the form to close whether errors were corrected or not, with the intent being to allow incremental updates if needed. Many subjects simply ignored the error indicators and saved their data regardless, or, in looking at their task instructions, did not see the indicator appear and flash. Alternate approaches for this issue would have likely have positively impacted interface error rates significantly.

Other usability issues were noted by the researcher's observations, comments to the researcher by subjects, or from subject's PSSUQ questionnaires (see Appendix D).

- Even when stuck on a particular task, subjects rarely used the help system. In some cases, when help was used, the answer being sought was not clearly provided.

- Although provided in the improved interface, redo/undo functionality was rarely used – some subjects would close a form and re-open it to start entries new.
- An intentional usability issue in the basic interface, not alphabetizing the tabular or graphical data labels, was unintentionally missed in the implementation of the improved interface until subject tests began. The analysis tools in the improved interface still outperformed the basic interface, but this was an often mentioned issue from subject observation.

There were usability changes to the improved interface that seemed particularly effective, including widespread use of tooltips, default values, a clear model representation, consistency of form behavior and control placement throughout. In the tabular data analysis tool, row striping, "sparkline" graphs (Tufte, 2004), a static first reference column, and coordinated scrolling of data and statistics were improved features. In the graphical analysis, the addition of optional minimum and maximum bound lines, the use of grid lines, and multiple data sets displayed on a single graph were appreciated by subjects.

There was also evidence of learning, something that the experimental design was intended to reduce. The two tests each subject had to perform, one basic, one improved, were staged to be a week or more apart. Yet it was clear that many subjects were bringing in knowledge or approaches that they remembered from their first test cycle. Subjects using the basic interface first, would often look for menu based options in the advanced interface, but the advanced interface had more limited menu-based functions.

Subjects who first worked with the improved interface would often look for ways to multi-select graphs in the basic graph analysis interface (by holding down shift or control when selecting from a list), although no such option existed. In both cases, subjects who had had difficulty with tabular data, finding summary statistics or scrolling for off-screen values, would go directly to the correct locations in their second trial.

Observations of these types of issues that indicated some learning may be occurring led to the data analysis of paired data to see what effect a given first interface had. Interestingly, subjects testing the basic interface in their first trial had significantly lower overall data entry errors in three categories – overall, factory, and distribution data entry. There is no clear cause for this; perhaps subjects who had worked with the basic interface first took more care with entries in their interaction with the advanced interface. The subjects using the basic interface first also had a better mean time, by over a minute, to complete analysis tasks than those who did analysis with the improved interface first. This may indicate that the relative ease of the improved interface for analysis caused the basic interface to be even more problematic for subjects encountering it during their second trial; again, it is not known what the specific cause is. Finally, in three categories (effective task completion, expected functions available, and overall system satisfaction), subjects who used the improved interface first gave these questionnaire measures significantly lower (better) ratings, in each case by approximately one step on the one to seven rating scale. It is possible that the usability improvements in the improved interface gave the users a higher sense of satisfaction, which lead to the overall better scoring, but there is no clear explanation. What is clear is there was some impact on scores in these areas based on the order of testing, and that effect would have to be looked at for future experimental designs.

It is noted that for comparison studies of interfaces, such as this one, the impact of asking users to "think aloud" can affect completion times, as can the style of interaction used by the moderator (Dumas & Loring, 2008). In this study, while subjects were encouraged to think aloud at the beginning of the test cycle, the researcher minimized all other contact during the test cycle, generally only asking "what are you thinking now" if the subject seemed to be stalled. With awareness of the timing constraints, the researcher kept interactions to a minimum in all trials, and this is not expected to have a significant impact on the assessment of the times recorded.

There was significant variation among subjects to their attention to the questionnaire. Some subjects filled in the same answer on every question, making no comments. Some subjects provided detailed commentary, asked questions about the definition of questionnaire topics, and provided extensive comments. Many subjects asked about cases where they wanted to answer not applicable, for instance, regarding error messages if none were encountered (or at least recalled). Because of the sizable sample size for the study, these variations are expected to have a uniform impact, and the usability measures gathered should be accurate.

One of the key strengths of this study is the subject-based tests and the resulting data analysis, which will support an answer to the last of the research questions: What is the actual effect of increased usability for specific interface elements on simulation operations, such as data entry and solution analysis?

For the final study stage, the data analysis, the findings are fairly clear: of 37 individual usability measures, only 6 did not meet at least a 10% confidence level in the difference between mean value between the basic and improved interface. A summary of the data values – p-level significance and means – are shown in Appendix V. It is important to note that for all data provided, a lower value is a better result, this includes questionnaire values (from a one-to-seven scale, one being strongest agreement), task times, entry errors, and task failures.

For data entry, two measures – seconds for distributor data entry and errors in run set entry proved superior in the basic interface design. As discussed above, this is seen as a result of specific usability issues that were not discovered until subject testing began, when unfortunately there was no iteration planned to respond to discovered issues. All other significant data entry measures (seconds for run set data entry, data entry errors for factory and for distributor, and data entry task failures) were lower (better) for the improved interface. This data results in a mixed outcome for the data entry assessment, with usability issues seen in subject testing that would likely improve scores had they been addressed within the study protocol.

The results for the improved interface in analysis are stronger. Of five measures, two (the time for table analysis, and the number of analysis value errors) are significantly stronger for the analysis task. Analysis task failures, with a p-value of .104, is just outside of the 90% confidence limit, as is overall time for analysis, with a p-value of .172 which meets an 82% confidence limit. Only one measure, seconds for analysis on the graph, is far from significant with a p-value of .79. In general, this implies that the process was effective for the design of the analysis elements, although again, observed usability issues during subject testing, if corrected, would likely improve the results.

The results of the PSSUQ questionnaire (Lewis, 1993) are very clear. In all individual measures and summary measures, the improved interface scores significantly lower on the one (strongly agree) to seven (strongly disagree) scale used in the survey. In almost every category, the improved interface scores one point lower, or better, than the basic interface. The scores for the improved interface in the various survey categories have values from 1.63 (effectively complete tasks) to 2.67 (clear error messages), with a score of 1.96 for overall interface quality. For the basic interface, the lowest mean value is 2.31 (could be productive quickly), the high value is 3.64 (clear error messages), with an overall interface quality score of 2.78.

Summary of Results

Results are presented in terms of the study stages where the results were produced. The stage 1 and 2 processes resulted in collection of guidelines, practices, and initial use models that described the interface, the simulation, the assessment and design processes, and the experiment. Stage 3 paper prototyping resulted in a series of low-fidelity paper prototypes improved through iterative design based on usability assessment of tasks planned for the interfaces. Stage 4, the heuristic assessment, examined the usability of the high-fidelity interface prototypes, resulting in detailed assessment input and revised designs for the operational system. Stage 5, subject-based usability testing, resulted in collection of both qualitative usability issues and quantitative assessment data, including time on task, error rates, task failures, and usability assessment measures from a pre-validated usability questionnaire. Stage 6 provided analysis and consideration of the findings from prior stages, resulting in the study findings and conclusions. Quantitative measures found mixed usability results for data entry, generally positive results for analysis, and completely positive measures for user satisfaction. Differences in mean levels of measures were statistically significant in 31 of 37 measures. Of these, two significant measures found the data entry basic interface had superior usability (this is validated by observed usability issues unaddressed in the improved interface). In all other measures, support was for the superior usability of the improved interface (four measures for data entry, two for data analysis, and the remainder for user system satisfaction ratings).

Chapter 5

Conclusions, Implications, Recommendations, and Summary

Conclusions

Hypothesis Support/Rejection

The following is a restatement of the core hypotheses being examined in this study:

H(1) If a simulation-focused usability design process is applied to the data entry aspects of a simulation interface, there will be significant reduction in data entry time, interaction errors, and task failure rates.

H(2) If a simulation-focused usability design process is applied to the results analysis elements of a simulation interface, there will be significant reduction in analysis time, incorrect result reporting, and task failure rates.

H(3) If a simulation-focused usability design process is generally applied to a simulation interface, there will be significant increases in user satisfaction measures, including overall satisfaction, system usefulness, information quality, and interface quality.

The experiment encompasses the following independent variables:

IV(1) Simulation interface data entry element design. Data entry will have two levels – basic and improved.

IV(2) Simulation interface results analysis element design. Results analysis will have two levels – basic and improved.

IV(3) Simulation interface support element design. Support elements will have two levels – basic and improved.

IV(1), IV(2), and IV(3) were represented experimentally by the basic and improved interfaces developed in stages 1 through 4 of the study.

The experiment encompasses the following dependent variables:

DV(1) Data entry performance. Measures will include data entry time, interaction errors, and task failure counts.

DV(2) Results analysis performance. Measures will include analysis time, result errors, and task failure counts.

DV(3) Overall user satisfaction. Measures will include scores for overall satisfaction, system usefulness, information quality, and interface quality.

Data was collected during the stage 5 of the study in a designed experiment, and analyzed in stage 6 of the study. DV(1) is represented by four measures of data entry time, four measures of data entry errors, and one measure of task failures. DV(2) is represented by three measures of data entry time, one measure of result errors, and one measure of task failures. DV(3) is represented by four measures for overall satisfaction, system usefulness, information quality, and interface quality. These four measures are aggregates of 19 measures of individual usability properties. It should be noted that for all collected measures (time on task, errors, task failures, survey measures), a lower value is a more positive result.

Data analysis is summarized in Appendix V (and presented in detail in Appendixes U1, U2, and U3). Hypothesis acceptance will be based on 90% confidence levels, that is, the p-value for ANOVA F-tests of difference in means must be .10 or lower to be deemed significant. This leads to the following assessments:

The results for H(1), improved data entry, are mixed (see Figures 5 and 6 below). At the 90% confidence level, two DV(1) measures found significant improvements in the basic interface, and four DV(1) measures showed significant improvement in the improved interface. Given this mixed result from data analysis, the H(1) hypothesis that the process as proposed improves data entry cannot be completely accepted based solely on the analysis data. However, after examining all results, and particularly the exposure of specific usability issues in the stage 4 testing, it is clear that the process to create the IV(1) lacked necessary iteration in the stages 4 and 5 (heuristic assessment and subject-based usability testing) to bring the usability to the required level. Were this process corrected, it is likely, but not certain, that improved results would be demonstrated.

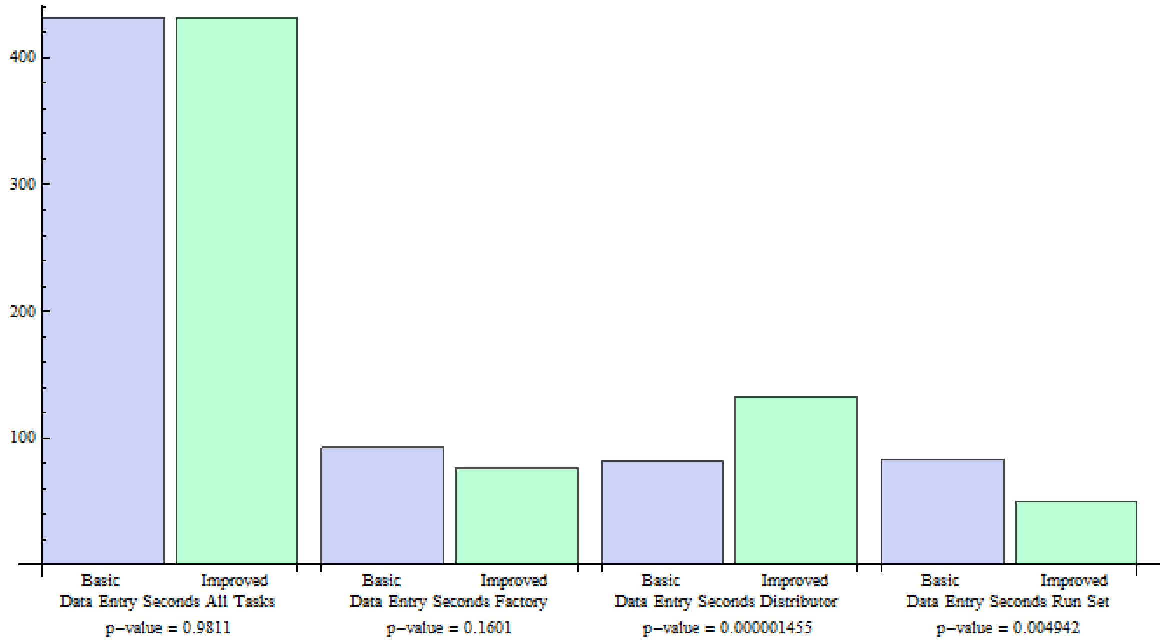

Figure 5. Comparison of results for basic and improved interface data entry times.

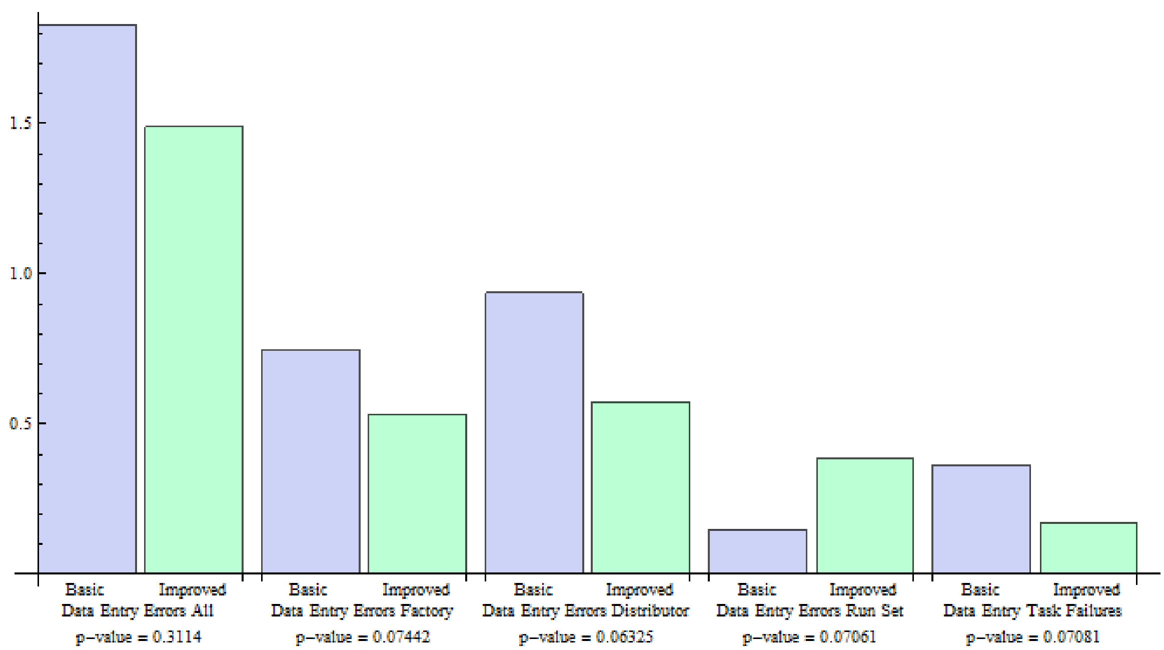

Figure 6. Comparison of results for basic and improved interface data errors and task failures.

The results for H(2), improved analysis, are more positive (see Figures 7 and 8 below). Of the five measures, two were significant at a 90% confidence level for the improved interface. Two others were significant for the improved interface at fairly high levels, with p-values of .104 and .172, however these do not meet the significance test. None of the measures indicate any significant improvements for the basic interface. Based on this data analysis, there is significant support to accept the H(2) hypothesis, that the usability process improved the analysis measures. Again, observed usability issues during stage 5 testing would indicate further process improvement is possible, and would likely strengthen the results.

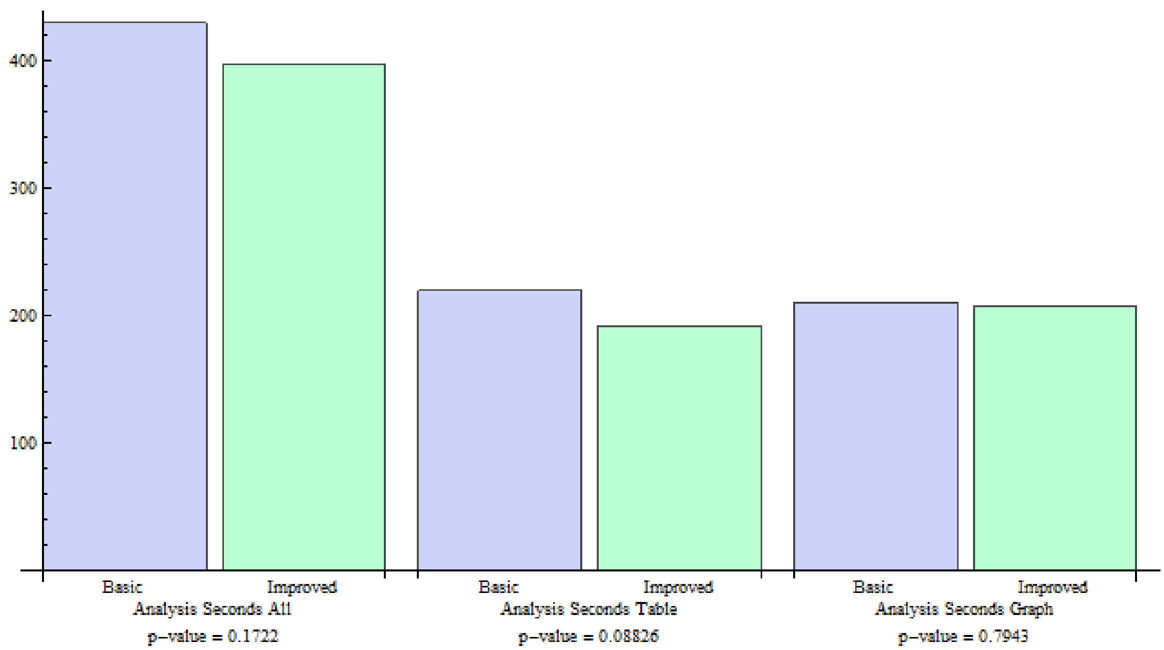

Figure 7. Comparison of results for basic and improved interface analysis task times.

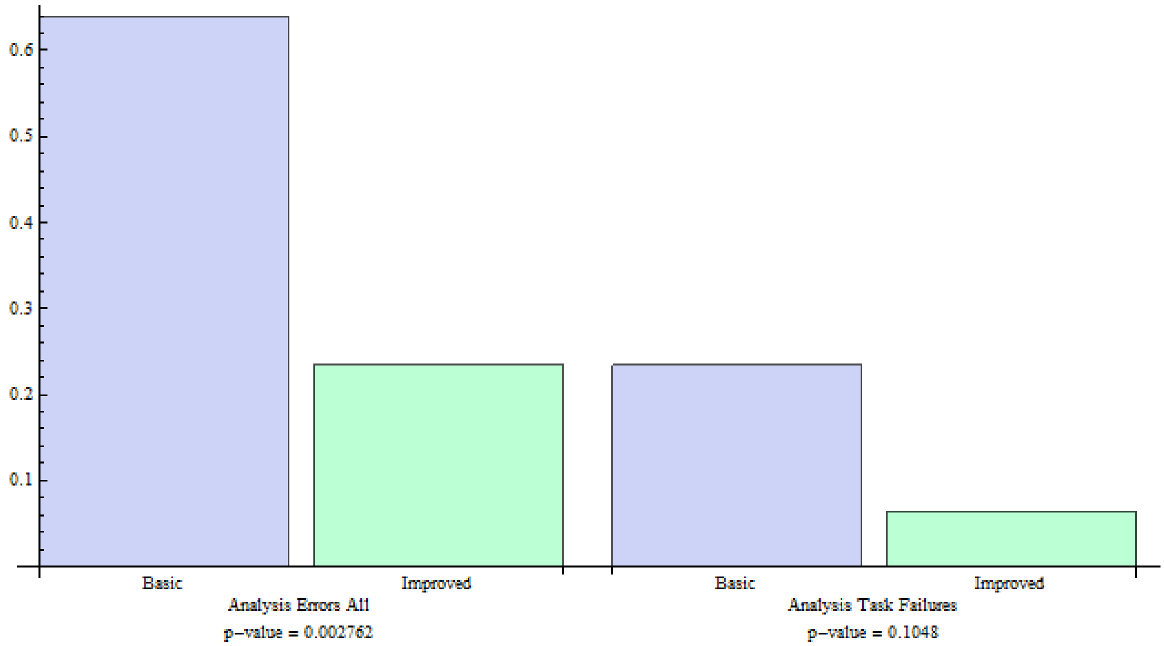

Figure 8. Comparison of results for basic and improved interface analysis errors and task failures.

Results for H(3), assessment of overall user satisfaction, are solidly positive (see Figure 9 below). All four aggregate measures, as well as all 19 individual measures drawn from the survey instrument, indicate a solid improvement in perceived usability for overall satisfaction, system usefulness, information quality, and interface quality. Based on the data analysis, there is significant support to accept the H(3) hypothesis, that the usability process improved overall user satisfaction. To temper this however, it should be pointed out that the difference in mean satisfaction was approximately 1 point for all measures based on the 1 to 7 ranking scale used in the survey instrument, a difference of approximately 14%. It is still seen as likely that usability process improvements to address observed usability issues would further strength these results.

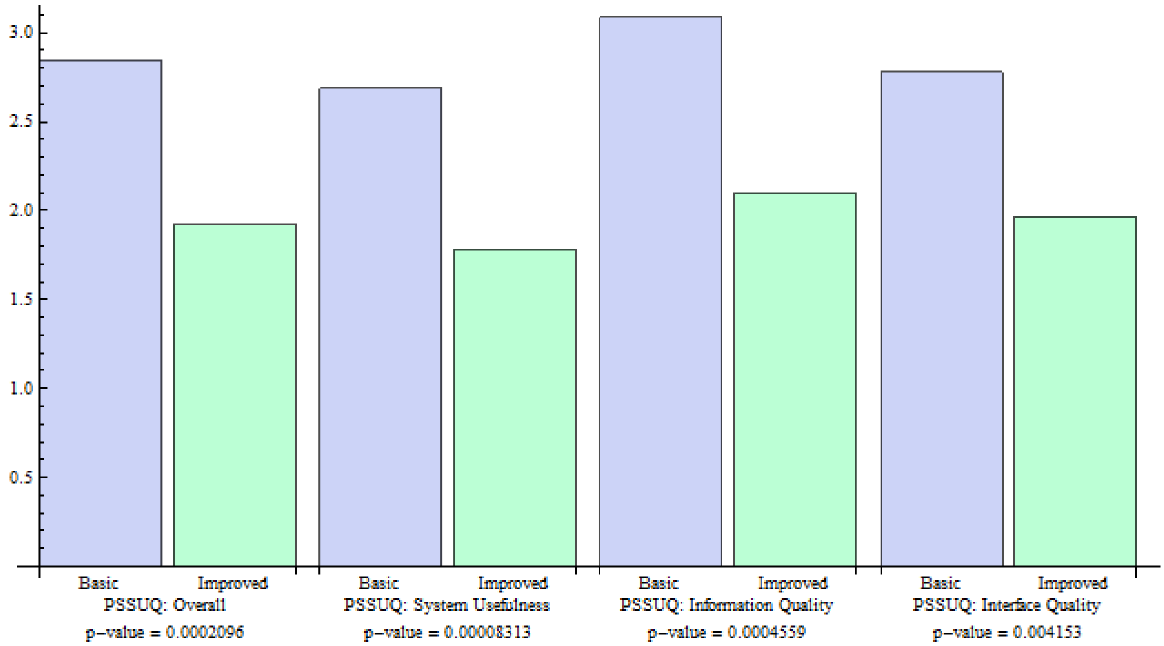

Figure 9. Comparison of results for PSSUQ (Lewis, 1993) aggregate measures.

Alternative Explanations of Results

Given the relative strength of the experimental structures, the sample sizes and the significance level of accepted measures, the conclusions drawn from the results are likely correct. However, correlation is not causation, and it is possible that other factors have impacted these results. Nevertheless, the data analysis supports the observed results and qualitative assessment, and seems to imply that there is value to the usability processes in terms of analysis improvement and user satisfaction, although uncertainty in the data entry results makes that claim harder to support.

Strengths, Weaknesses, and Limitations of the Study

Again, strengths of the study include a well reviewed and structured experimental design with a healthy sample size (n=47), a relative high level (p-value = .10) for acceptance of significance, and a solid foundation in current literature research and accepted usability processes.

One clear weakness of the usability process applied in this study was the lack of iteration at the heuristic assessment in stage 4 and in subject-based testing in stage 5 to allow for address of observed usability issues. Each interface was assessed for usability heuristics only once, and resulting updated interfaces were not subjected to a follow on evaluation. This may have resulted in at least some of the unexpected usability issues found during stage 5 subject-based usability tests. Also, as operational interfaces were tested by subjects for the first time in the stage 5, an iteration step with a small number of users to address any obvious usability issues would also have likely improved overall usability. Iteration through usability processes is seen as a key practice, even when the process or the skill set of participants may be less than ideal (Bailey, 2005).

A potential minor weakness may lie in the crafting of the heuristics used in the stage 4 assessment. The heuristics used were adapted from three sources (Green & Petre, 1996; Karoulis, et al., 2005; Nielsen & Mack, 1994) to provide what was believed to be a thorough review of issues. However, the heuristic set applied was not experimentally confirmed in content against others. Many studies exist looking at refinement of heuristics, and a more pointed effort looking at simulation characteristics may be able to develop a set with proven applicability.

The applicability of the study's results is limited to the application space. This study looked specifically at the form of simulation application where a custom user interface is developed to provide data entry, analysis, and other required support for a discrete-event simulation engine. It does not look at custom simulation modeling environments or tools, such as SimEvents (M. A. Gray, 2007), nor does it consider the complexities of distributed simulation usability (Dawson, 2008). Modeling usability processes for those simulation areas is an area for follow on parallel research.

The study has, by necessity, limited scope of the usability process to a selected set of recommended practices. There are certainly other usability design and assessment methods available that may provide benefit in specific to simulation interfaces – including, but not limited to, cognitive walkthroughs, action analysis, field observations, and usability surveys (Holzinger, 2005). Applicability of these approaches are left to follow on research as well.

It is possible that there are limitations introduced due to the skill sets of the researcher, his volunteer designers, and the subject population. For instance, the help system developed was based on the researcher's expertise, and not that of a professional help system developer. However, all participants were considered for their capability to participate. Subjects were screened and seemed representative for the terms of the study.

A final limitation is the selection of the measures collected to assess usability. While time on task, task errors, task completion, and survey assessments are standard measures, there are other potentially effective measures, depending on specific goals of the testing. These other measures include efficiency, learnability, usability issue capture, self-reported metrics, behavioral and physiological, combined an cooperative metrics, live application metrics, and card sorting for navigational assessment (Tullis & Albert, 2008).

Overall Conclusions

It is easy to be disheartened at the inability to conclude to completely and strongly support the three hypotheses that are the basis of the core study experiment. It was also somewhat disappointing at first to see the appearance of usability issues in the improved interface during subject-based testing. This led to the realization of a weakness in the proposed usability process, i.e. the need to include design iteration steps in the fourth and stage 5 assessments. However, the disappointment quickly turned to appreciation for the illumination of issues through literature-based research and experimental design and execution. Without such practice and experimentation, there would be no way to validate processes and discover improvements. And regardless of the issues found, there is clear benefit to the research and experimentation performed in this study, and the implications of that work is discussed below.

Implications

Study Impact and Contributions

The original goal of the study was to demonstrate measurable effects of usability design experimentally to bring more focus on including usability design in simulation development. The study makes a good case for this, both in the generally positive support for the base hypotheses, but more so in the in-depth presentation of the effects and effectiveness of the usability design and assessment processes used.

It was also felt the study would provide benefit by identification of usability design and assessment methods that may contribute to effective simulation use and improvement. This has been done, with support, review, and organization of literature sources and associated processes not available in the same form in a single resource.

Finally, the study illustrates use of usability design and assessment methods in a typical simulation development, thus providing some guidance for developers that may attempt to apply or expand on the processes presented. Krug (2010) states that one reason usability is not more widely examined, is because many people do not have firsthand experience. Hopefully, by exposing the typical issues a developer may find in applying a usability process to simulation, the failures and successes of the approaches will have equal value in guiding others performing follow on research or similar development.

It should be noted that the study has had local impact in the researcher's workplace. Usability processes have been created for software teams that include UML use cases and designs, paper prototyping, heuristic assessment, and subject-based usability testing for a variety of applications. There is little question that there will be continuing local benefit from these usability processes.

Implications for Future Research

Given the demonstration of a usability process tailored to this class of discrete-event simulations, the foundation in supporting literature review, the partial success of hypothesis testing to verify the benefit of the usability process to the simulation operations, and the assessment of the experimental approach issues, it is hoped there is sufficient weight to say that if development of a simulation involves an interface design, it should also have a usability design process associated with it. It should no longer be enough to declare that a given simulation user interface is user friendly. A simulation interface should have usability goals, design, and assessment to validate that it provides the benefits of the underlying simulation model to its users efficiently and effectively.

The approach presented in this study should also be expanded to look at usability issues in select simulation-based applications, custom simulation environments and tools, or related areas of simulation-based and other decision support. Adjacent design spaces where applications are impacted by complexity issues in data entry, solution analysis, or similar tasks could also benefit from much of the research presented.

Recommendations

Recommended future research or changes in research methods or theoretical concepts

- Formal UML extension and alternate UML extensions for UI designs, similar to examined extensions (Phillips, et al., 2001).
- Development of checklists for usability issues for typical Windows-based application development elements and controls. This could be done for specific simulation concerns or for usability in general, and could possibly be an automated feature for interface design environments.
- Validated extensions to standard usability heuristics, optimized for simulation usability assessment. This study used a set of modified heuristics, but they have not been validated using an experimental approach (Chattratichart & Lindgaard, 2008).
- A heuristic set based on Edward Tufte's works (Tufte, 1990, 2002a, 2002b, 2006) on visual designs for information.
- Applicability of usability methods not explored here to discrete-event simulation development.
- Usability assessment of self-contained discrete-event simulation tools and environments for specific improvements, including automated support for usability measures and assessment.

- A pattern-based discussion of key interface components that are applied to simulation or complex interfaces with usability considerations, similar to Tidwell (2011).
- Comparisons of effectiveness of error indication styles in data entry.
- The impact of some level of training on usability assessments or comparisons.
- Cross-over studies of visual programming methods and usability with simulation tools and environments.
- Effectiveness of different graphical data representations and support tools on simulation analysis.
- Effective use of sparklines (Tufte, 2004) in simulation application interfaces.
- Alternate interfaces for design development of simulation interfaces – e.g. an automated paper prototype tool (Li, et al., 2010)
- Tools for automating usability assessment of existing simulation projects without modifying the simulation software directly – e.g. plug-in based usability instrumentation (Bateman, et al., 2009)
- Alternate interfaces for simulations (3D, touchscreen, tactile, haptics, etc.)

Recommended changes in practice

The key change that this study calls for is this: to gain the potential benefits of usability methods applied to discrete-event simulation applications, usability methods must become more integrated in simulation design processes. As with calls for general integration of usability into software development (Seffah & Metzker, 2004) or for expanded usability tests of complex systems (Redish, 2007), usability methods should be integrated at basic levels into discrete-event simulation training, classes, curricula, and standard texts, both in industry and academia. Educational programs for simulation developers (such as the doctoral program outlined in Pidd, Robinson, Davies, Hoad, and Cheng (2010)) should review the basic usability approaches that would support their work. Simulation tools should include support for best practices in interface design and usability assessment, including support for key measures such as time-on-task, task success, and frequency of use (Tullis & Albert, 2008). Studies such as this one, as well as others that look at aspects of simulation usability (Dawson, 2008; Kuljis, 1996; Ören & Yilmaz, 2005; Pidd, 1996), provide an outline for the specific usability concerns that should be considered in the effort to provide such support. It is up to usability practitioners and simulation developers to continue to work as partners (Chilana, et al., 2010) to effectively study and improve their processes and products, to the continuing benefit of their users and customers.

Summary

This research outlines a study that was performed to determine the effects of user interface design variations on the usability and solution quality of complex, multivariate discrete-event simulations. Specifically, this study examined four key research questions: what are the user interface considerations for a given simulation model, what are the current best practices in user interface design for simulations, how is usability best evaluated for simulation interfaces, and specifically what are the measured effects of varying levels of usability of interface elements on simulation operations such as data entry and solution analysis.

The overall goal of the study was to show the benefit of applied usability practices in simulation design, supported by experimental evidence from testing two alternative simulation user interfaces designed with varying usability. Evaluating the solutions derived from alternate varied interfaces to a single core simulation provides a quantitative measure of usability importance not available in the current literature. Other beneficial aspects of the study includes identifying which usability aspects contribute to effective simulation use, as well as identifying usability issues specific to those elements, through standard usability assessment. Finally, the study illustrates use of usability design and assessment methods in simulation development, providing some guidance for interested developers.

The methodology for the study is broken into six stages. Stage 1 is focused on user and task analysis and modeling, and includes research into the literature supporting discrete-event simulation and usability methods applicable to simulation design and assessment, as well as selection of the simulation performance measures and usability design, evaluation, and test methods appropriate to the study. Stage 2 is centered on concept and use models, and includes the design of the experiment for testing alternative simulation interfaces, selection of development tools, definition and requirements of the two interfaces to be tested (labeled basic and improved), and definition of a general multivariate discrete event simulation for the experimental phase.

The next three phases involve volunteer subjects for design and test activities. Stage 3 is a paper prototype and usability assessment exercise, based on a standard process (Snyder, 2003). An iterative process, it involves the creation and refinement of paper prototype interfaces, based on the initial definitions from earlier stages, represented by UML models and task templates. Refinement is performed through an initial design cycle and multiple structured usability test exercises, where each participant takes a role in applying the tasks to the prototypes to uncover usability design issues. The results from this stage include refined paper prototypes of the two simulation interfaces to be developed.

Stage 4 testing focuses on the final interface prototypes and their assessment. It involves development of high fidelity computer-based prototypes of the two alternative interfaces, as well as heuristic usability assessment of those prototypes. The heuristic analysis process is based on a standard approach proposed and applied in many usability studies (Karoulis, et al., 2005; Mankoff, et al., 2003; Nielsen, 1993). Volunteer participants with interface design experience assess each form in the prototypes against each heuristic category, providing specific design feedback that will shape the next design cycle.

Stage 5 is the final subject-based cycle, and provides for final development of working models of the simulation and the two alternate interfaces. A standard subject-based usability test (Dumas & Redish, 1999; Rubin & Chisnell, 2008) is performed, where each subject tests each of the two interfaces following a standard set of tasks for simulation data entry and solution analysis. Measures gathered will include time on task, entry or analysis errors, and task failures. In addition, each subject fills out a pre-validated usability assessment questionnaire (Lewis, 1993) to determine user satisfaction measures such as system usefulness, information quality, interface quality, and overall satisfaction. The assessment is designed to be run across approximately 45 subjects as a within-subjects or repeated measures design, with half the subjects using one interface first, and half the other interface, with a delay of one week minimum between tests. This design is intended to reduce interface learning and to reduce individual differences in subject capabilities (Leedy & Ormrod, 2010).

Stage 6 of the study includes data analysis of qualitative and quantitative data gathered in the prior stages. This includes descriptive statistics, graphical data analysis (using box-whisker plots), and analysis of variance (ANOVA) of quantitative data to determine significance of differences in mean performance measures from subject-based testing. A confidence limit of 90% is used in assessing whether differences in mean measures are significant to proving the hypotheses the measures support.

Once executed, the study resulted in strong statistical data that provides mixed to positive support for the hypotheses that improvements in usability of simulation interface elements will improve data entry, solution quality, and overall simulation interactions. Evidence for data entry was mixed, for solution quality was positive to neutral, and for overall usability was very positive. Several limitations were noted including insufficient iteration in the stage 4 and 5 testing to maximize usability issue discovery and address, use of customized heuristics, the scope of the simulation application space considered, and concentration on a standard but limited set of usability practices.

In other benefits, the study demonstrated application of usability-based interface design best practices and processes that could provide guidelines for increasing use of usability practices in future discrete-event simulation interface designs. The study also supplies support, review, and organization of literature sources and associated processes not available in the same form in a single resource.

It is hoped there is sufficient weight in the results of the study to say that if development of a simulation involves an interface design, it should also have a usability design process associated with it. It should no longer be enough to declare that a given simulation user interface is user friendly. A simulation interface should have usability goals, design, and assessment to validate that it provides the benefits of the underlying simulation model to its users as efficiently and effectively as possible. Studies such as this one, as well as others that look at aspects of simulation usability (Dawson, 2008; Kuljis, 1996; Ören & Yilmaz, 2005; Pidd, 1996), provide an outline for the specific usability concerns that should be considered in the effort to provide such support. It is up to usability practitioners and simulation developers to continue to work as partners (Chilana, et al., 2010) to effectively study and improve their processes and products, to the continuing benefit of their users and customers.

Appendixes

Appendix A

Heuristic Evaluation Form Outline

Evaluation Title: <evaluation>		Date: __________
Heuristic	**Details**	**Evaluation Notes**
Simple and natural dialog and aesthetic and minimalist design	Dialogs should not contain irrelevant or rarely needed information. Appropriate level of abstractions used. The role of elements should be clear.	
Visibility of the system status – provide feedback	The system should keep users informed through appropriate feedback within reasonable time. Expose dependencies between components. Provide progressive evaluation of progress.	
Speak the users' language: match between system and real world	The system should use the user's language rather than system oriented terms. Information should appear in a natural and logical order. Provides a close mapping of problem world to program world.	
Minimize the users' cognitive load: recognition rather than recall	Make objects, actions and options visible. The user should not have to remember information from one part of the application to another. Instructions should be visible or easily retrievable. Reduce hard mental operations.	
Consistency and standards	Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.	
Flexibility and efficiency of use – provide shortcuts	Accelerators - unseen by the novice user - may often speed up the interaction for the expert user. Allow users to tailor frequent actions. Evaluate effort required for changes.	

Heuristic	Details	Evaluation Notes
Support users' control and freedom	Users often choose system functions by mistake and will need a clear exit to leave the unwanted state. Support undo and redo. Do not force premature commitment.	
Prevent user from making errors	Careful design, which prevents problems from occurring, is more important than clear error messages.	
Help users recognize, diagnose and recover from errors with constructive error messages.	Error messages should be expressed in plain language (no codes), precisely indicate the problem, and suggest a solution.	
Help and documentation	Help and documentation should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.	
Other notes:		

Adapted from Green and Petre (1996), Karoulis et al. (2005), Nielsen and Mack (1994).

Appendix B

Final Subject Consent Form

NOVA SOUTHEASTERN UNIVERSITY
Graduate School of Computer and Information Sciences

Consent Form for Participation in the Research Study Entitled
The Impact of the User Interface on Simulation Usability and Solution Quality

Funding Source: None
IRB approval # wang07280901

Principal investigator:
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Institutional Review Board
Nova Southeastern University
Office of Grants and Contracts
(954) 262-5369/Toll Free: (866) 499-0790
IRB@nsu.nova.edu

Study Location:
UTC Fire & Security
8985 Town Center Parkway
Bradenton, FL 34202
Contact: Lucas Clarke, (941) 739-4310

Description of the Study:

This study involves the evaluation of user interfaces for discrete-event simulations, a type of tool employed in decision support. The purpose of this study is to determine the most effective methods to design, develop, and evaluate simulation interfaces. In particular, the study will look at user-based tests of two different user interfaces for a single simulation model, each designed with varying levels of ease-of-use. Participants in the study will perform directed tasks for interface evaluation and design or for direct use of the simulation interfaces. All participants' identities will be kept anonymous.

If you are selected for the evaluation and design exercises, you will be asked to pre-read instructions and an overview of planned activities, and you will then work interactively with the principal investigator through a planned set of design exercises. This work may take up to 90 minutes, and you will be asked to fill out assessment forms with your input. In order for you to participate in this phase of the study, you must be a professional software developer, usability analyst, or equivalent. You must have at least 10 years of experience in the design and development of user interfaces for software programs.

If you are selected for the direct use of the simulation tool, you will be asked to pre-read instructions and an overview of planned activities. You will then work through a series of data input and output analysis tasks as outlined in task instructions, using a user interface developed to interface with a simulation tool. During the tasks the principal investigator will observe your actions, and data you enter into the simulation tool will be captured for your session. The principal investigator will be with you throughout the study, and you are encouraged to ask questions or voice comments during your tasks. You will then be asked to complete a questionnaire about your experience with the interface. The test requires two sessions, each lasting approximately half an hour. In order to participate in this test, you must have basic computer literacy, defined as the use of e-mail and/or a web browser once per week. You must also be able to commit to two test sessions, with a delay of at least seven days between sessions. No other experience is required.

Initials: ________ **Date:** ________

3301 College Avenue • Fort Lauderdale, Florida 33314-7796 • (954) 262-2000 • 800-541-6682, ext. 2000
Fax: (954) 262-3915 • Web site: *www.scis.nova.edu*

Risks and Benefits:

There are no direct benefits to participating in this study, and there are minimal risks to you. If you have any concerns about the risks or benefits of participating in this study, you can contact Bruce Montgomery or the university's human research oversight board (the Institutional Review Board or IRB) office at the numbers indicated above.

Costs and Payments:

There are no costs to you for participating in this study, outside of the time you are providing. No direct payments or other compensation will be made for participating in this study.

Confidentiality and Privacy:

The session data you enter in the computer-based tools, the investigator's observation notes, and any forms you fill out (such as assessments or questionnaires) will be kept for up to 36 months and will be destroyed after that time using appropriate means to ensure destruction. With the exception of your signature on this consent form, none of the data collected will identify you by name, in order to maintain your confidentiality. All information obtained in this study is strictly confidential, unless disclosure is required by law. The university's human research oversight board (the Institutional Review Board or IRB) and regulatory agencies may review all study related research records. All information gathered will be kept in locked cabinets or password protected computer files.

Participant's Right to Withdraw from the Study:

You have the right to refuse to participate or to withdraw from the study at any time, without penalty. If you choose to withdraw, you may request that any of your data which has been collected be destroyed, unless prohibited by state or federal law.

Other Considerations:

If significant new information related to the study becomes available which may impact your willingness to continue to participate, the investigator will provide this information to you.

Voluntary Consent by Participant:

I have read the preceding consent form, or it has been read to me, and I fully understand the contents of this document and voluntarily consent to participate in the research study entitled "The Impact of the User Interface on Simulation Usability and Solution Quality". All of my questions concerning the research have been answered. I hereby agree to participate in this research study. If I have any questions in the future about this study, they will be answered by Bruce Montgomery. A copy of this form has been given to me. This consent ends at the conclusion of this study.

Participant's Signature: ______________________________ Date: ________________

Witness's Signature: ______________________________ Date: ________________

Appendix C

Paper Prototyping Task Outline

Task n	**<task title>**
Goal/output	<goal description>
Inputs/assumptions	<input 1> <input 2…n>
Steps	<step 1> <step 2…n>
Time for expert	<estimated task time>
Instructions for user	<user directions>
Special considerations	<considerations>

Format of task outline from Snyder (2003, Chap. 6).

Appendix D

Post Test Questionnaire

Post Test Questionnaire

Subject number ____ Test Date/Time ___/___/___ ___:___ AM/PM

This questionnaire, which starts on the following page, gives you an opportunity to tell us your reactions to the system you used. Your responses will help us understand what aspects of the system you are particularly concerned about and the aspects that satisfy you. To as great a degree as possible, think about all the tasks that you have done with the system while you answer these questions.

Please read each statement and indicate how strongly you agree or disagree with the statement by circling a number on the scale. If a statement does not apply to you, circle N/A. Please write comments to elaborate on your answers if you wish.

After you have completed this questionnaire, I'll go over your answers with you to make sure I understand all of your responses.

Thank you!

Questionnaire format follows the Post-Study System Usability Questionnaire (PSSUQ) (Lewis, 1993)

1. Overall, I am satisfied with how easy it is to use this system.

STRONGLY AGREE	1	2	3	4	5	6	7	STRONGLY DISAGREE	N/A

COMMENTS:

2. It was simple to use this system.

STRONGLY AGREE	1	2	3	4	5	6	7	STRONGLY DISAGREE	N/A

COMMENTS:

3. I could effectively complete the tasks and scenarios using this system.

STRONGLY AGREE	1	2	3	4	5	6	7	STRONGLY DISAGREE	N/A

COMMENTS:

4. I was able to complete the tasks and scenarios quickly using this system.

STRONGLY AGREE	1	2	3	4	5	6	7	STRONGLY DISAGREE	N/A

COMMENTS:

5. I was able to efficiently complete the tasks and scenarios using this system.

STRONGLY AGREE	1	2	3	4	5	6	7	STRONGLY DISAGREE	N/A

COMMENTS:

6. I felt comfortable using this system.

STRONGLY AGREE	1	2	3	4	5	6	7	STRONGLY DISAGREE	N/A

COMMENTS:

7. It was easy to learn to use this system.

STRONGLY AGREE	1	2	3	4	5	6	7	STRONGLY DISAGREE	N/A

COMMENTS:

8. I believe I could become productive quickly using this system.

STRONGLY AGREE	1	2	3	4	5	6	7	STRONGLY DISAGREE	N/A

COMMENTS:

9. The system gave error messages that clearly told me how to fix problems.

STRONGLY AGREE	1	2	3	4	5	6	7	STRONGLY DISAGREE	N/A

COMMENTS:

10. Whenever I made a mistake using the system, I could recover easily and quickly.

STRONGLY AGREE	1	2	3	4	5	6	7	STRONGLY DISAGREE	N/A

COMMENTS:

11. The information (such as on-line help, on-screen messages and other documentation)
provided with this system was clear.

STRONGLY AGREE	1	2	3	4	5	6	7	STRONGLY DISAGREE	N/A

COMMENTS:

12. It was easy to find the information I needed.

STRONGLY AGREE	1	2	3	4	5	6	7	STRONGLY DISAGREE	N/A

COMMENTS:

13. The information provided for the system was easy to understand.

STRONGLY AGREE	1	2	3	4	5	6	7	STRONGLY DISAGREE	N/A

COMMENTS:

14. The information was effective in helping me complete the tasks and scenarios.

STRONGLY AGREE	1	2	3	4	5	6	7	STRONGLY DISAGREE	N/A

COMMENTS:

15. The organization of information on the system screens was clear.

STRONGLY AGREE	1	2	3	4	5	6	7	STRONGLY DISAGREE	N/A

COMMENTS:

Note: The interface below includes those items that you use to interact with the system. For example, some components of the interface are the keyboard, the mouse, the screens (including their use of graphics and language).

16. The interface of this system was pleasant.

STRONGLY								STRONGLY	
AGREE	1	2	3	4	5	6	7	DISAGREE	N/A

COMMENTS:

17. I liked using the interface of this system.

STRONGLY								STRONGLY	
AGREE	1	2	3	4	5	6	7	DISAGREE	N/A

COMMENTS:

18. This system has all the functions and capabilities I expect it to have.

STRONGLY								STRONGLY	
AGREE	1	2	3	4	5	6	7	DISAGREE	N/A

COMMENTS:

19. Overall, I am satisfied with this system.

STRONGLY								STRONGLY	
AGREE	1	2	3	4	5	6	7	DISAGREE	N/A

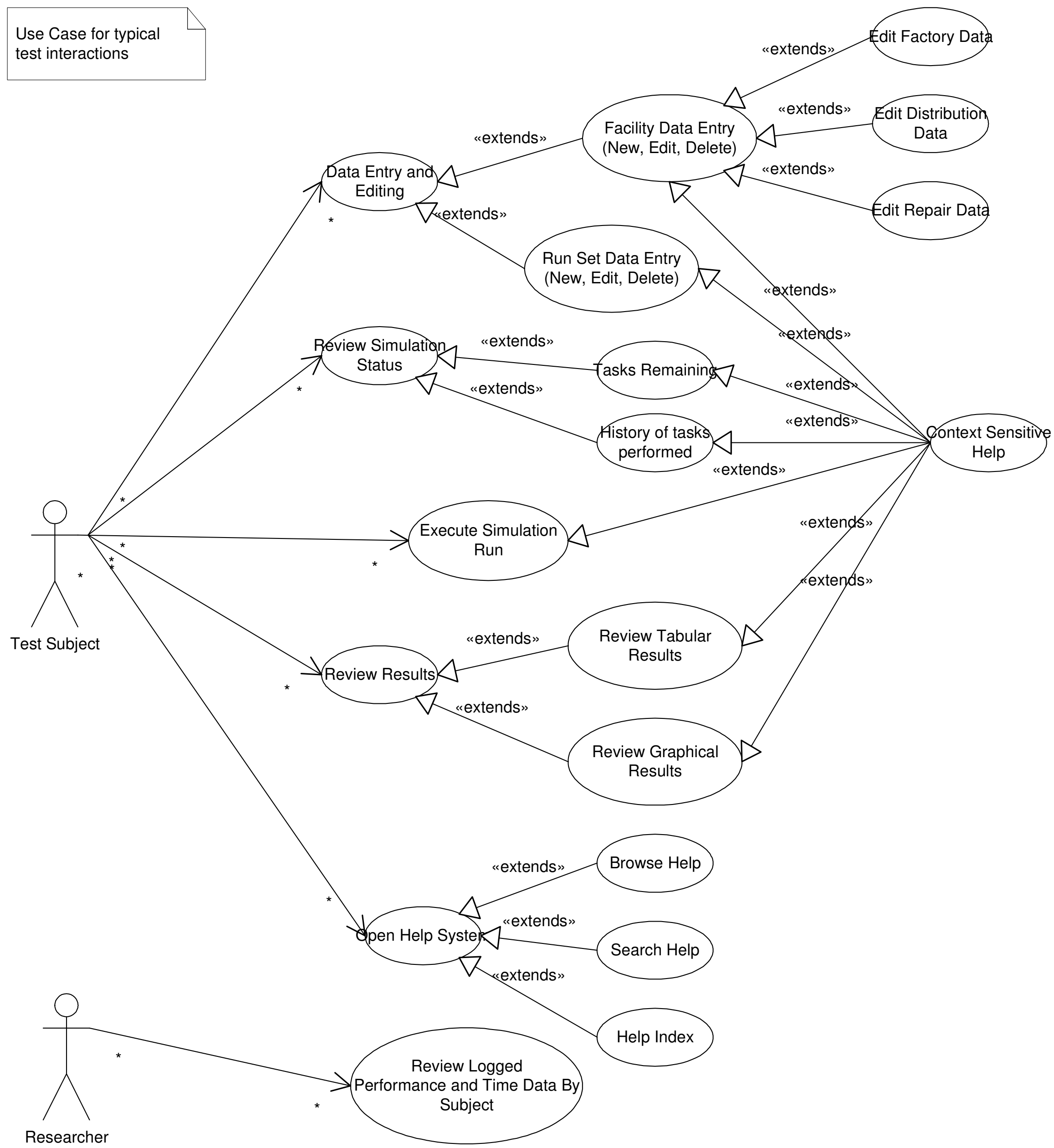
COMMENTS:

ADDITIONAL COMMENTS:

END OF POST TEST QUESTIONAIRRE

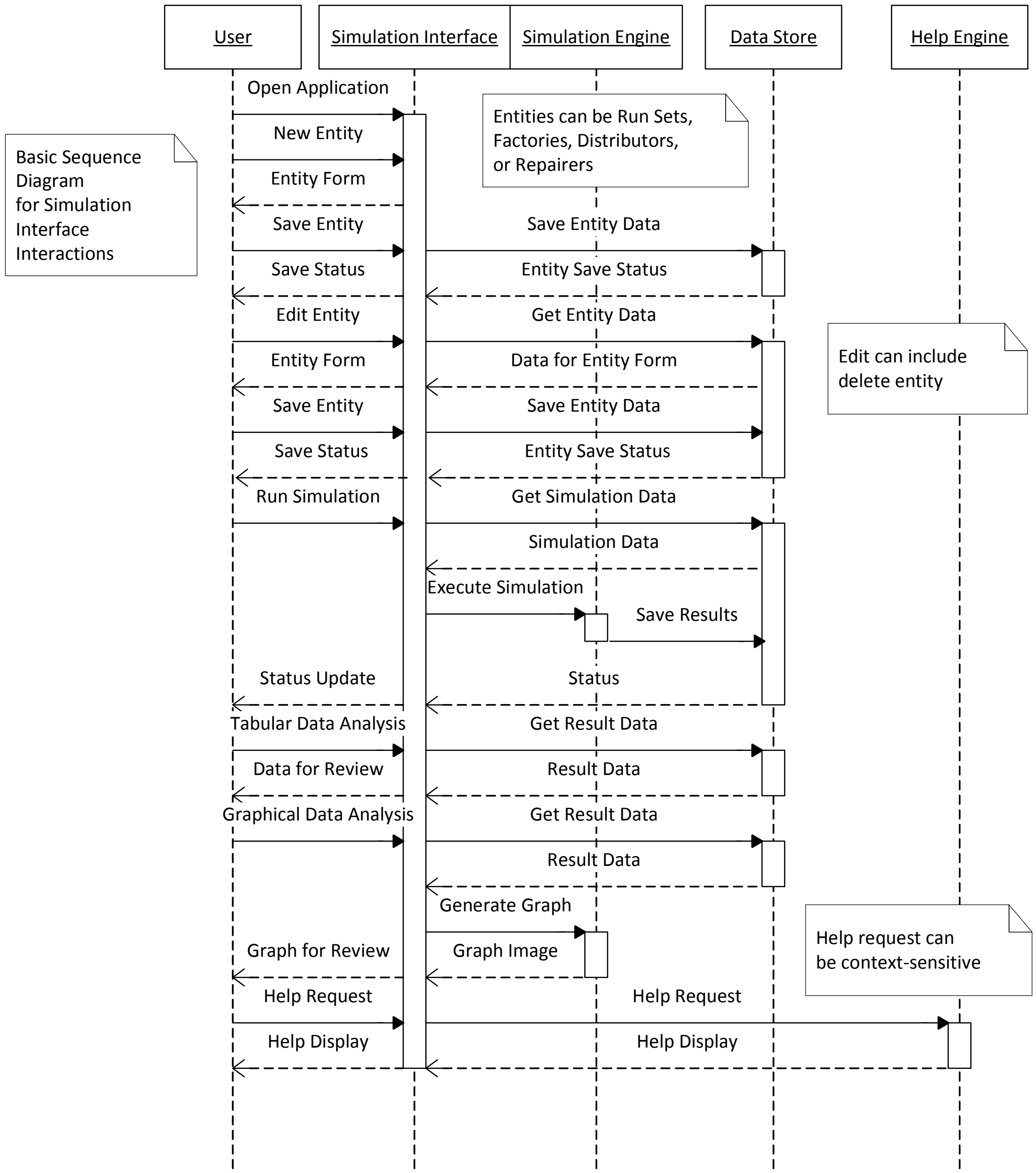
Appendix E

Final UML Simulation Interface Use Case


Use Case for typical test interactions
Edit Factory Data
«extends»
Facility Data Entry (New, Edit, Delete)
«extends»
Edit Distribution Data
«extends»
«extends»
Edit Repair Data
Data Entry and Editing
«extends»
Run Set Data Entry (New, Edit, Delete)
«extends»
«extends»
Review Simulation Status
«extends»
Tasks Remaining
«extends»
«extends»
History of tasks performed
«extends»
Context Sensitive Help
«extends»
Execute Simulation Run
«extends»
«extends»
Test Subject
Review Tabular Results
«extends»
Review Results
«extends»
Review Graphical Results
Browse Help
«extends»
«extends»
Open Help System
Search Help
«extends»
Help Index
Researcher
Review Logged Performance and Time Data By Subject

Appendix F

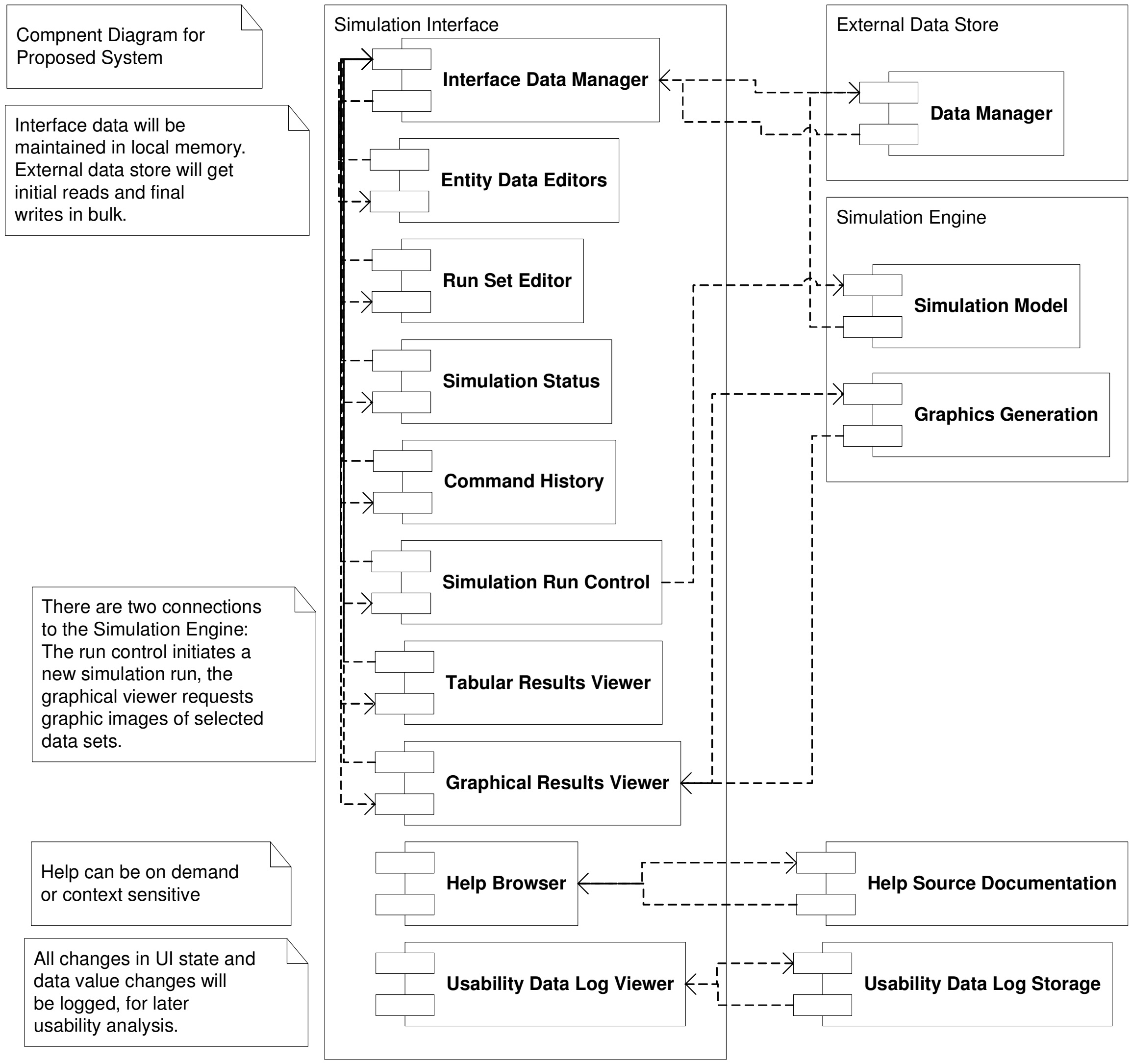
Final UML Simulation Application Sequence Diagram



User
Simulation Interface
Simulation Engine
Data Store
Help Engine
Basic Sequence Diagram for Simulation Interface Interactions
Entities can be Run Sets, Factories, Distributors, or Repairers
Edit can include delete entity
Help request can be context-sensitive
Open Application
New Entity
Entity Form
Save Entity
Save Entity Data
Save Status
Entity Save Status
Edit Entity
Get Entity Data
Entity Form
Data for Entity Form
Save Entity
Save Entity Data
Save Status
Entity Save Status
Run Simulation
Get Simulation Data
Simulation Data
Execute Simulation
Save Results
Status Update
Status
Tabular Data Analysis
Get Result Data
Data for Review
Result Data
Graphical Data Analysis
Get Result Data
Result Data
Generate Graph
Graph for Review
Graph Image
Help Request
Help Request
Help Display
Help Display

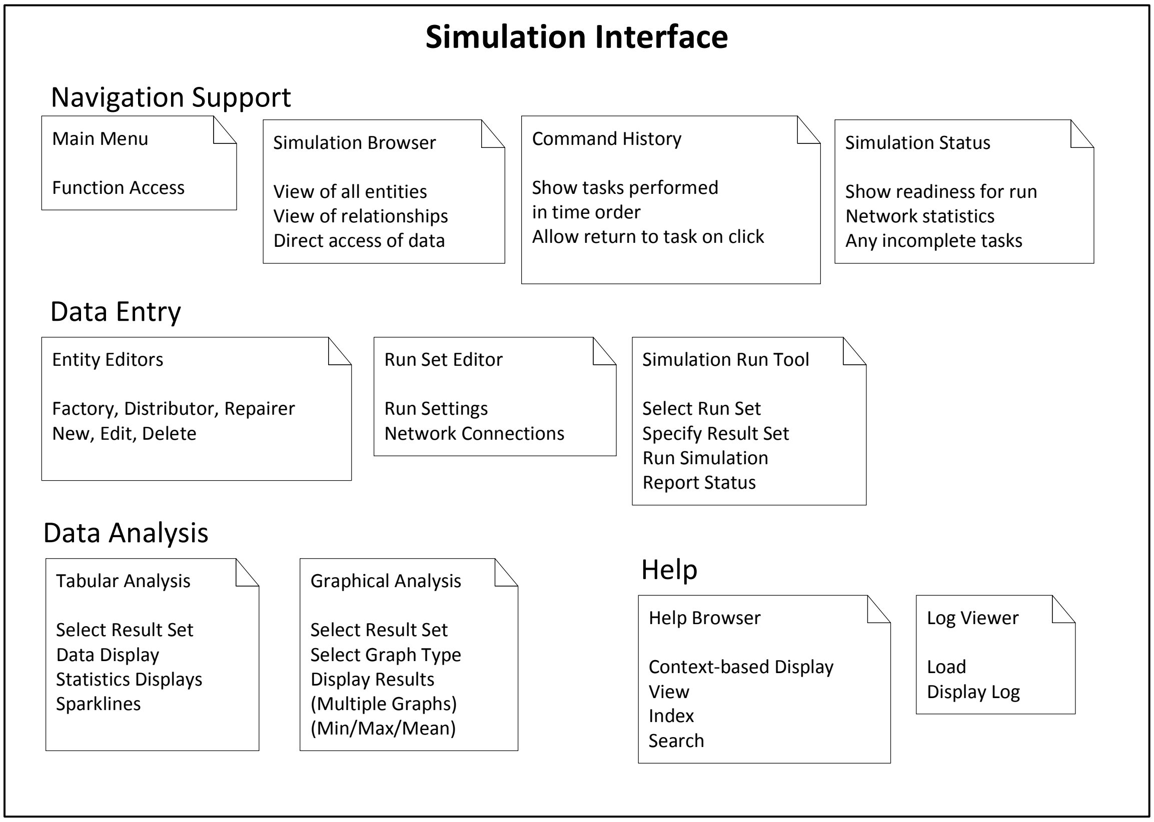
Appendix G

Final UML Simulation Application Component Diagram


Compnent Diagram for Proposed System
Interface data will be maintained in local memory. External data store will get initial reads and final writes in bulk.
There are two connections to the Simulation Engine: The run control initiates a new simulation run, the graphical viewer requests graphic images of selected data sets.
Help can be on demand or context sensitive
All changes in UI state and data value changes will be logged, for later usability analysis.
Simulation Interface
Interface Data Manager
Entity Data Editors
Run Set Editor
Simulation Status
Command History
Simulation Run Control
Tabular Results Viewer
Graphical Results Viewer
Help Browser
Usability Data Log Viewer
External Data Store
Data Manager
Simulation Engine
Simulation Model
Graphics Generation
Help Source Documentation
Usability Data Log Storage

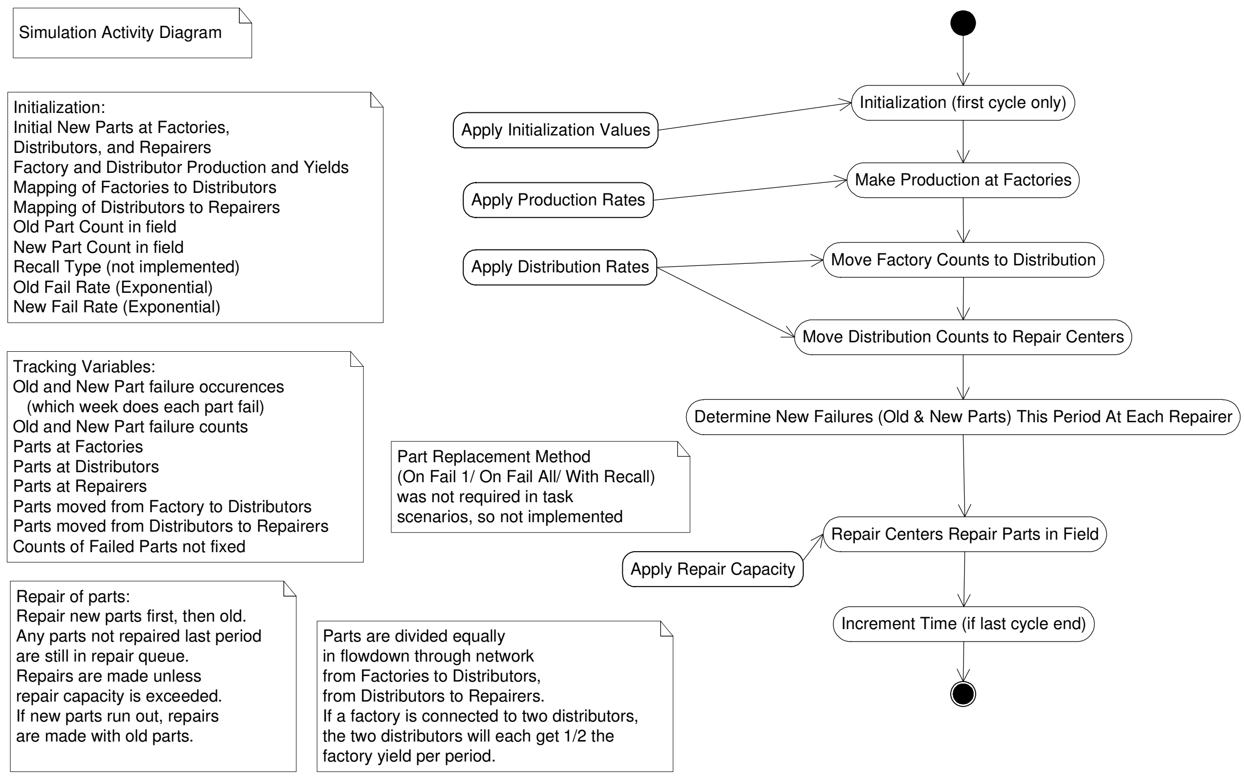
Appendix H

Final UML Simulation Interface Cluster Diagram


Simulation Interface
Navigation Support
Main Menu
Function Access
Simulation Browser
View of all entities
View of relationships
Direct access of data
Command History
Show tasks performed
in time order
Allow return to task on click
Simulation Status
Show readiness for run
Network statistics
Any incomplete tasks
Data Entry
Entity Editors
Factory, Distributor, Repairer
New, Edit, Delete
Run Set Editor
Run Settings
Network Connections
Simulation Run Tool
Select Run Set
Specify Result Set
Run Simulation
Report Status
Data Analysis
Tabular Analysis
Select Result Set
Data Display
Statistics Displays
Sparklines
Graphical Analysis
Select Result Set
Select Graph Type
Display Results
(Multiple Graphs)
(Min/Max/Mean)
Help
Help Browser
Context-based Display
View
Index
Search
Log Viewer
Load
Display Log

Appendix I

Final UML Simulation Activity Diagram


Simulation Activity Diagram
Initialization:
Initial New Parts at Factories,
Distributors, and Repairers
Factory and Distributor Production and Yields
Mapping of Factories to Distributors
Mapping of Distributors to Repairers
Old Part Count in field
New Part Count in field
Recall Type (not implemented)
Old Fail Rate (Exponential)
New Fail Rate (Exponential)
Tracking Variables:
Old and New Part failure occurences
(which week does each part fail)
Old and New Part failure counts
Parts at Factories
Parts at Distributors
Parts at Repairers
Parts moved from Factory to Distributors
Parts moved from Distributors to Repairers
Counts of Failed Parts not fixed
Repair of parts:
Repair new parts first, then old.
Any parts not repaired last period
are still in repair queue.
Repairs are made unless
repair capacity is exceeded.
If new parts run out, repairs
are made with old parts.
Parts are divided equally
in flowdown through network
from Factories to Distributors,
from Distributors to Repairers.
If a factory is connected to two distributors,
the two distributors will each get 1/2 the
factory yield per period.
Part Replacement Method
(On Fail 1/ On Fail All/ With Recall)
was not required in task
scenarios, so not implemented
Apply Initialization Values
Initialization (first cycle only)
Apply Production Rates
Make Production at Factories
Apply Distribution Rates
Move Factory Counts to Distribution
Move Distribution Counts to Repair Centers
Determine New Failures (Old & New Parts) This Period At Each Repairer
Repair Centers Repair Parts in Field
Apply Repair Capacity
Increment Time (if last cycle end)

Appendix J

Paper Prototyping Task Profiles

Typical Tasks:

Enter and save data for a new Factory: Factory Name, Factory Production Rate, Production Type, Factory Overall Yield

Enter and save data for a new Distribution Center: Distribution Center Name, Factory to Distribution Rate, Distribution to Repair Center, Distribution Loss Rate, Connected Factories, Connected Repair Centers

Enter data for a new Repair Center: Repair Center Name, Part Repair Capacity

Change data for an existing Distribution Center: Change Distribution Loss Rate, Change Connected Repair Centers

Create new Simulation Run Case: Simulation Run Case, Initial Old Parts In Field count, Old Part Failure Rate, New Part Failure Rate

Execute selected Simulation Run Case

Use results analysis by table to find highest Field Failure Rate in month 17

Use results analysis by graph to find Old Parts In Field count in month 15

Task Outlines

Task 1	**Enter/save Element Data**
Goal/output	Enter textual, numeric, enumerated, and connection data for a simulation object
Inputs/assumptions	Varies by element type Numeric – real, integer, and percentage inputs Text – simple text input Enumerated – discrete choices Connection – association with other elements
Steps	Create new element Present data fields Edit fields Save or abandon entries
Time for expert	One minute
Instructions for user	User may need help with object descriptions, valid bounds, types of data
Special considerations	

Task 2	Open/Edit Existing Element Data
Goal/output	Locate an existing simulation element and change textual, numeric, enumerated, and connection data
Inputs/assumptions	Varies by object type Numeric – real, integer, and percentage inputs Text – simple text input Enumerated – discrete choices Connection – association with other objects
Steps	Identify element to open/edit Present current data fields Edit fields Save, Save As, or abandon changed entries
Time for expert	One minute
Instructions for user	User may need help with object descriptions, valid bounds, types of data
Special considerations	

Task 3	Enter/save Run Set
Goal/output	Enter data associated with a set of elements and other run conditions – save elements as a run set
Inputs/assumptions	Numeric – real, integer, and percentage inputs Text – simple text input
Steps	Create new run set Present data fields Edit fields Save or abandon entries
Time for expert	One minute
Instructions for user	User may need description of run set and parameters, bounds, data types
Special considerations	Saving a run set saves all the current elements with that run set – the association between elements and run sets has to be clear

Task 4	Open/Edit Existing Run Set
Goal/output	Edit the data associated with a given run set, also be able to access element data associated with a run set
Inputs/assumptions	Numeric – real, integer, and percentage inputs Text – simple text input
Steps	Identify run set to open/edit Load elements associated with run set Edit run set fields Save, Save As, or abandon changes
Time for expert	One minute
Instructions for user	Run set descriptions, parameter bounds, other help
Special considerations	Opening a run set will load all the element data associated with that run set, any edited elements will be overwritten.

Task 5	Execute a Run Set/Save an Output Set
Goal/output	Submit run set and element data to simulation engine, receive output data set
Inputs/assumptions	Text – Names for output data sets?
Steps	Select run set Execute run set Submit run set/Receive output data Save, Save As, or abandon output data
Time for expert	One minute
Instructions for user	Select/execute flow, saving/naming output
Special considerations	

Task 6	Examine Output Set Tabular Output
Goal/output	Open and Examine the data from a given output set in a tabular display with summary statistics
Inputs/assumptions	
Steps	Select output data Scroll through data Close display
Time for expert	Several minutes
Instructions for user	Descriptions of fields, mechanics of review
Special considerations	

Task 7	Examine Output Set Graphical Output
Goal/output	Open and Examine one of a set of graphs for output data sets
Inputs/assumptions	
Steps	Select output data Select graph type Examine graph Close display
Time for expert	Several minutes
Instructions for user	Descriptions of data types, mechanics of review
Special considerations	

Appendix K

IRB (Institutional Review Board) Permission Letter

NOVA SOUTHEASTERN UNIVERSITY
Office of Grants and Contracts
Institutional Review Board

MEMORANDUM

To: Bruce R. Montgomery

From: Ling Wang, Ph.D.
Institutional Review Board

Date: August 4, 2009

Re: *The Impact of the User Interface on Simulation Usability and Solution Quality*

IRB Approval Number: wang07280901

I have reviewed the above-referenced research protocol at the center level. Based on the information provided, I have determined that this study is exempt from further IRB review. You may proceed with your study as described to the IRB. As principal investigator, you must adhere to the following requirements:

1) CONSENT: If recruitment procedures include consent forms these must be obtained in such a manner that they are clearly understood by the subjects and the process affords subjects the opportunity to ask questions, obtain detailed answers from those directly involved in the research, and have sufficient time to consider their participation after they have been provided this information. The subjects must be given a copy of the signed consent document, and a copy must be placed in a secure file separate from de-identified participant information. Record of informed consent must be retained for a minimum of three years from the conclusion of the study.

2) ADVERSE REACTIONS: The principal investigator is required to notify the IRB chair and me (954-262-5369 and 954-262-2020 respectively) of any adverse reactions or unanticipated events that may develop as a result of this study. Reactions or events may include, but are not limited to, injury, depression as a result of participation in the study, life-threatening situation, death, or loss of confidentiality/anonymity of subject. Approval may be withdrawn if the problem is serious.

3) AMENDMENTS: Any changes in the study (e.g., procedures, number or types of subjects, consent forms, investigators, etc.) must be approved by the IRB prior to implementation. Please be advised that changes in a study may require further review depending on the nature of the change. Please contact me with any questions regarding amendments or changes to your study.

The NSU IRB is in compliance with the requirements for the protection of human subjects prescribed in Part 46 of Title 45 of the Code of Federal Regulations (45 CFR 46) revised June 18, 1991.

Cc: Protocol File

3301 College Avenue • Fort Lauderdale, FL 33314-7796 • (954) 262-5369
Fax: (954) 262-3977 • Email: *inga@nsu.nova.edu* • Web site: www.nova.edu/cwis/ogc

Appendix L

Permission Letter for Test Facility Use

8985 Town Center Parkway
Bradenton, FL 34202
Tel 941.309.8559 Fax 941.308.8127
www.utcfireandsecurity.com

Kathy Legere
HR Manager

EDWARDS
A UTC Fire & Security Company

June 14, 2010

To Whom It May Concern:

As a local representative of Edwards, I have discussed the proposed use of Edwards facilities for dissertation study subject trials with Bruce Montgomery, and I give permission for him to conduct study activities at the Bradenton facility. This facility use is limited to the use of conference rooms and/or his office. It is understood that no testing or preparation will take place during normal working hours, and no disruption of active Edwards work tasks will occur as a result of these studies.

While Edwards employees may volunteer to participate in the study, they may not be directly compensated in any way, including payment or prizes. Further, no notices regarding the study may be posted within the Edwards facility. Also, no Edwards equipment may be used for the study, including computers or network access. Any equipment required for performance of study activities will be supplied by Bruce.

While we support Bruce's endeavor to complete his dissertation studies, Edwards reserves the right to suspend this permission for facility use at any time.

Signed,
Kathy Legere
Kathy Legere,
HR Manager
Edwards, A UTC Fire and Security Company

Appendix M

Test Plan Handouts

Test Plan Outline for Paper Prototype Assessment

Thank you for agreeing to participate in this usability assessment exercise. During the session, the facilitator will follow this set of steps to ensure, as far as possible, that instructions to all participants are the same for each design session.

The objective for this exercise will be to review and identify usability and related design issues in a set of paper prototypes of the interfaces for a simulation application. This assessment is based on guidelines for a paper prototyping process (Snyder, 2003). This session is expected to run for 90 minutes or less, and you may be asked to return for a follow-on session.

Materials:

- Consent forms
- Test plan outline (this document)
- Initial paper prototypes
- Initial task outlines

Session Activities:

- Review consent forms and make sure each participant signs a consent form
- Overview discussion of the test plan (this document)
- Overview discussion of the application to be reviewed
- Review of the task outlines (changes will be captured by the facilitator)
- Review of the paper prototypes and their interface elements in terms of the application and task outlines (changes captured by the facilitator)
- Usability testing of updated prototypes – this is a structured exercise where the team will take on roles of observers, users, and the computer to assess the prototype interface's response to each of the updated task outlines – the facilitator will detail each team member's responsibilities in this phase

This session is intended to be an interactive exercise to get your opinion on the content and format of the interfaces, you are encouraged to ask questions and make observations at any point during the process. At the end of the session, the facilitator will gather any notes he and the team has made on revisions to the task outlines or prototype interfaces. These notes will be used to shape future design iterations.

Again, thank you for your participation.

References: Paper prototyping process (Snyder, 2003), general testing procedures (Dumas & Redish, 1999; Rubin & Chisnell, 2008)

Test Plan Outline for Interface Prototype Assessment

Thank you for agreeing to participate in this usability assessment exercise. During the session, the facilitator will follow this set of steps to ensure, as far as possible, that instructions to all participants are the same for each design session.

The objective for this exercise will be to review and identify usability and related design issues in a set of computer-based prototypes of the interfaces for a simulation application. This assessment is based on a technique known as heuristic evaluation, a usability engineering method that employs a small set of evaluators to examine and judge the compliance of a given interface with selected recognized usability principals (Nielsen & Mack, 1994). This session is expected to run for 90 minutes or less, and you may be asked to return for a follow-on session.

Materials:

- Consent forms
- Test plan outline (this document)
- PC with interface examples
- Heuristic assessment forms

Session Activities:

- Review consent forms and make sure each participant signs a consent form
- Overview discussion of the test plan (this document)
- Overview discussion of the heuristic assessment method and heuristic rules
- Overview discussion of the application to be reviewed
- Heuristic review of the interface prototypes – for each interface, the team will review the forms for the heuristic rules on the assessment forms
- Discussion of results

This session is intended to be an interactive exercise to get your opinion on the content and format of the interfaces, you are encouraged to ask questions and make observations at any point during the process. At the end of the session, the facilitator will gather the heuristic assessment forms and any additional materials the team has used to assess the prototype interfaces. These findings will be used to shape future design iterations.

Again, thank you for your participation.

References: Heuristics adapted from Green and Petre (1996), Karoulis et al. (2005), Nielsen and Mack (1994); General testing procedures (Dumas & Redish, 1999; Rubin & Chisnell, 2008)

Test Plan Outline for Simulation Data Input and Analysis Experiment

Thank you for agreeing to participate in this usability assessment exercise. During the session, the facilitator will follow this set of steps to ensure, as far as possible, that instructions to all participants are the same for each design session.

The objective for this exercise will be to observe your interaction with the computer-based user interface of a simulation tool. This assessment is based on a technique known as user-based usability testing, which allows observation of actual users performing selected tasks to look for issues with an interface.

You will be encouraged to try to "think out loud" during your interaction with the interface. Remember that you are not being tested, and there are no wrong actions; your taking this test helps the facilitator understand about issues with the program's user interface. As outlined in the consent form, your screen interaction with the interface will be recorded, but no audio or video recording will be made.

Session Activities:

- Review consent forms and make sure each participant signs a consent form
- Overview discussion of the experiment and test plan
- When ready, the subject will state, "I'm ready to begin." The subject will be presented with the test instructions.
- The facilitator will state, "Please begin", at which point we will begin, and the subject will begin performing the test instruction tasks using the interface.
- During testing, the subject will be encouraged to think aloud to comment on the tasks they are performing and how the interface is responding.
- Once the subject has completed the tasks, the subject should state, "I'm done." (Should the interaction phase run over time, the facilitator may also end the interaction.)
- The subject will then fill out a brief questionnaire about using the interface

This session is a structured exercise with time limits, please try and follow all written and verbal instructions. If you have any questions, please ask the facilitator at any time. The findings from these sessions will be used to determine which of the two user interfaces being tested has the best usability characteristics, and what usability issues they may have.

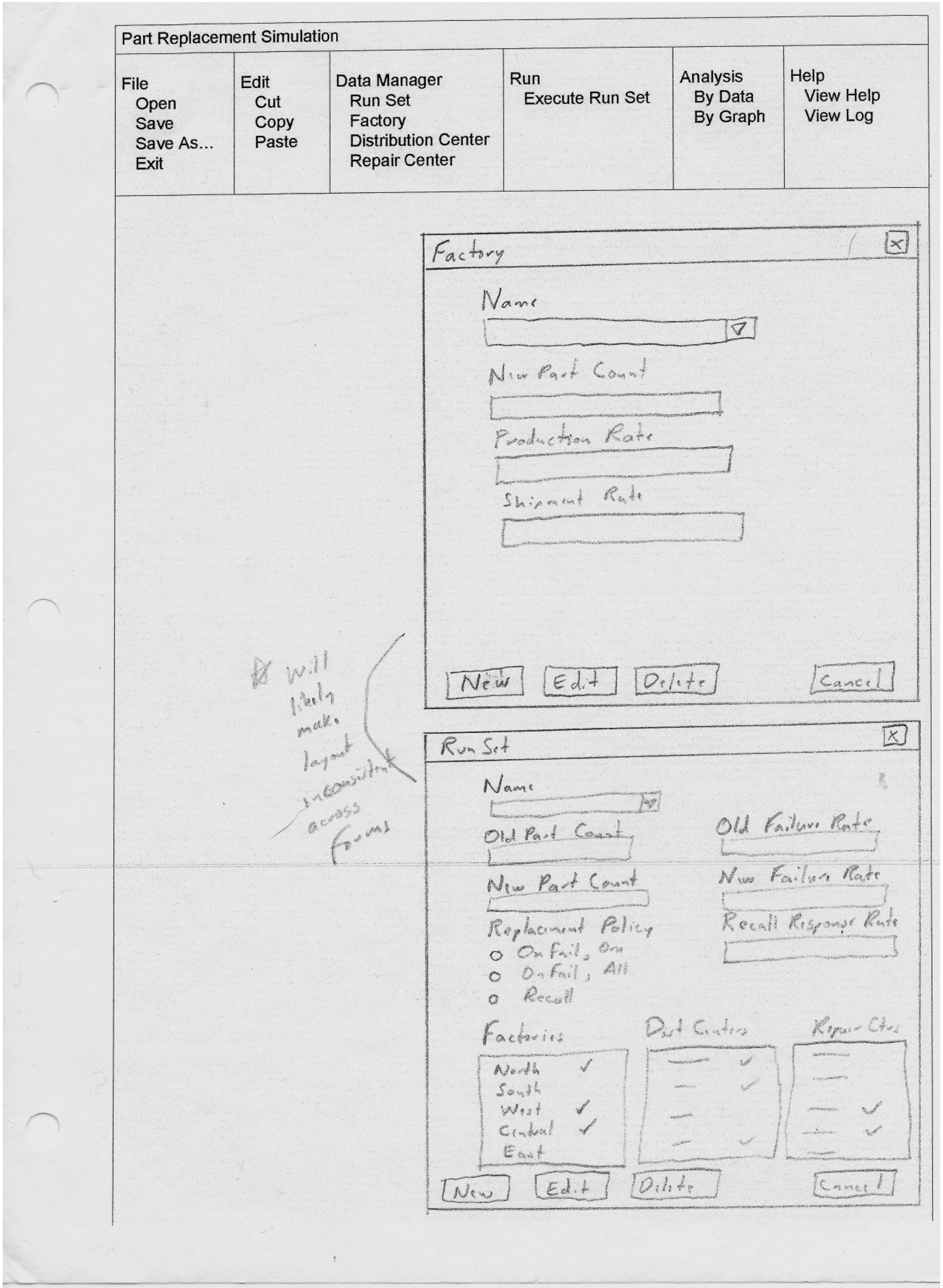
Finally, please do not discuss the content of this simulation test procedure with others who have not taken the test, but may in the future.

Again, thank you for your participation.

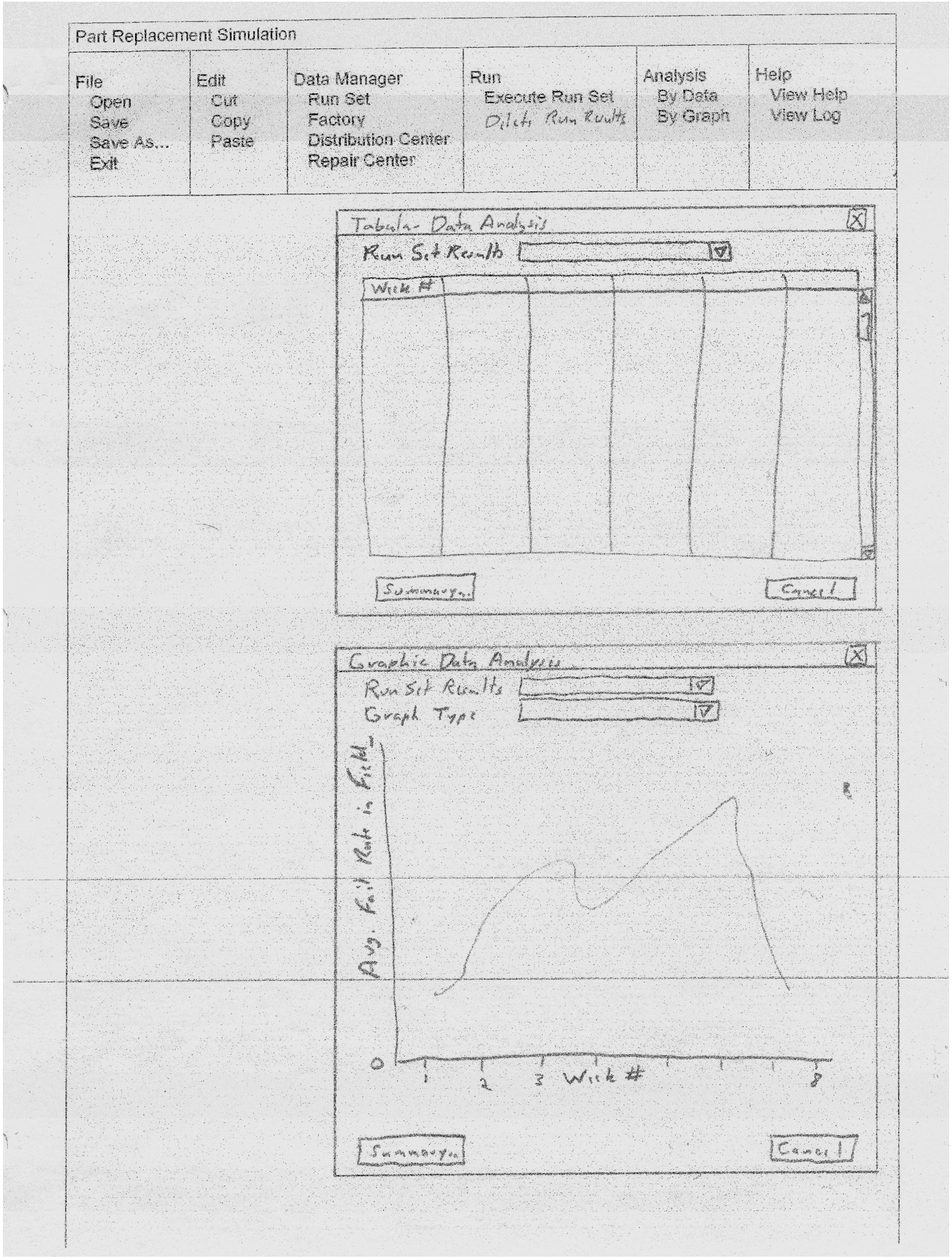
References: User-based testing procedures (Dumas & Redish, 1999; Rubin & Chisnell, 2008)

Appendix N

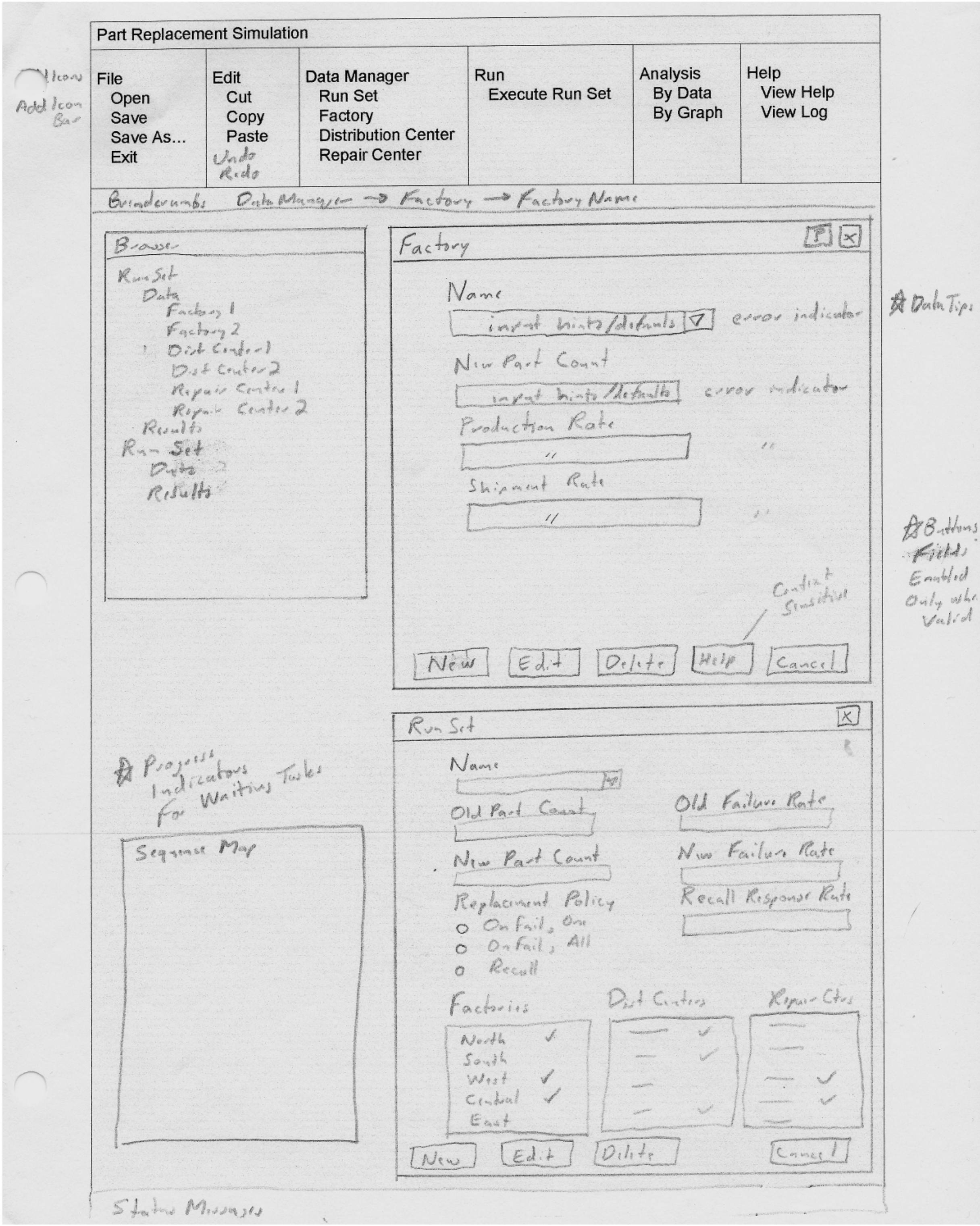
Initial Paper Prototypes



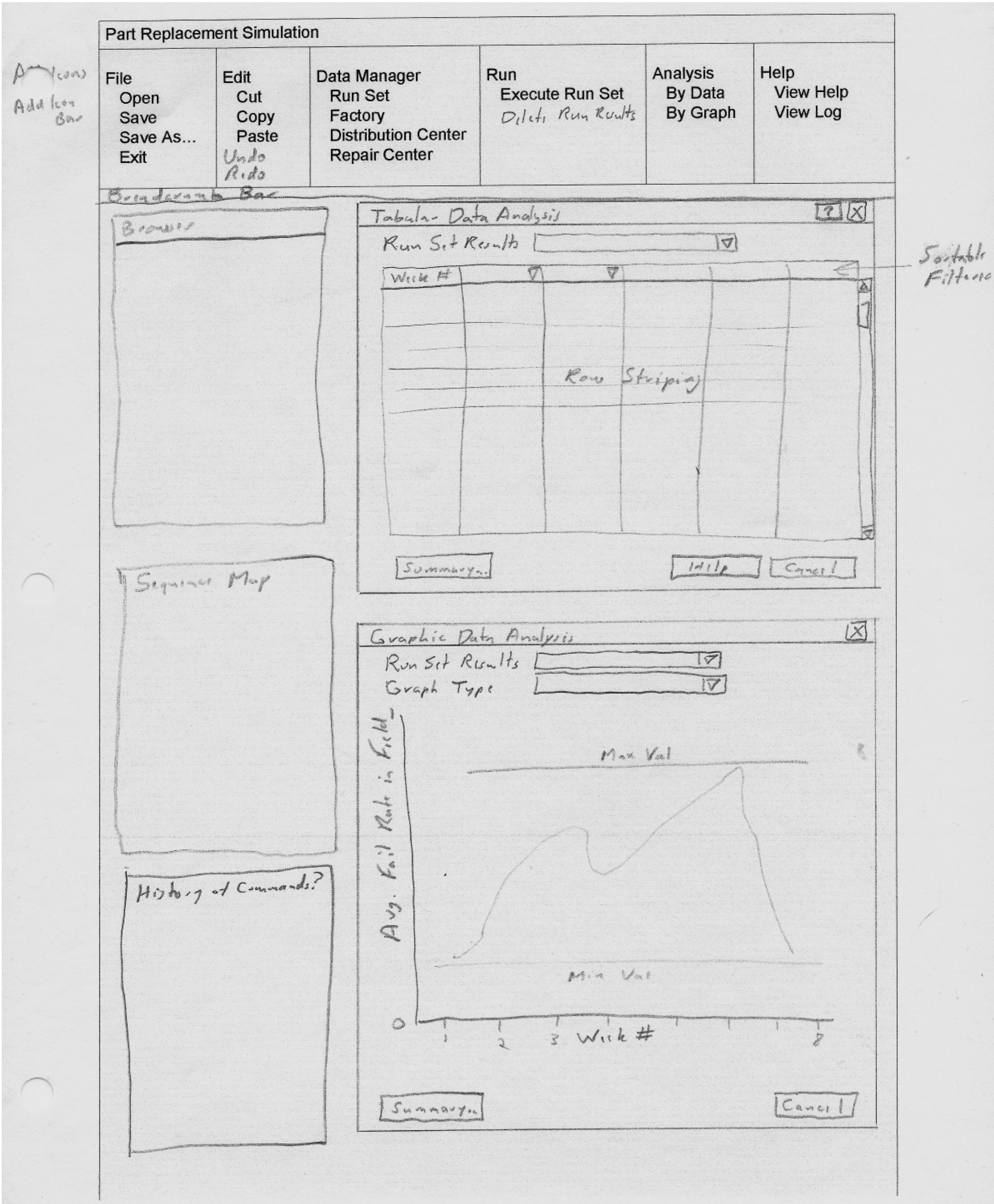
Basic entry displays – entity and run set.



Basic analysis displays – tabular and graphic.



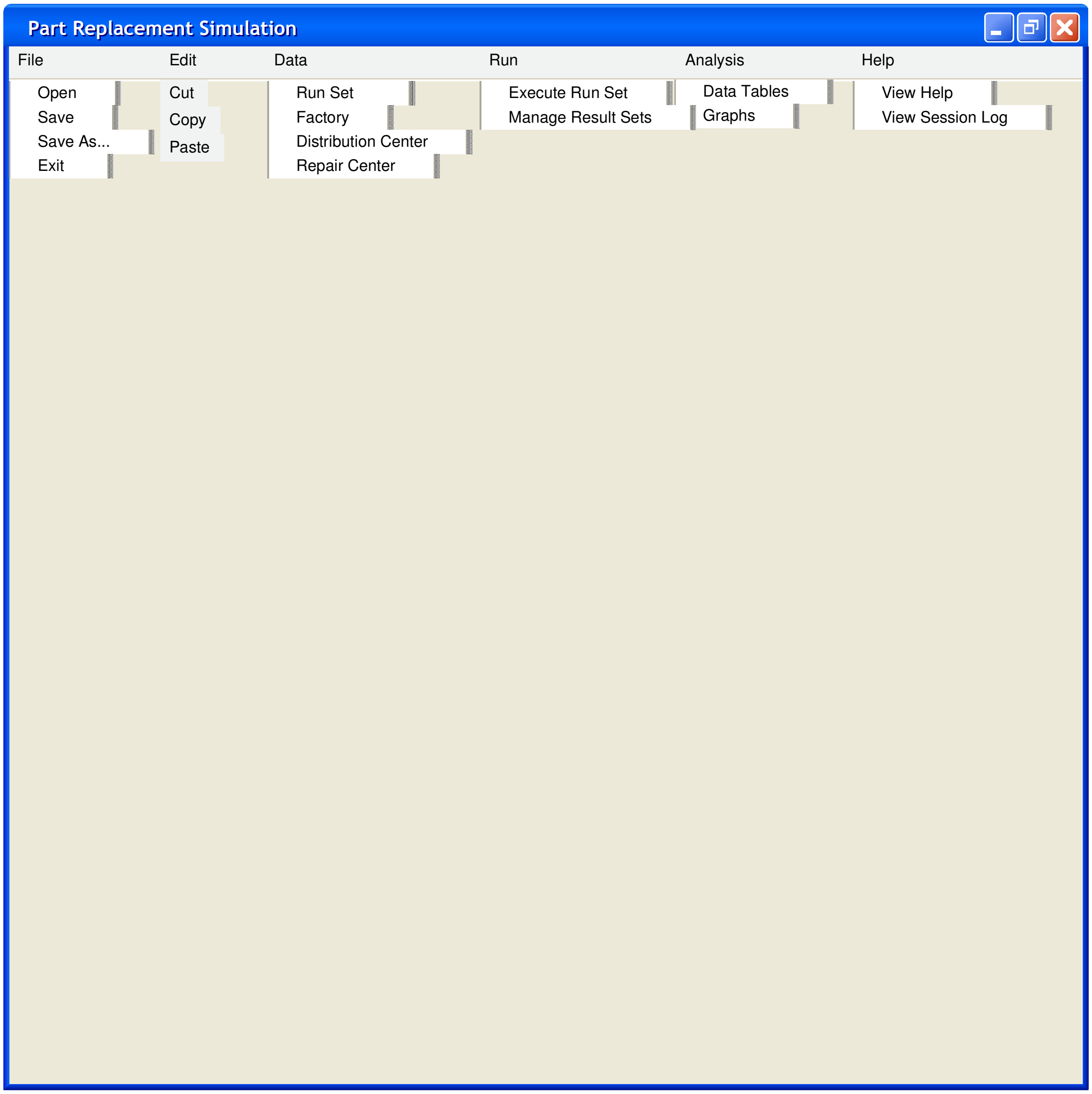
Improved entry displays – entity and run set.



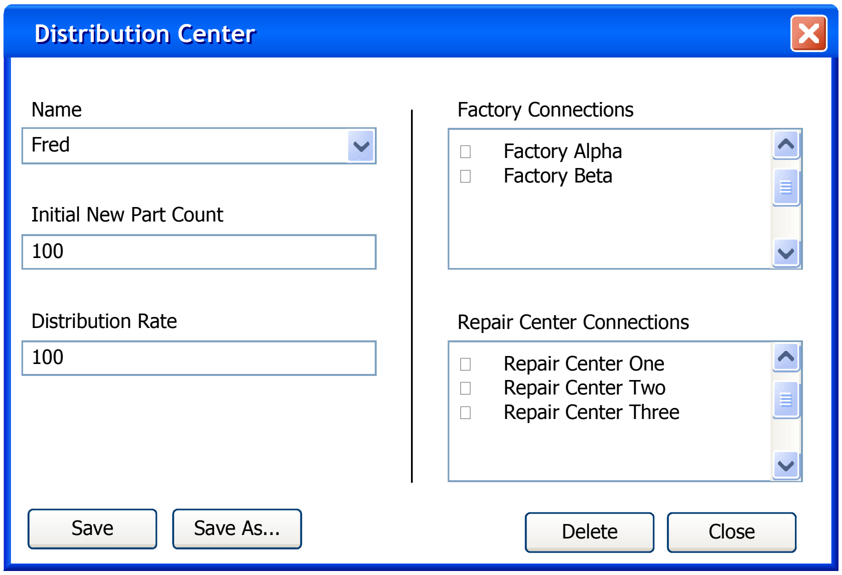
Improved analysis displays – tabular and graphic

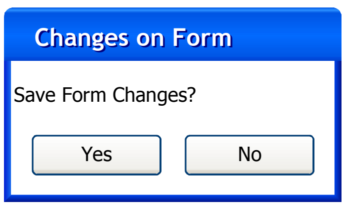
Appendix O

Final Paper Prototypes

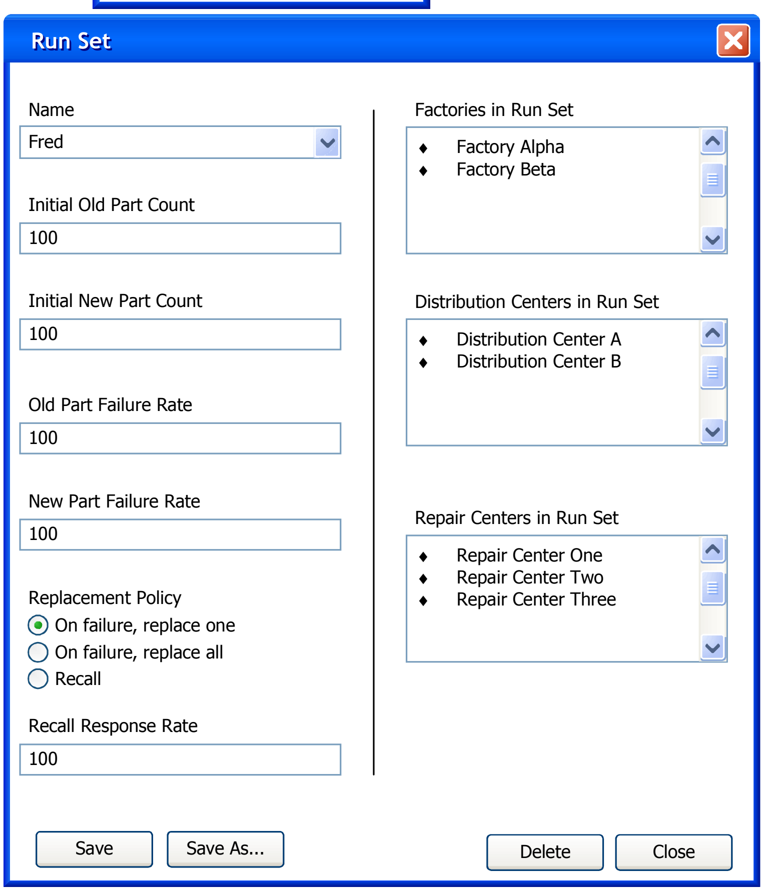


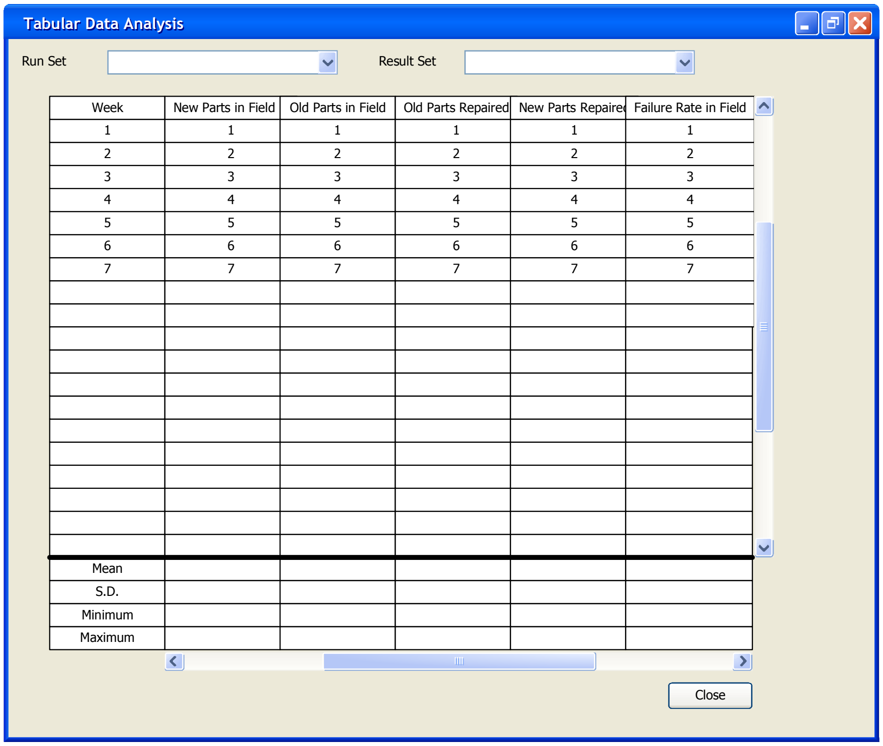
Basic display – main form.

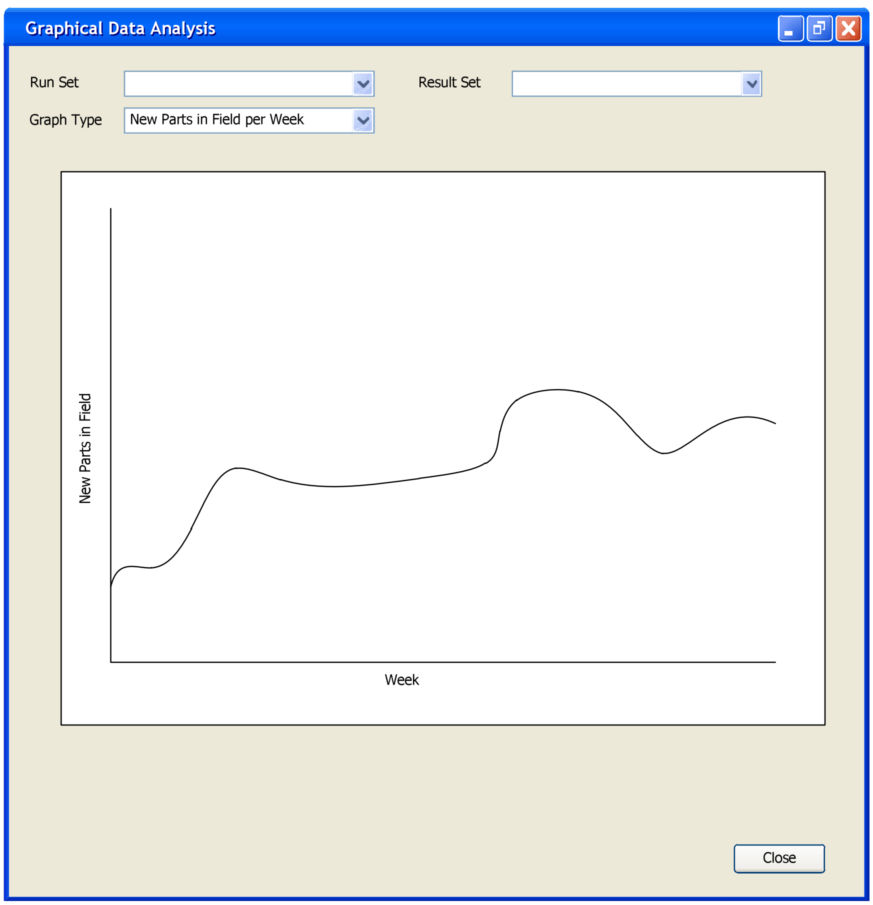




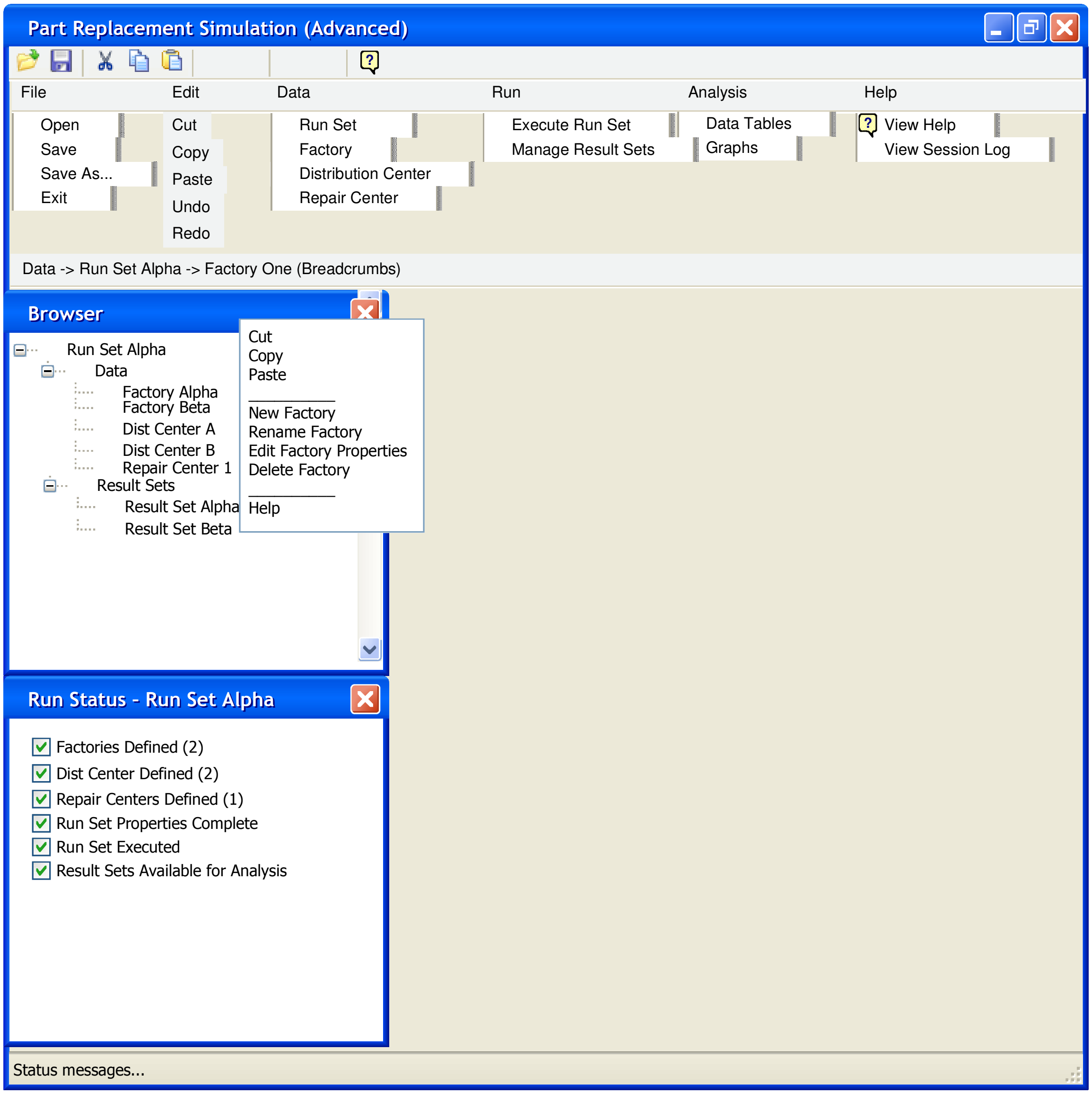
Basic data entry forms – entity and run set.



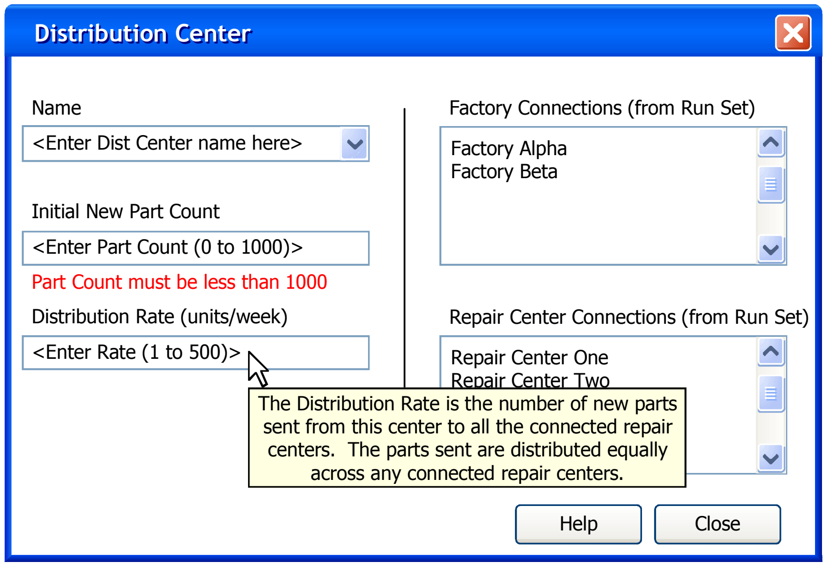


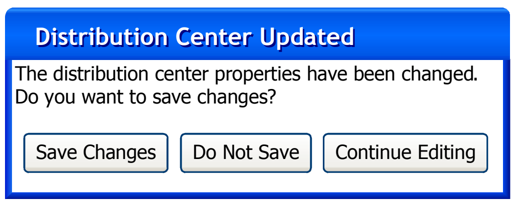


Basic analysis displays – tabular and graphic.

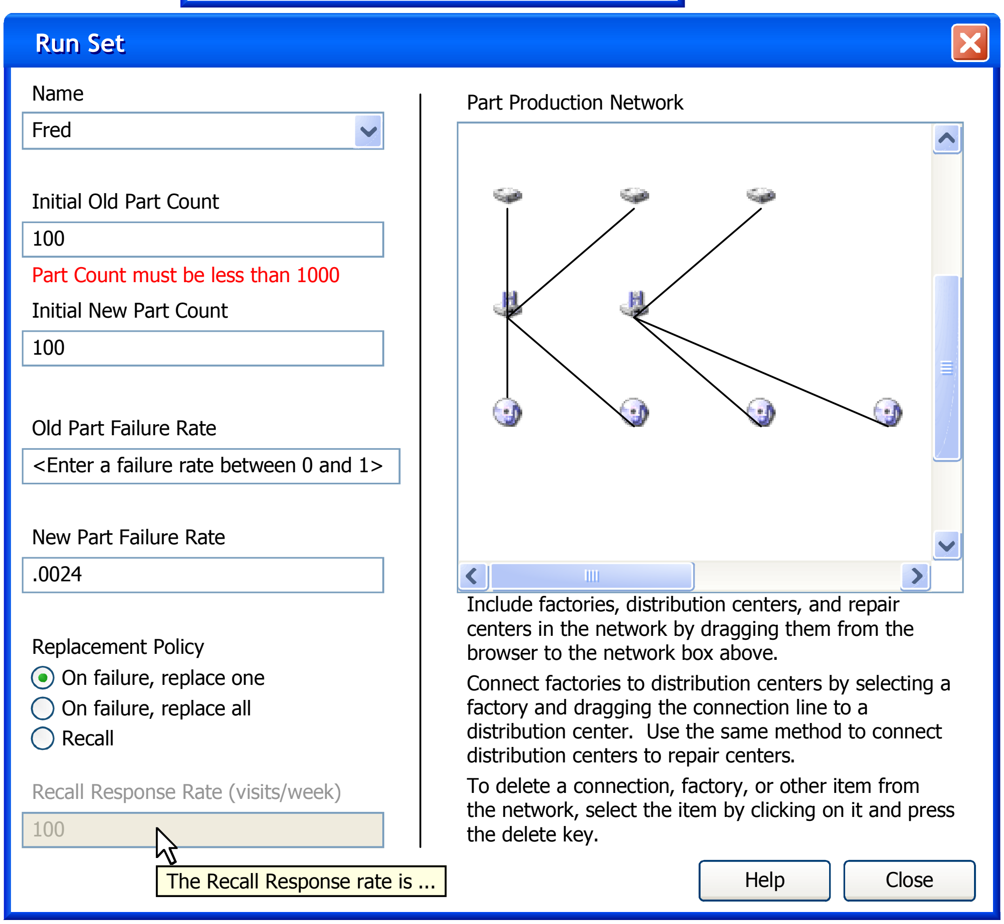


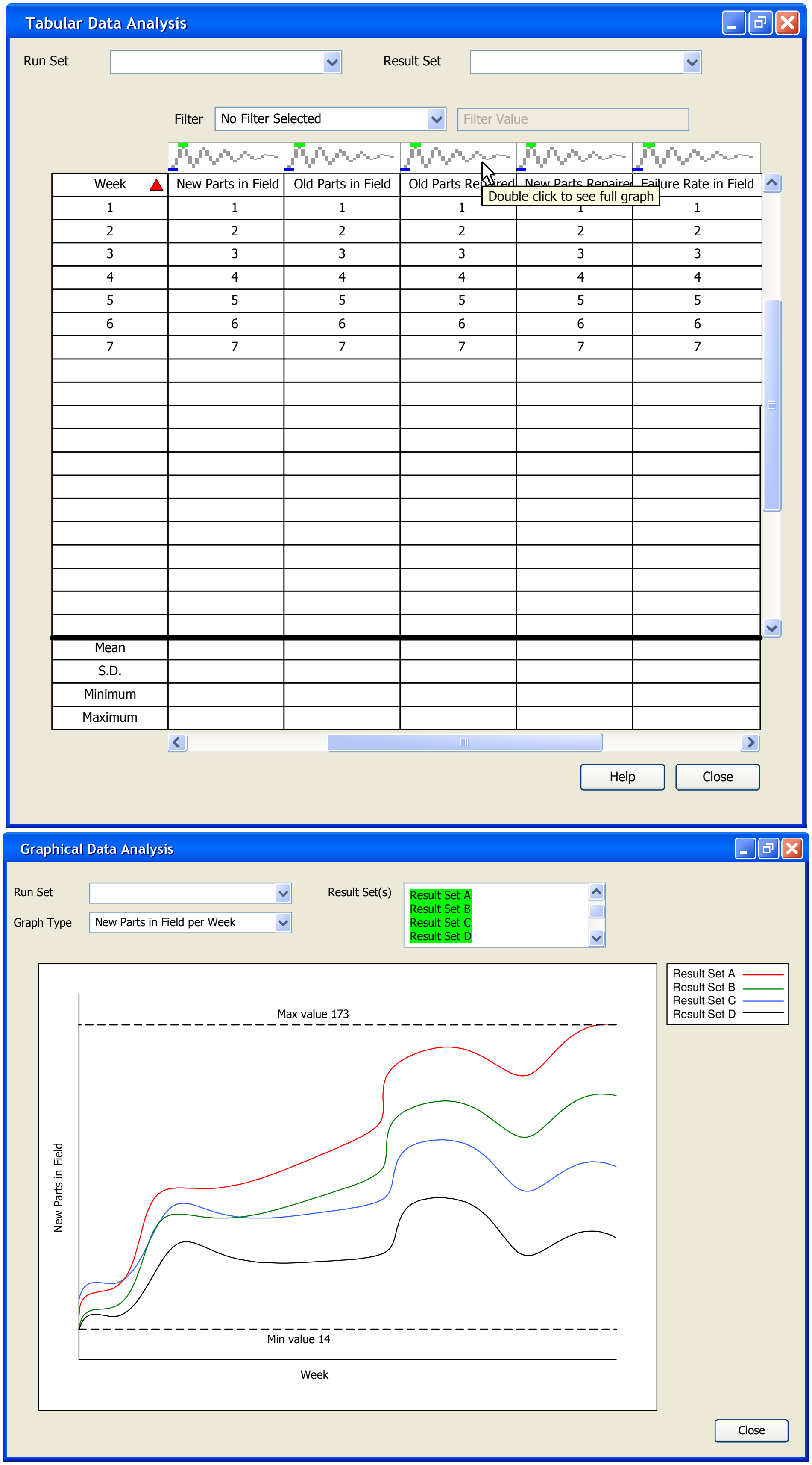
Improved display – main menu/form.





Improved data entry forms – entity and run set.





Improved analysis displays – tabular and graphic.

Appendix P

Assessment Notes from Heuristic Analysis

Assessment Notes from Heuristic Analysis – Basic Interface

Heuristic: Simple and natural dialog and aesthetic and minimalist design
- Simple, Standard – no – Non-natural backward flow (Form 1)
- Not clear where to start, would start at File (Form 1)
- Edit fields not left aligned properly (Forms 3-5)
- Select/unselect all (Form 4)
- Can't read column names (Form 7)
- Menu only form – too abstract (Form 1)
- Not natural (Forms 2-5)
- No label on x-axis (Form 8)

Heuristic: Visibility of the system status – provide feedback
- Invalid options are shown (Form 1)
- No mouse over (Form 2)
- No result or progress bar (Form 6)
- No feedback (Form 1)
- Dependencies unknown, menu for data is not progressive – need to enter factory before run set?
- No feedback on run – do not know if success or fail (Form 6)
- Menu form – no feedback (Form 1)
- Distribution Centers may be empty w/o explanation
- No indication when form data is complete
- No status update for run set execution

Heuristic: Speak the users' language: match between system and real world
- No context for data (Forms 2-6)
- Cannot slice & dice in form (Form 7)
- Cannot compare result sets (Form 7)
- Menu terms are terse (Form 1)
- File/Data – not enough information to know what they are for (Form 1)
- What does delete do (scary for user) (Form 2)
- Relevant data may not be displayable at same time (Form 7)

Heuristic: Minimize the users' cognitive load: recognition rather than recall
- Dependencies not shown, accepts bad data (Forms 2-6)
- Cannot graph more than one data element, no description of x and y axis (Form 8)
- No clear ranges of data or units of measure
- No legends for data axis (Form 8)
- Cannot graph more than one data set (Form 8)
- No way to print (Form 8)
- No way to compare any data sets other than manually.
- No visible options (Form 1)

- On fail – options are not obvious as to what they do (Form 2)
- What is yield? Why does a dist center have a yield? (Form 4)
- User likely to mismatch week # with other data (Forms 7-8)

Heuristic: Consistency and standards
- Labeling style and positioning is not standard (Forms 2-6)
- Unclear if close will save or lose changes (Form 2)
- Delete of last run set?
- Form layouts are not consistent
- Percentages not handled consistently
- Hard to tell from paper model
- General – no idea of units
- Forms have consistent buttons but vary layout

Heuristic: Flexibility and efficiency of use – provide shortcuts
- No hot keys (Form 1)
- Need select all, unselect all (Form 4)
- All forms modal – have to close and open many forms (all forms)
- Could add speed keys
- Not met at all in basic interface – no way to tailor/customize

Heuristic: Support users' control and freedom
- No undo/redo (Forms 2-6)
- Could lose data if close accidentally pressed (Form 2)
- Exit hidden under file not obvious (Form 1)
- No undo/redo
- User will not know what delete does (Forms 2-4)

Heuristic: Prevent user from making errors
- Accepts bad data (Forms 2-6)
- Does not prompt user to save
- Does not check input value limits
- Allows overwriting data (Form 6)
- No prevention evident
- No checking function, all UI functions available regardless of appropriateness – no enable/disable
- No range, data type checks – may cause crashes

Heuristic: Help users recognize, diagnose and recover from errors with constructive error messages.
- No clear path to help
- No solutions suggested with errors
- No errors for bad data – evaluated and then fails
- No feedback

Heuristic: Help and documentation
- Flat file, no links, no sequence of actions, only accessible from form 1 (Form 1)
- No clear path to help
- No context help, no search – may overload user with too much information
- Other:
- Unclear what "answer" is. What is being optimized.
- Could search for answer rather than produce data.

Assessment Notes from Heuristic Analysis – Improved Interface

Note: Many notes from heuristic analysis of became visual markups of screen redesigns.

Heuristic: Simple and natural dialog and aesthetic and minimalist design
- Save/Close – better to use OK/Close
- Avoid horizontal scrolls (Form 1)
- All forms – what grows on resizing?
- Splitters? (Form 7)
- Graph legends (Form 8)
- Generate graph button – How do we tell if current graph is displaying selections? (Form 8)
- Add icons to buttons (Form 2)
- Pulldowns removed from form (Forms 2-4)
- Sort/move columns – clear row header – freeze row 1 – scroll regions together (Form 7)

Heuristic: Visibility of the system status – provide feedback
- Simulation status is good, but needs feedback about which item in browser is selected (Form 1)
- Merge forms 1 & 2 – drop extraneous buttons and status windows – maintain single form view of application as much as possible
- Icons in history?
- Unit display (Forms 2-5)
- Combine forms 1, 2, and 6

Heuristic: Speak the users' language: match between system and real world

Heuristic: Minimize the users' cognitive load: recognition rather than recall
- What does command history mean (Form 1)
- Button to clear history? (Form 1)
- Show all/hide all for tree view (Form 1)
- "add" buttons by facility icons (Form 2)
- Tooltips to network icons
- Date and time stamp result sets

- Tooltips on tree icons

Heuristic: Consistency and standards
- Great use of icons in upper left of each form matching the menus (Form 1)
- Save/Close -> OK/Cancel
- Toolbars on data entry forms

Heuristic: Flexibility and efficiency of use – provide shortcuts
- Default actions on double click for icons?

Heuristic: Support users' control and freedom
- No comments

Heuristic: Prevent user from making errors
- No comments

Heuristic: Help users recognize, diagnose and recover from errors with constructive error messages.
- No comments

Heuristic: Help and documentation
- No comments

Other:
- No comments

Form Numbers:
(1) Main form
(2) Run Set/Network form
(3) Factory
(4) Distributor
(5) Repair Center
(6) Execute Run Set
(7) Tabular Analysis
(8) Graphical Analysis
(9) Log Viewer

Appendix Q

Test Task Handout

Task Instructions for Simulation Data Input and Analysis Experiment

The facilitator will have the interface up and running for your use before you begin. Please follow each task below in order. Please remember to "think aloud" as you perform these tasks.

1) Please enter your subject number ________ in the form shown on the screen and press Start Test Session to continue to the next step.

This simulation looks at the manufacturing, distribution, and repair of parts for industrial machines. The machines each use a set of 6 identical parts. An old version of the part is failing faster than it should; so a new part is being made with a better failure rate.

You will now begin some data entry tasks. Some data for the simulation has already been entered for you. Remember to "think aloud" and talk about what you are doing and why you make your choices on the interface. You may use any part of the application at any time, including Help functions.

2) Add a new Factory. Find a function for adding a new Factory and enter the following data:
    a. Factory Name is "New York"
    b. The Initial New Part Count is 110
    c. The Production Rate is 27
    d. Distribution Rate is 42
    e. Yield is 91.65%
    f. Save your changes when data entry is complete

3) Add a new Distribution Center. Find a function for adding a new Distribution Center and enter the following data:
    a. Distribution Center Name is "Northeast"
    b. Initial New Part Count is 14
    c. Distribution Rate is 175
    d. Yield is 98.27%
    e. Save your changes when data entry is complete

4) From the main form, make the following network connections:
    a. Connect Distribution Center "Northeast" to both Factory "Maryland" and Factory "New York"
    b. Connect Distribution Center "Northeast" to Repair Center "Denver"

5) Delete a Repair Center. Find a function to delete Repair Center "Ocala".
    a. Delete repair center "Ocala"

6) Modify an existing Run Set. Find a function to edit the data for Run Set "Test Cycle 301" and make the following changes:
    a. Change Old Part Count to 19569
    b. Change New Fail Rate to 0.0966
    c. Change Replacement Policy to "On Fail All"
    d. Save your changes when data entry is complete

7) Run the simulation. Find a function to Run Simulation and use the following settings:
    a. Select Run Set "Test Cycle 301"
    b. Enter the Result Set Name as "Added Capacity Model"
    c. Run the Simulation

You will now begin a set of data analysis tasks. Remember to "think aloud" and talk about what you are doing and why you make your choices on the interface.

8) Using the Results - Data Table option, find answers to the following questions. Tell the facilitator what your answer is.
    a. For Result Set "Extra Shift", what is the Mean of "Old Parts Failed"?
    b. For Result Set "Limited Production", what is the smallest value for "Old Parts Running"?
    c. For Result Set "Limited Production", what week does "Repair Parts at Start" go from 28 to 0.
    d. Close the Table analysis form.

9) Using the Results - Graph option, find answers to the following questions. Tell the facilitator what your answer is.
    a. For Result Set "Limited Production", approximately what is the highest value for "New Parts Running"?
    b. For Result Set "Limited Plus", what week does the value of "Old Parts Remaining" reach approximately 18500?
    c. Looking at the "New Parts Remaining" for both Result Sets "Double Line" and "Full Production", which Result Set has the highest value in week 51?
    d. Close the Graph analysis form.

10) Select File and Exit from the Main Menu.

11) Close the Session Manager window.

You have completed the interactive portion of the testing. Please tell the facilitator "I'm done". The facilitator will stop the screen recording, and you may fill out the post-test questionnaire.

Thanks for your participation.

Appendix R

Mathematica Source Code for Simulation Engine

```
(* The Sim Module *)
(* initialize *)
rsOldParts = {}  (* setup the vector of oldparts in the field - when will they fail? *)
rsNewParts = {} (* same *)
rsOldPartsFailed = {}
rsNewPartsFailed = {}
fDistParts = {}
fPartsToD = {}
newPartsToD = {}
dDistParts = {}
dPartsToR = {}
newPartsToR = {}
rsRecallParts = {}
rsReplaceParts = {}
fConns = Tally[Flatten[fToD]][[All,2]]
dConns = Tally[Flatten[dToR]][[All,2]]
runLabels = {"Week","FNewParts","FNewParts+Prod","FNewPartsToD","FNewParts",
  "DNewParts","DNewParts+Prod","DNewPartsToR","DNewParts","rsOldParts","rsNewParts",
  "rsOldPartsFailed","rsNewPartsFailed","rsOldParts","rsNewParts","RNewParts",
  "RNewParts+Prod","rCapacityThisCycle","rRepairable","rNonRepairable"}

productionSim[nWeeks_] := Module[{tMax = nWeeks},
(* list of all initial old part failure times *)
rsOldParts = Floor[50*RandomReal[ExponentialDistribution[rsOldFailureRate],rsOldPartCount]];
(* list of all initial new part failure times *)
rsNewParts = Floor[50*RandomReal[ExponentialDistribution[rsNewFailureRate], rsNewPartCount]];
(* if a recall, how many recall arrivals (failures) for old parts *)
rsRecallPartPercentage = Table[PDF[ChiSquareDistribution[rsRecallRate],x],{x,0,tMax}];
(* Maintain the counts of any failed parts left over from week to week to deal with *)
rNewPartsFailed = Table[0,{Length[rNewParts]}];
rOldPartsFailed = Table[0,{Length[rNewParts]}];
allRunData = {};

(*for t= 0 to n weeks - discrete steps per week *)
For [t=0,t<tMax, t++,
Print ["Week ",t];
runData ={};
runData = Append[runData,t];
(* flow down new parts from factories to distribution to repair centers *)

(* Take new parts at factories this week, flow to connected distributors *)
(* New parts at factory equals what was there plus new production - yield adjustment *)
 Print["fNewParts at start ",fNewParts];
runData = Append[runData,Total[fNewParts]];
fNewParts = fNewParts + Floor[(fProdRate*fYield)];
runData = Append[runData,Total[fNewParts]];
Print["fNewParts w/added production ",fNewParts];
(* Based on the distribution rate, see what parts will be distributed *)
fDistParts =  Partition[Riffle[fNewParts, fDistRate],2];
Print["  fDistParts ",fDistParts];
fDistParts = Min /@ fDistParts;
Print["  fDistParts ",fDistParts];
(* These distributed parts are divided equally to connected distributors *)
fPartsToD = Floor[fDistParts/ fConns];
Print["  fPartsToD ",fPartsToD];
newPartsToD = Map[fPartsToD[[#]] &,fToD];
Print["  newPartsToD ",newPartsToD];
newPartsToD = Total[newPartsToD,{-1}];
Print["  newPartsToD ",newPartsToD];
runData = Append[runData,Total[newPartsToD]];
(* Also calculate what parts are left at the factory *)
fNewParts = If[#<0,0,#]& /@(fNewParts-fDistRate);
Print["fNewParts at end ",fNewParts];
runData = Append[runData,Total[fNewParts]];

(* Take new parts at distributors this week, flow to connected repairers *)
(* New parts at distributors equals what was there plus new arrivals - yield adjustment *)
Print["dNewParts at start ",dNewParts];
runData = Append[runData,Total[dNewParts]];
dNewParts = dNewParts + Floor[(newPartsToD*dYield)];
Print["dNewParts w/added production ",dNewParts];
runData = Append[runData,Total[dNewParts]];
(* Based on the distribution rate, see what parts will be distributed *)
dDistParts =  Partition[Riffle[dNewParts, dDistRate],2];
Print["  dDistParts ",dDistParts];
dDistParts = Min /@ dDistParts;
Print["  dDistParts ",dDistParts];
(* These distributed parts are divided equally to connected distributors *)
dPartsToR = Floor[dDistParts/ dConns];
Print["  dPartsToR ",dPartsToR];
newPartsToR = Map[dPartsToR[[#]] &,dToR];
Print["  newPartsToR ",newPartsToR];
newPartsToR = Total[newPartsToR,{-1}];
Print["  newPartsToR ",newPartsToR];
runData = Append[runData,Total[newPartsToR]];
(* Also calculate what parts are left at the factory *)
dNewParts = If[#<0,0,#]& /@(dNewParts-dDistRate);
Print["dNewParts at end ",dNewParts];
runData = Append[runData,Total[dNewParts]];

(* print - number of old and new parts running at start of week t *)
Print["Count rsOldParts ", Length[rsOldParts], " rsNewParts ", Length[rsNewParts]];
runData = Append[runData,Length[rsOldParts]];
runData = Append[runData,Length[rsNewParts]];
(* print - number of old and new parts failed in week t *)
Print["Count failed Old Parts ", Count[rsOldParts,t]," New Parts ",Count[rsNewParts,t]];
(* save the lists of failed and still active parts*)
```

```
rsOldPartsFailed = Select[rsOldParts, # == t &];
rsNewPartsFailed = Select[rsNewParts, # == t &];
Print["  Old Failed ", Length[rsOldPartsFailed]," New Failed ",Length[rsNewPartsFailed]];
runData = Append[runData,Length[rsOldPartsFailed]];
runData = Append[runData,Length[rsNewPartsFailed]];
rsOldParts = Select[rsOldParts, # != t &];
rsNewParts = Select[rsNewParts, # != t &];
Print["  Old Parts ", Length[rsOldParts]," New Parts ",Length[rsNewParts]];
runData = Append[runData,Length[rsOldParts]];
runData = Append[runData,Length[rsNewParts]];

(* Add parts from production into repair center parts *)
Print["rNewParts at start ",rNewParts];
runData = Append[runData,Total[rNewParts]];
rNewParts = rNewParts + newPartsToR;
Print["rNewParts w/added production ",rNewParts];
runData = Append[runData,Total[rNewParts]];

(* Distribute parts across repair centers *)
r1 = Table[RandomInteger[{0,Length[rNewParts]-1}],{Length[rsNewPartsFailed]}];
rNewPartsFailed = rNewPartsFailed + Tally[Flatten[r1]][[All,2]];
Print ["  rNewPartsFailed ", rNewPartsFailed];
r1 = Table[RandomInteger[{0,Length[rNewParts]-1}],{Length[rsOldPartsFailed]}];
rOldPartsFailed = rOldPartsFailed + Tally[Flatten[r1]][[All,2]];
Print ["  rOldPartsFailed ", rOldPartsFailed];

(* First, fix new broken parts  - with new parts if possible, old if necessary *)
(* Compare to capacity to see what can be fixed, add non repaired parts to next cycle *)
rCapacityThisCycle = rCapacity;
Print ["rCapacityThisCycle ", rCapacityThisCycle];
rRepairable = Min/@ Partition[Riffle[rCapacityThisCycle,rNewPartsFailed],2];
Print ["  rRepairable ", rRepairable];
(* rNonRepairable must be added to the next cycles failed parts! *)
rNonRepairable = If[#<0,0,#]& /@(rNewPartsFailed - rCapacityThisCycle);
Print ["  rNonRepairable ", rNonRepairable];
runData = Append[runData,Total[rCapacityThisCycle]];
runData = Append[runData,Total[rRepairable]];
runData = Append[runData,Total[rNonRepairable]];

(* Fix as many of the repairable parts with new parts as possible *)
rNewPartsFixed = Min/@ Partition[Riffle[rNewParts,rRepairable],2];
Print ["  rNewPartsFixed ", rNewPartsFixed];
rNewPartsNotFixed = If[#<0,0,#]& /@(rRepairable - rNewParts);
Print ["  rNewPartsNotFixed ", rNewPartsNotFixed];
rNewPartsRemaining = If[#<0,0,#]& /@(rNewParts - rRepairable);
Print ["  rNewPartsRemaining ", rNewPartsRemaining];
rNewParts = rNewPartsRemaining;
Print ["  rNewParts ", rNewParts];
rCapacityThisCycle = rCapacityThisCycle - rNewPartsFixed;
Print ["  rCapacityThisCycle ", rCapacityThisCycle];
```

```
(* Count the new parts fixed and add that to the population of running parts starting at time t *)
Print ["  Total[rNewPartsFixed] ", Total[rNewPartsFixed]];
rAddedRunningNewParts = Floor[50*RandomReal[ExponentialDistribution[rsNewFailureRate], Total[rNewPartsFixed]]] + (t+1);
Print ["  rAddedRunningNewParts ", rAddedRunningNewParts];
Print ["  Length[rAddedRunningNewParts] ", Length[rAddedRunningNewParts]];
(* New parts that weren't fixed will be replaced with old parts limited only by capacity *)
rNewPartsFixedWithOld  = Min/@ Partition[Riffle[rNewPartsNotFixed,rCapacityThisCycle],2];
Print ["  rNewPartsFixedWithOld ", rNewPartsFixedWithOld];
rNonRepairableWithOld = If[#<0,0,#]& /@(rNewPartsNotFixed - rCapacityThisCycle);
(* rNonRepairableWithOld must be added to the next cycles failed parts! *)
Print ["  rNonRepairableWithOld ", rNonRepairableWithOld];
rCapacityThisCycle = rCapacityThisCycle - rNewPartsFixedWithOld;
Print ["  rCapacityThisCycle ", rCapacityThisCycle];
Print ["  Total[rNewPartsFixedWithOld] ", Total[rNewPartsFixedWithOld]];
rAddedRunningOldParts = Floor[50*RandomReal[ExponentialDistribution[rsOldFailureRate], Total[rNewPartsFixedWithOld]]] + (t+1);
Print ["  rAddedRunningOldParts ", rAddedRunningOldParts];
Print ["  Length[rAddedRunningOldParts] ", Length[rAddedRunningOldParts]];

(* Now - fix the old failed parts - with new parts if possible, old if necessary *)
(* Compare to capacity to see what can be fixed, add non repaired parts to next cycle *)
rOldRepairable = Min/@ Partition[Riffle[rCapacityThisCycle,rOldPartsFailed],2];
Print ["rOldRepairable ", rOldRepairable];
rOldNonRepairable = If[#<0,0,#]& /@(rOldPartsFailed - rCapacityThisCycle);
(* rOldNonRepairable must be added to the next cycles failed parts! *)
Print ["  rOldNonRepairable ", rOldNonRepairable];
(* Fix as many of the repairable parts with new parts as possible *)
rOldPartsFixed = Min/@ Partition[Riffle[rNewParts,rOldRepairable],2];
Print ["  rOldPartsFixed ", rOldPartsFixed];
rOldPartsNotFixed = If[#<0,0,#]& /@(rOldRepairable - rNewParts);
Print ["  rOldPartsNotFixed ", rOldPartsNotFixed];
rNewPartsRemaining = If[#<0,0,#]& /@(rNewParts - rOldRepairable);
Print ["  rNewPartsRemaining ", rNewPartsRemaining];
rNewParts = rNewPartsRemaining;
Print ["  rNewParts ", rNewParts];
rCapacityThisCycle = rCapacityThisCycle - rOldPartsFixed;
Print ["  rCapacityThisCycle ", rCapacityThisCycle];
(* Count the new parts fixed and add that to the population of running parts starting at time t *)
Print ["  Total[rOldPartsFixed] ", Total[rOldPartsFixed]];
rAddedRunningNewParts = Join[rAddedRunningNewParts,  Floor[50*RandomReal[ExponentialDistribution[rsNewFailureRate],
  Total[rOldPartsFixed]]]+ (t+1)];
Print ["  rAddedRunningNewParts ", rAddedRunningNewParts];
Print ["  Length[rAddedRunningNewParts] ", Length[rAddedRunningNewParts]];
(* New parts that weren't fixed will be replaced with old parts limited only by capacity *)
rOldPartsFixedWithOld  = Min/@ Partition[Riffle[rOldPartsNotFixed,rCapacityThisCycle],2];
Print ["  rOldPartsFixedWithOld ", rOldPartsFixedWithOld];
rOldNonRepairableWithOld = If[#<0,0,#]& /@(rOldPartsNotFixed - rCapacityThisCycle);
(* rOldNonRepairableWithOld must be added to the next cycles failed parts! *)
Print ["  rOldNonRepairableWithOld ", rOldNonRepairableWithOld];
rCapacityThisCycle = rCapacityThisCycle - rOldPartsFixedWithOld;
Print ["  rCapacityThisCycle ", rCapacityThisCycle];
```

```
Print ["  Total[rOldPartsFixedWithOld]  ", Total[rOldPartsFixedWithOld]];
rAddedRunningOldParts = Join [rAddedRunningOldParts, Floor[50*RandomReal[ExponentialDistribution[rsOldFailureRate],
  Total[rOldPartsFixedWithOld]]] + (t+1)];
Print ["  rAddedRunningOldParts ", rAddedRunningOldParts];
Print ["  Length[rAddedRunningOldParts] ",Length[rAddedRunningOldParts]];

(* Add up any parts that can't be repaired this cycle *)
rNewPartsFailed = rNonRepairable + rNonRepairableWithOld;
Print ["  rNewPartsFailed ", rNewPartsFailed];
rOldPartsFailed = rOldNonRepairable + rOldNonRepairableWithOld;
Print ["  rOldPartsFailed ", rOldPartsFailed];

rsNewParts = Join [rsNewParts, rAddedRunningNewParts];
Print ["  rsNewParts ", rNewPartsFixed];
rsOldParts = Join [rsOldParts, rAddedRunningOldParts];
Print ["  rsOldParts ", rOldPartsFixed];
Print["rNewParts after Repairs ",rNewParts];

Print["runLabels ",runLabels];
Print["runData ",runData];
allRunData = Append[allRunData,runData];
Print ["-------------------------------------------"];
];
Print["Parts left running >=",tMax];
Print[" Old ", Length[Select[rsOldParts,# >= tMax &]]];
Print[" New ", Length[Select[rsNewParts,# >= tMax &]]];
]

productionSim[52];
```

Appendix S

Session Notes Form

SESSION NOTES:

Subject Number ____________________ Date _____________ Time Start ____________

____ Consent Form?

____ Review Experiment, Intro Form – Remind users not to rush

____ Start Screen Recorder

____ When Ready To Begin, Provide Task Form

Tasks:

Data Entry:

Enter Subject Number: Completed ____ Notes:

Add Repair Center: Completed ____ Notes:

Add Factory: Completed ____ Notes:

Add Distribution Center: Completed ____ Notes:

Delete Repair Center: Completed ____ Notes:

Modify Run Set: Completed ____ Notes:

Run Simulation: Completed ____ Notes:

Data Table:

Extra Shift – Mean of Old Parts Failed: Completed ___ Value ________ Notes:

Limited Production – Smallest of Old Parts Running: Completed ___ Value _______ Notes:

Limited Production – “Repair Parts at Start” goes from 28 to 0: Completed _____ Value ____
Notes:

Graphs:

Limited Production - highest value for “New Parts Running”: Completed ____ Value ______
Notes:

Limited Plus – week “Old Parts Remaining” reaches 18,500: Completed ____ Value ______
Notes:

Result Set with highest Week 51 value: Value: New Parts Remaining or Full Production
Completed: ____
Notes:

_____ After close, save the recording: Sim1Sub__-MMDDYY.avi

_____ Survey completion

Misc observations:

Appendix T

Raw Collected Experimental Data

Trial	Subject	Interface	FirstInt	DataSecsAll	DataSecsFac	DataSecsDis	DataSecsRun	DataErrAll	DataErrFac	DataErrDis	DataErrRun	DataTaskFail
1.	109.	1.	2.	366.	77.	67.	47.	2.	1.	1.	0.	0.
2.	109.	2.	2.	334.	73.	107.	35.	2.	1.	1.	0.	0.
3.	110.	1.	1.	598.	143.	117.	65.	2.	1.	1.	0.	1.
4.	110.	2.	1.	482.	86.	165.	40.	4.	1.	1.	2.	0.
5.	111.	1.	1.	439.	104.	64.	54.	2.	1.	1.	0.	0.
6.	111.	2.	1.	511.	47.	263.	48.	3.	1.	1.	1.	0.
7.	112.	1.	1.	402.	128.	75.	55.	2.	1.	1.	0.	0.
8.	112.	2.	1.	385.	83.	99.	34.	2.	1.	1.	0.	0.
9.	113.	1.	1.	403.	116.	77.	53.	2.	1.	1.	0.	0.
10.	113.	2.	1.	324.	32.	77.	29.	0.	0.	0.	0.	0.
11.	114.	1.	1.	534.	80.	74.	198.	2.	1.	1.	0.	1.
12.	114.	2.	1.	419.	63.	96.	39.	0.	0.	0.	0.	0.
13.	115.	1.	1.	356.	72.	82.	52.	2.	1.	1.	0.	0.
14.	115.	2.	1.	379.	105.	113.	39.	0.	0.	0.	0.	0.
15.	116.	1.	1.	259.	52.	58.	32.	3.	1.	1.	1.	1.
16.	116.	2.	1.	424.	142.	62.	53.	0.	0.	0.	0.	0.
17.	117.	1.	1.	327.	74.	53.	69.	2.	1.	1.	0.	0.
18.	117.	2.	1.	266.	43.	96.	37.	0.	0.	0.	0.	0.
19.	118.	1.	1.	380.	47.	65.	102.	0.	0.	0.	0.	0.
20.	118.	2.	1.	325.	36.	120.	42.	0.	0.	0.	0.	0.
21.	119.	1.	1.	352.	73.	90.	43.	2.	1.	0.	1.	0.
22.	119.	2.	1.	306.	40.	89.	33.	0.	0.	0.	0.	0.
23.	120.	1.	1.	388.	58.	63.	48.	0.	0.	0.	0.	0.
24.	120.	2.	1.	357.	29.	78.	37.	0.	0.	0.	0.	0.
25.	121.	1.	1.	588.	69.	116.	101.	0.	0.	0.	0.	0.
26.	121.	2.	1.	387.	140.	146.	59.	0.	0.	0.	0.	0.
27.	122.	1.	1.	582.	123.	86.	148.	5.	1.	4.	0.	2.
28.	122.	2.	1.	605.	296.	273.	47.	5.	1.	2.	2.	1.
29.	123.	1.	1.	431.	95.	103.	54.	0.	0.	0.	0.	0.
30.	123.	2.	1.	303.	53.	69.	43.	0.	0.	0.	0.	0.
31.	124.	1.	1.	441.	123.	70.	34.	4.	1.	1.	2.	1.
32.	124.	2.	1.	515.	74.	142.	38.	0.	0.	0.	0.	0.
33.	125.	1.	1.	496.	126.	76.	50.	2.	1.	1.	0.	0.
34.	125.	2.	1.	630.	93.	241.	44.	0.	0.	0.	0.	1.
35.	126.	1.	1.	498.	341.	70.	58.	0.	0.	0.	0.	0.
36.	126.	2.	1.	417.	34.	72.	53.	0.	0.	0.	0.	0.
37.	127.	1.	1.	333.	51.	59.	56.	4.	1.	1.	2.	0.
38.	127.	2.	1.	487.	44.	208.	36.	4.	1.	1.	2.	1.
39.	128.	1.	1.	408.	81.	91.	58.	2.	1.	1.	0.	0.
40.	128.	2.	1.	471.	175.	201.	57.	0.	0.	0.	0.	0.
41.	129.	1.	2.	703.	132.	114.	150.	2.	1.	1.	0.	2.
42.	129.	2.	2.	646.	77.	199.	106.	8.	3.	4.	1.	1.
43.	130.	1.	2.	412.	95.	70.	86.	0.	0.	0.	0.	0.
44.	130.	2.	2.	505.	86.	157.	45.	0.	0.	0.	0.	0.
45.	131.	1.	2.	709.	119.	134.	58.	5.	1.	4.	0.	1.
46.	131.	2.	2.	701.	68.	360.	52.	2.	1.	1.	0.	1.
47.	132.	1.	1.	516.	155.	70.	327.	2.	1.	1.	0.	0.
48.	132.	2.	1.	330.	94.	66.	49.	1.	0.	0.	1.	0.
49.	133.	1.	2.	307.	45.	69.	41.	2.	1.	1.	0.	0.
50.	133.	2.	2.	346.	35.	129.	34.	3.	2.	1.	0.	0.
53.	135.	1.	2.	498.	304.	61.	60.	0.	0.	0.	0.	0.
54.	135.	2.	2.	463.	165.	180.	48.	0.	0.	0.	0.	0.
55.	136.	1.	2.	331.	72.	158.	43.	0.	0.	0.	0.	0.
56.	136.	2.	2.	492.	60.	63.	26.	0.	0.	0.	0.	0.
57.	137.	1.	1.	537.	62.	77.	91.	2.	1.	1.	0.	1.
58.	137.	2.	1.	497.	56.	84.	51.	2.	1.	1.	0.	0.
59.	138.	1.	2.	381.	75.	68.	52.	2.	1.	1.	0.	1.
60.	138.	2.	2.	362.	52.	110.	55.	2.	1.	1.	0.	0.
61.	140.	1.	2.	480.	118.	86.	87.	2.	1.	1.	0.	1.
62.	140.	2.	2.	404.	232.	112.	67.	3.	1.	1.	1.	0.
63.	141.	1.	2.	624.	68.	126.	450.	2.	1.	1.	0.	2.
64.	141.	2.	2.	550.	41.	210.	71.	5.	1.	2.	2.	0.
65.	142.	1.	2.	371.	46.	79.	44.	2.	1.	1.	0.	0.
66.	142.	2.	2.	122.	56.	138.	44.	2.	1.	1.	0.	1.
67.	143.	1.	2.	287.	54.	52.	51.	0.	0.	0.	0.	0.
68.	143.	2.	2.	327.	37.	103.	33.	3.	1.	0.	2.	0.
69.	144.	1.	2.	432.	63.	74.	74.	0.	0.	0.	0.	0.
70.	144.	2.	2.	500.	69.	89.	61.	1.	0.	1.	0.	1.
71.	145.	1.	2.	367.	78.	69.	48.	2.	1.	1.	0.	0.
72.	145.	2.	2.	408.	29.	156.	47.	2.	1.	1.	0.	0.
73.	146.	1.	2.	391.	56.	103.	62.	2.	1.	1.	0.	0.
74.	146.	2.	2.	380.	75.	79.	58.	2.	0.	0.	2.	0.
75.	147.	1.	2.	314.	42.	58.	54.	2.	1.	1.	0.	0.
76.	147.	2.	2.	361.	34.	78.	35.	2.	1.	1.	0.	0.
77.	148.	1.	2.	418.	37.	103.	146.	2.	1.	1.	0.	1.
78.	148.	2.	2.	416.	34.	144.	33.	2.	1.	1.	0.	0.
79.	149.	1.	2.	372.	87.	89.	53.	1.	0.	0.	1.	0.
80.	149.	2.	2.	335.	52.	77.	31.	0.	0.	0.	0.	0.
81.	150.	1.	2.	407.	75.	68.	62.	2.	1.	1.	0.	0.
82.	150.	2.	2.	574.	98.	123.	118.	0.	0.	0.	0.	0.
83.	151.	1.	2.	507.	65.	116.	101.	6.	2.	4.	0.	1.
84.	151.	2.	2.	505.	119.	129.	47.	2.	1.	1.	0.	0.
85.	152.	1.	2.	336.	59.	78.	69.	1.	1.	0.	0.	0.
86.	152.	2.	2.	427.	50.	133.	54.	3.	1.	2.	0.	0.
87.	153.	1.	1.	381.	67.	85.	63.	0.	0.	0.	0.	1.
88.	153.	2.	1.	349.	49.	79.	66.	0.	0.	0.	0.	0.
89.	154.	1.	2.	369.	78.	77.	45.	2.	1.	1.	0.	0.
90.	154.	2.	2.	554.	76.	214.	140.	2.	0.	0.	2.	0.
91.	155.	1.	1.	558.	110.	54.	152.	2.	1.	1.	0.	0.
92.	155.	2.	1.	467.	41.	105.	37.	1.	1.	0.	0.	0.
93.	156.	1.	1.	402.	78.	87.	43.	5.	1.	4.	0.	0.
94.	156.	2.	1.	553.	43.	115.	40.	2.	1.	1.	0.	1.
95.	157.	1.	2.	312.	62.	58.	39.	0.	0.	0.	0.	0.
96.	157.	2.	2.	377.	59.	94.	81.	0.	0.	0.	0.	0.

Trial	Subject	Interface	FirstInt	AnaSecsAll	AnaSecsTab	AnaSecsGraph	AnaErrAll	AnaTaskFail
1.	109.	1.	2.	375.	111.	264.	2.	1.
2.	109.	2.	2.	330.	154.	176.	0.	0.
3.	110.	1.	1.	569.	302.	267.	1.	1.
4.	110.	2.	1.	468.	214.	254.	0.	1.
5.	111.	1.	1.	361.	177.	184.	1.	0.
6.	111.	2.	1.	252.	123.	129.	0.	0.
7.	112.	1.	1.	443.	192.	251.	1.	0.
8.	112.	2.	1.	274.	147.	127.	1.	0.
9.	113.	1.	1.	427.	218.	209.	0.	0.
10.	113.	2.	1.	518.	386.	132.	0.	0.
11.	114.	1.	1.	436.	245.	191.	0.	0.
12.	114.	2.	1.	302.	122.	180.	0.	0.
13.	115.	1.	1.	400.	195.	205.	1.	0.
14.	115.	2.	1.	479.	190.	289.	2.	0.
15.	116.	1.	1.	436.	296.	140.	1.	0.
16.	116.	2.	1.	379.	273.	106.	0.	0.
17.	117.	1.	1.	299.	138.	161.	0.	0.
18.	117.	2.	1.	324.	112.	212.	0.	0.
19.	118.	1.	1.	367.	191.	176.	0.	0.
20.	118.	2.	1.	256.	101.	155.	0.	0.
21.	119.	1.	1.	331.	186.	145.	0.	0.
22.	119.	2.	1.	279.	118.	161.	0.	0.
23.	120.	1.	1.	347.	179.	168.	0.	1.
24.	120.	2.	1.	395.	250.	145.	0.	0.
25.	121.	1.	1.	586.	286.	300.	1.	0.
26.	121.	2.	1.	400.	116.	284.	0.	0.
27.	122.	1.	1.	535.	332.	203.	1.	4.
28.	122.	2.	1.	682.	268.	414.	0.	1.
29.	123.	1.	1.	313.	145.	168.	0.	0.
30.	123.	2.	1.	220.	93.	127.	0.	0.
31.	124.	1.	1.	497.	279.	218.	2.	0.
32.	124.	2.	1.	345.	152.	193.	1.	0.
33.	125.	1.	1.	553.	321.	232.	1.	0.
34.	125.	2.	1.	322.	157.	165.	0.	0.
35.	126.	1.	1.	533.	275.	258.	0.	0.
36.	126.	2.	1.	523.	141.	382.	1.	0.
37.	127.	1.	1.	360.	153.	207.	1.	0.
38.	127.	2.	1.	392.	256.	136.	0.	0.
39.	128.	1.	1.	561.	266.	295.	0.	0.
40.	128.	2.	1.	406.	208.	198.	0.	0.
41.	129.	1.	2.	909.	626.	283.	1.	1.
42.	129.	2.	2.	621.	272.	349.	0.	0.
43.	130.	1.	2.	666.	394.	272.	1.	0.
44.	130.	2.	2.	479.	214.	265.	0.	0.
45.	131.	1.	2.	462.	254.	208.	3.	1.
46.	131.	2.	2.	608.	302.	306.	1.	1.
47.	132.	1.	1.	392.	209.	183.	0.	0.
48.	132.	2.	1.	351.	147.	204.	0.	0.
49.	133.	1.	2.	377.	216.	161.	2.	0.
50.	133.	2.	2.	340.	168.	172.	0.	0.
53.	135.	1.	2.	259.	110.	149.	0.	0.
54.	135.	2.	2.	360.	142.	218.	0.	0.
55.	136.	1.	2.	295.	152.	143.	0.	0.
56.	136.	2.	2.	534.	378.	156.	0.	0.
57.	137.	1.	1.	565.	260.	305.	0.	0.
58.	137.	2.	1.	312.	137.	175.	0.	0.
59.	138.	1.	2.	369.	159.	210.	0.	0.
60.	138.	2.	2.	334.	143.	191.	1.	0.
61.	140.	1.	2.	320.	118.	202.	1.	1.
62.	140.	2.	2.	377.	181.	196.	0.	0.
63.	141.	1.	2.	438.	218.	220.	1.	0.
64.	141.	2.	2.	377.	184.	193.	1.	0.
65.	142.	1.	2.	362.	181.	181.	0.	0.
66.	142.	2.	2.	317.	142.	175.	0.	0.
67.	143.	1.	2.	374.	197.	177.	2.	0.
68.	143.	2.	2.	380.	189.	191.	0.	0.
69.	144.	1.	2.	424.	170.	254.	0.	0.
70.	144.	2.	2.	439.	274.	165.	0.	0.
71.	145.	1.	2.	454.	232.	222.	1.	0.
72.	145.	2.	2.	278.	118.	160.	0.	0.
73.	146.	1.	2.	445.	226.	219.	1.	0.
74.	146.	2.	2.	564.	203.	361.	0.	0.
75.	147.	1.	2.	416.	199.	217.	0.	0.
76.	147.	2.	2.	335.	163.	172.	0.	0.
77.	148.	1.	2.	311.	162.	149.	0.	0.
78.	148.	2.	2.	392.	212.	180.	1.	0.
79.	149.	1.	2.	319.	149.	170.	1.	0.
80.	149.	2.	2.	303.	112.	191.	0.	0.
81.	150.	1.	2.	474.	167.	307.	0.	0.
82.	150.	2.	2.	505.	136.	369.	0.	0.
83.	151.	1.	2.	491.	247.	244.	1.	0.
84.	151.	2.	2.	521.	285.	236.	0.	0.
85.	152.	1.	2.	320.	156.	164.	0.	0.
86.	152.	2.	2.	443.	242.	201.	0.	0.
87.	153.	1.	1.	443.	243.	200.	1.	0.
88.	153.	2.	1.	321.	156.	165.	0.	0.
89.	154.	1.	2.	337.	175.	162.	0.	0.
90.	154.	2.	2.	454.	263.	191.	2.	0.
91.	155.	1.	1.	445.	180.	265.	0.	0.
92.	155.	2.	1.	298.	146.	152.	0.	0.
93.	156.	1.	1.	438.	274.	164.	1.	1.
94.	156.	2.	1.	561.	300.	261.	0.	0.
95.	157.	1.	2.	365.	156.	209.	0.	0.
96.	157.	2.	2.	359.	194.	165.	0.	0.

Trial	Subject	Interface	FirstInt	Uq1	Uq2	Uq3	Uq4	Uq5	Uq6	Uq7	Uq8	Uq9	Uq10
1.	109.	1.	2.	3.	2.	3.	2.	2.	2.	2.	2.	2.	2.
2.	109.	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.	n	2.
3.	110.	1.	1.	2.	2.	1.	2.	1.	2.	1.	1.	2.	2.
4.	110.	2.	1.	3.	2.	1.	2.	1.	1.	1.	1.	2.	1.
5.	111.	1.	1.	3.	3.	2.	3.	2.	2.	2.	2.	6.	4.
6.	111.	2.	1.	2.	2.	2.	2.	3.	2.	2.	1.	3.	2.
7.	112.	1.	1.	2.	1.	2.	3.	1.	1.	1.	1.	4.	3.
8.	112.	2.	1.	1.	1.	1.	1.	1.	1.	1.	1.	2.	1.
9.	113.	1.	1.	2.	3.	2.	2.	2.	3.	2.	1.	6.	4.
10.	113.	2.	1.	2.	2.	2.	2.	2.	2.	2.	2.	n	n
11.	114.	1.	1.	2.	2.	1.	2.	1.	2.	1.	1.	2.	1.
12.	114.	2.	1.	1.	1.	1.	1.	1.	1.	1.	1.	2.	2.
13.	115.	1.	1.	4.	4.	2.	3.	4.	4.	3.	3.	5.	4.
14.	115.	2.	1.	3.	4.	2.	3.	3.	3.	4.	3.	4.	3.
15.	116.	1.	1.	2.	2.	3.	3.	3.	1.	2.	2.	n	3.
16.	116.	2.	1.	1.	1.	2.	2.	2.	2.	2.	1.	1.	2.
17.	117.	1.	1.	2.	1.	1.	3.	2.	1.	1.	1.	n	3.
18.	117.	2.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
19.	118.	1.	1.	2.	1.	2.	2.	1.	1.	1.	1.	3.	3.
20.	118.	2.	1.	2.	1.	2.	1.	2.	1.	2.	1.	3.	2.
21.	119.	1.	1.	6.	5.	5.	5.	6.	4.	4.	5.	n	n
22.	119.	2.	1.	2.	2.	1.	2.	2.	1.	3.	1.	2.	3.
23.	120.	1.	1.	5.	4.	3.	3.	3.	4.	3.	3.	6.	3.
24.	120.	2.	1.	3.	3.	3.	3.	3.	3.	3.	3.	n	n
25.	121.	1.	1.	4.	4.	2.	5.	2.	6.	6.	5.	6.	7.
26.	121.	2.	1.	2.	1.	2.	1.	2.	2.	2.	1.	n	1.
27.	122.	1.	1.	1.	2.	2.	2.	2.	2.	2.	2.	3.	2.
28.	122.	2.	1.	1.	2.	2.	2.	2.	2.	2.	2.	2.	2.
29.	123.	1.	1.	2.	2.	1.	1.	1.	1.	1.	1.	4.	2.
30.	123.	2.	1.	2.	2.	1.	1.	1.	1.	1.	1.	n	n
31.	124.	1.	1.	5.	5.	2.	5.	2.	4.	4.	2.	3.	3.
32.	124.	2.	1.	3.	4.	3.	4.	1.	3.	3.	1.	1.	2.
33.	125.	1.	1.	2.	1.	2.	2.	2.	3.	2.	2.	4.	2.
34.	125.	2.	1.	2.	1.	1.	2.	2.	2.	1.	2.	2.	1.
35.	126.	1.	1.	4.	5.	5.	4.	4.	5.	4.	3.	3.	6.
36.	126.	2.	1.	2.	2.	2.	2.	2.	2.	2.	2.	3.	3.
37.	127.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
38.	127.	2.	1.	1.	2.	2.	1.	1.	1.	1.	1.	2.	1.
39.	128.	1.	1.	3.	2.	2.	2.	3.	3.	2.	2.	n	n
40.	128.	2.	1.	2.	2.	2.	2.	2.	3.	3.	2.	5.	2.
41.	129.	1.	2.	3.	3.	5.	4.	2.	4.	3.	1.	1.	4.
42.	129.	2.	2.	5.	3.	1.	5.	1.	5.	2.	1.	6.	5.
43.	130.	1.	2.	4.	4.	3.	3.	4.	5.	5.	3.	5.	5.
44.	130.	2.	2.	2.	2.	1.	2.	2.	2.	1.	2.	3.	2.
45.	131.	1.	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.
46.	131.	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.
47.	132.	1.	1.	6.	6.	3.	6.	5.	5.	6.	5.	5.	4.
48.	132.	2.	1.	2.	2.	3.	3.	2.	2.	2.	2.	1.	2.
49.	133.	1.	2.	1.	1.	1.	2.	2.	2.	1.	1.	n	n
50.	133.	2.	2.	2.	2.	1.	2.	2.	1.	1.	1.	1.	1.
53.	135.	1.	2.	2.	2.	1.	3.	2.	3.	3.	1.	7.	n
54.	135.	2.	2.	1.	1.	2.	1.	1.	1.	1.	1.	3.	1.
55.	136.	1.	2.	3.	3.	2.	2.	3.	3.	1.	1.	1.	1.
56.	136.	2.	2.	2.	2.	1.	2.	2.	4.	2.	1.	1.	2.
57.	137.	1.	1.	3.	2.	2.	4.	4.	2.	2.	1.	n	2.
58.	137.	2.	1.	1.	1.	1.	1.	1.	1.	1.	1.	n	2.
59.	138.	1.	2.	6.	5.	6.	7.	6.	6.	3.	4.	n	n
60.	138.	2.	2.	2.	2.	2.	2.	2.	3.	2.	1.	4.	3.
61.	140.	1.	2.	6.	4.	4.	6.	5.	5.	5.	7.	6.	5.
62.	140.	2.	2.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
63.	141.	1.	2.	1.	1.	1.	1.	1.	1.	1.	1.	n	1.
64.	141.	2.	2.	1.	2.	1.	2.	1.	1.	1.	1.	n	1.
65.	142.	1.	2.	2.	2.	2.	3.	3.	2.	2.	2.	n	3.
66.	142.	2.	2.	3.	3.	2.	2.	2.	2.	2.	2.	n	4.
67.	143.	1.	2.	3.	2.	2.	2.	2.	3.	3.	3.	n	3.
68.	143.	2.	2.	2.	2.	1.	3.	2.	2.	2.	1.	1.	1.
69.	144.	1.	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.	n
70.	144.	2.	2.	2.	3.	2.	2.	2.	2.	2.	3.	2.	2.
71.	145.	1.	2.	1.	2.	1.	2.	3.	2.	1.	2.	1.	1.
72.	145.	2.	2.	2.	2.	2.	1.	2.	1.	1.	1.	1.	2.
73.	146.	1.	2.	6.	6.	5.	5.	5.	4.	5.	7.	n	n
74.	146.	2.	2.	2.	2.	2.	2.	2.	1.	1.	2.	4.	3.
75.	147.	1.	2.	6.	6.	5.	5.	5.	5.	3.	4.	n	n
76.	147.	2.	2.	2.	1.	1.	2.	2.	2.	1.	1.	5.	2.
77.	148.	1.	2.	2.	2.	1.	2.	2.	1.	1.	3.	2.	3.
78.	148.	2.	2.	2.	1.	1.	2.	1.	1.	1.	1.	n	1.
79.	149.	1.	2.	5.	4.	4.	5.	4.	4.	4.	3.	3.	3.
80.	149.	2.	2.	2.	2.	1.	1.	1.	1.	1.	1.	3.	2.
81.	150.	1.	2.	3.	4.	2.	3.	4.	4.	4.	3.	5.	4.
82.	150.	2.	2.	2.	1.	1.	2.	1.	1.	1.	1.	4.	4.
83.	151.	1.	2.	1.	1.	1.	1.	2.	1.	1.	1.	2.	1.
84.	151.	2.	2.	1.	1.	1.	2.	2.	1.	1.	1.	1.	1.
85.	152.	1.	2.	1.	1.	1.	1.	1.	1.	1.	1.	n	n
86.	152.	2.	2.	1.	1.	1.	1.	1.	1.	1.	1.	n	1.
87.	153.	1.	1.	2.	1.	2.	2.	1.	1.	1.	1.	3.	1.
88.	153.	2.	1.	2.	1.	1.	2.	1.	1.	1.	1.	2.	1.
89.	154.	1.	2.	3.	2.	3.	4.	2.	3.	1.	2.	4.	3.
90.	154.	2.	2.	4.	5.	2.	3.	4.	5.	4.	4.	7.	5.
91.	155.	1.	1.	2.	3.	3.	3.	4.	1.	2.	1.	7.	6.
92.	155.	2.	1.	2.	1.	1.	2.	1.	1.	1.	1.	4.	1.
93.	156.	1.	1.	3.	3.	3.	2.	2.	2.	4.	2.	4.	1.
94.	156.	2.	1.	3.	3.	6.	4.	5.	4.	3.	3.	7.	7.
95.	157.	1.	2.	5.	5.	4.	4.	4.	5.	3.	4.	n	n
96.	157.	2.	2.	2.	2.	1.	1.	2.	2.	1.	1.	1.	1.

Trial	Subject	Interface	FirstInt	Uq11	Uq12	Uq13	Uq14	Uq15	Uq16	Uq17	Uq18
1.	109.	1.	2.	2.	2.	2.	2.	2.	2.	2.	2.
2.	109.	2.	2.	n	2.	2.	2.	2.	2.	2.	2.
3.	110.	1.	1.	1.	1.	1.	2.	2.	1.	1.	2.
4.	110.	2.	1.	2.	1.	1.	2.	3.	2.	1.	2.
5.	111.	1.	1.	3.	3.	3.	4.	2.	2.	3.	4.
6.	111.	2.	1.	2.	2.	2.	2.	2.	2.	2.	3.
7.	112.	1.	1.	5.	2.	1.	2.	1.	1.	2.	2.
8.	112.	2.	1.	1.	1.	1.	1.	2.	1.	1.	1.
9.	113.	1.	1.	4.	3.	2.	2.	2.	3.	2.	3.
10.	113.	2.	1.	n	2.	2.	2.	2.	2.	2.	n
11.	114.	1.	1.	2.	2.	1.	2.	2.	2.	1.	2.
12.	114.	2.	1.	1.	1.	1.	1.	1.	1.	1.	1.
13.	115.	1.	1.	5.	3.	3.	3.	4.	4.	4.	4.
14.	115.	2.	1.	3.	4.	4.	3.	4.	2.	3.	3.
15.	116.	1.	1.	n	3.	3.	3.	2.	3.	3.	2.
16.	116.	2.	1.	1.	1.	1.	1.	2.	2.	1.	2.
17.	117.	1.	1.	n	2.	2.	2.	1.	2.	1.	1.
18.	117.	2.	1.	2.	1.	1.	1.	2.	2.	1.	1.
19.	118.	1.	1.	3.	2.	2.	2.	1.	2.	2.	2.
20.	118.	2.	1.	2.	2.	1.	2.	1.	3.	3.	2.
21.	119.	1.	1.	7.	6.	7.	6.	5.	5.	5.	7.
22.	119.	2.	1.	n	n	n	n	2.	2.	1.	3.
23.	120.	1.	1.	n	4.	3.	4.	3.	2.	4.	2.
24.	120.	2.	1.	n	5.	4.	4.	5.	4.	5.	4.
25.	121.	1.	1.	7.	7.	6.	6.	7.	6.	7.	5.
26.	121.	2.	1.	6.	2.	2.	2.	2.	2.	1.	1.
27.	122.	1.	1.	3.	2.	2.	2.	2.	2.	2.	2.
28.	122.	2.	1.	2.	2.	2.	2.	2.	2.	1.	2.
29.	123.	1.	1.	4.	1.	2.	1.	1.	1.	1.	1.
30.	123.	2.	1.	n	1.	1.	1.	2.	1.	1.	1.
31.	124.	1.	1.	n	3.	4.	4.	3.	3.	5.	3.
32.	124.	2.	1.	2.	2.	4.	4.	3.	5.	5.	6.
33.	125.	1.	1.	n	1.	1.	2.	2.	1.	1.	1.
34.	125.	2.	1.	1.	1.	1.	1.	2.	1.	1.	1.
35.	126.	1.	1.	3.	6.	5.	6.	3.	3.	4.	2.
36.	126.	2.	1.	4.	2.	2.	2.	2.	2.	2.	2.
37.	127.	1.	1.	1.	1.	1.	1.	2.	1.	2.	1.
38.	127.	2.	1.	n	1.	1.	1.	1.	2.	2.	2.
39.	128.	1.	1.	3.	2.	3.	2.	2.	2.	2.	2.
40.	128.	2.	1.	3.	2.	2.	3.	2.	3.	3.	2.
41.	129.	1.	2.	3.	4.	5.	5.	2.	3.	3.	4.
42.	129.	2.	2.	2.	4.	4.	1.	3.	3.	5.	3.
43.	130.	1.	2.	5.	4.	3.	4.	5.	3.	4.	5.
44.	130.	2.	2.	3.	2.	2.	2.	2.	2.	2.	2.
45.	131.	1.	2.	2.	2.	2.	2.	2.	2.	2.	2.
46.	131.	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.
47.	132.	1.	1.	6.	6.	5.	5.	6.	4.	5.	4.
48.	132.	2.	1.	2.	2.	2.	2.	2.	2.	3.	3.
49.	133.	1.	2.	1.	1.	1.	1.	2.	1.	2.	2.
50.	133.	2.	2.	1.	2.	1.	1.	1.	1.	1.	2.
53.	135.	1.	2.	7.	2.	2.	1.	1.	3.	3.	2.
54.	135.	2.	2.	2.	2.	3.	3.	1.	1.	1.	2.
55.	136.	1.	2.	2.	4.	2.	2.	1.	3.	3.	3.
56.	136.	2.	2.	3.	2.	2.	2.	2.	2.	3.	4.
57.	137.	1.	1.	n	n	2.	2.	1.	2.	2.	n
58.	137.	2.	1.	n	2.	1.	1.	2.	1.	1.	n
59.	138.	1.	2.	7.	7.	4.	n	6.	7.	7.	7.
60.	138.	2.	2.	4.	2.	3.	2.	2.	3.	3.	4.
61.	140.	1.	2.	7.	6.	6.	6.	5.	6.	6.	6.
62.	140.	2.	2.	1.	1.	1.	1.	1.	1.	1.	1.
63.	141.	1.	2.	n	1.	1.	1.	1.	1.	1.	1.
64.	141.	2.	2.	4.	1.	1.	1.	1.	1.	1.	1.
65.	142.	1.	2.	3.	3.	3.	3.	3.	2.	2.	3.
66.	142.	2.	2.	3.	3.	3.	3.	3.	3.	2.	3.
67.	143.	1.	2.	n	4.	2.	2.	4.	3.	3.	3.
68.	143.	2.	2.	n	2.	2.	1.	2.	1.	2.	2.
69.	144.	1.	2.	n	2.	2.	2.	2.	2.	2.	2.
70.	144.	2.	2.	2.	2.	2.	2.	2.	3.	3.	3.
71.	145.	1.	2.	1.	2.	2.	2.	2.	1.	1.	3.
72.	145.	2.	2.	1.	1.	1.	1.	2.	1.	1.	2.
73.	146.	1.	2.	6.	5.	6.	6.	7.	5.	6.	7.
74.	146.	2.	2.	n	2.	1.	2.	3.	2.	1.	2.
75.	147.	1.	2.	n	6.	4.	4.	3.	4.	3.	6.
76.	147.	2.	2.	n	2.	2.	2.	2.	2.	1.	3.
77.	148.	1.	2.	1.	2.	1.	1.	1.	1.	2.	1.
78.	148.	2.	2.	1.	1.	1.	1.	1.	1.	1.	1.
79.	149.	1.	2.	3.	5.	5.	4.	4.	4.	5.	3.
80.	149.	2.	2.	1.	1.	1.	1.	1.	2.	1.	1.
81.	150.	1.	2.	4.	5.	5.	4.	5.	5.	5.	5.
82.	150.	2.	2.	3.	2.	3.	2.	1.	1.	1.	1.
83.	151.	1.	2.	2.	1.	1.	2.	1.	2.	1.	1.
84.	151.	2.	2.	1.	2.	1.	1.	1.	1.	1.	1.
85.	152.	1.	2.	1.	1.	1.	1.	1.	1.	1.	1.
86.	152.	2.	2.	n	1.	1.	1.	1.	1.	1.	1.
87.	153.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
88.	153.	2.	1.	2.	1.	1.	1.	1.	1.	1.	1.
89.	154.	1.	2.	4.	1.	2.	3.	2.	2.	3.	3.
90.	154.	2.	2.	7.	5.	6.	6.	5.	4.	5.	4.
91.	155.	1.	1.	n	n	3.	5.	5.	2.	2.	1.
92.	155.	2.	1.	n	3.	3.	2.	2.	1.	1.	1.
93.	156.	1.	1.	1.	4.	4.	2.	4.	1.	1.	1.
94.	156.	2.	1.	2.	4.	4.	3.	3.	2.	4.	4.
95.	157.	1.	2.	6.	4.	4.	4.	4.	4.	4.	6.
96.	157.	2.	2.	1.	2.	1.	1.	1.	1.	1.	1.

Trial	Subject	Interface	FirstInt	Uq19	UqOverall	UqUseful	UqInfoQual
1.	109.	1.	2.	2.	2.10526	2.25	2.
2.	109.	2.	2.	2.	2.	2.	2.
3.	110.	1.	1.	2.	1.52632	1.5	1.57143
4.	110.	2.	1.	2.	1.63158	1.5	1.71429
5.	111.	1.	1.	3.	2.94737	2.375	3.57143
6.	111.	2.	1.	2.	2.10526	2.	2.14286
7.	112.	1.	1.	2.	1.94737	1.5	2.57143
8.	112.	2.	1.	1.	1.10526	1.	1.28571
9.	113.	1.	1.	3.	2.68421	2.125	3.28571
10.	113.	2.	1.	2.	2.	2.	2.
11.	114.	1.	1.	1.	1.57895	1.5	1.71429
12.	114.	2.	1.	1.	1.10526	1.	1.28571
13.	115.	1.	1.	4.	3.68421	3.375	3.85714
14.	115.	2.	1.	3.	3.21053	3.125	3.57143
15.	116.	1.	1.	2.	2.47059	2.25	2.8
16.	116.	2.	1.	2.	1.52632	1.625	1.28571
17.	117.	1.	1.	1.	1.58824	1.5	2.
18.	117.	2.	1.	1.	1.15789	1.	1.28571
19.	118.	1.	1.	2.	1.84211	1.375	2.28571
20.	118.	2.	1.	2.	1.84211	1.5	1.85714
21.	119.	1.	1.	6.	5.52941	5.	6.2
22.	119.	2.	1.	2.	1.93333	1.75	2.33333
23.	120.	1.	1.	2.	3.38889	3.5	3.83333
24.	120.	2.	1.	4.	3.6875	3.	4.5
25.	121.	1.	1.	6.	5.47368	4.25	6.57143
26.	121.	2.	1.	2.	1.88889	1.625	2.5
27.	122.	1.	1.	2.	2.05263	1.875	2.28571
28.	122.	2.	1.	1.	1.84211	1.875	2.
29.	123.	1.	1.	2.	1.57895	1.25	2.14286
30.	123.	2.	1.	2.	1.25	1.25	1.25
31.	124.	1.	1.	2.	3.44444	3.625	3.33333
32.	124.	2.	1.	5.	3.21053	2.75	2.57143
33.	125.	1.	1.	1.	1.77778	2.	2.
34.	125.	2.	1.	1.	1.36842	1.625	1.28571
35.	126.	1.	1.	4.	4.15789	4.25	4.57143
36.	126.	2.	1.	2.	2.21053	2.	2.57143
37.	127.	1.	1.	1.	1.10526	1.	1.14286
38.	127.	2.	1.	2.	1.38889	1.25	1.16667
39.	128.	1.	1.	2.	2.29412	2.375	2.4
40.	128.	2.	1.	2.	2.47368	2.25	2.71429
41.	129.	1.	2.	3.	3.26316	3.125	3.42857
42.	129.	2.	2.	2.	3.21053	2.875	3.57143
43.	130.	1.	2.	5.	4.15789	3.875	4.42857
44.	130.	2.	2.	2.	2.	1.75	2.28571
45.	131.	1.	2.	2.	2.	2.	2.
46.	131.	2.	2.	2.	2.	2.	2.
47.	132.	1.	1.	5.	5.10526	5.25	5.28571
48.	132.	2.	1.	2.	2.15789	2.25	1.85714
49.	133.	1.	2.	1.	1.35294	1.375	1.2
50.	133.	2.	2.	1.	1.31579	1.5	1.14286
53.	135.	1.	2.	3.	2.66667	2.125	3.33333
54.	135.	2.	2.	1.	1.52632	1.125	2.14286
55.	136.	1.	2.	2.	2.21053	2.25	1.85714
56.	136.	2.	2.	2.	2.15789	2.	2.
57.	137.	1.	1.	2.	2.2	2.5	1.75
58.	137.	2.	1.	1.	1.1875	1.	1.6
59.	138.	1.	2.	7.	5.9375	5.375	6.
60.	138.	2.	2.	2.	2.52632	2.	2.85714
61.	140.	1.	2.	6.	5.63158	5.25	5.85714
62.	140.	2.	2.	1.	1.	1.	1.
63.	141.	1.	2.	1.	1.	1.	1.
64.	141.	2.	2.	1.	1.27778	1.25	1.5
65.	142.	1.	2.	3.	2.55556	2.25	3.
66.	142.	2.	2.	3.	2.66667	2.25	3.16667
67.	143.	1.	2.	3.	2.76471	2.5	3.
68.	143.	2.	2.	1.	1.66667	1.875	1.5
69.	144.	1.	2.	2.	2.	2.	2.
70.	144.	2.	2.	3.	2.31579	2.25	2.
71.	145.	1.	2.	2.	1.68421	1.75	1.57143
72.	145.	2.	2.	1.	1.36842	1.5	1.28571
73.	146.	1.	2.	6.	5.70588	5.375	6.
74.	146.	2.	2.	2.	2.	1.75	2.5
75.	147.	1.	2.	4.	4.5625	4.875	4.25
76.	147.	2.	2.	2.	1.94444	1.5	2.5
77.	148.	1.	2.	1.	1.57895	1.75	1.57143
78.	148.	2.	2.	1.	1.11111	1.25	1.
79.	149.	1.	2.	4.	4.	4.125	3.85714
80.	149.	2.	2.	1.	1.31579	1.25	1.42857
81.	150.	1.	2.	5.	4.15789	3.375	4.57143
82.	150.	2.	2.	1.	1.73684	1.25	2.71429
83.	151.	1.	2.	1.	1.26316	1.125	1.42857
84.	151.	2.	2.	1.	1.15789	1.25	1.14286
85.	152.	1.	2.	1.	1.	1.	1.
86.	152.	2.	2.	1.	1.	1.	1.
87.	153.	1.	1.	1.	1.26316	1.375	1.28571
88.	153.	2.	1.	1.	1.21053	1.25	1.28571
89.	154.	1.	2.	3.	2.63158	2.5	2.71429
90.	154.	2.	2.	3.	4.63158	3.875	5.85714
91.	155.	1.	1.	2.	3.05882	2.375	5.2
92.	155.	2.	1.	2.	1.66667	1.25	2.5
93.	156.	1.	1.	3.	2.47368	2.625	2.85714
94.	156.	2.	1.	5.	4.	3.875	4.28571
95.	157.	1.	2.	5.	4.41176	4.25	4.4
96.	157.	2.	2.	1.	1.26316	1.5	1.14286

Appendix U1

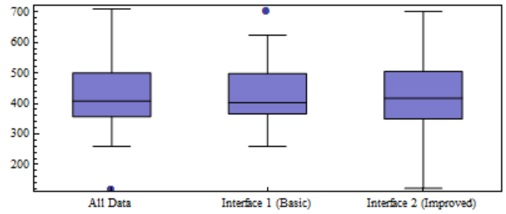
Data Analysis Details – Data Entry

Measure: **DataSecsAll** (Data Entry Seconds All Tasks) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	122.	259.	122.
25% Quartile	357.	366.25	351.
Median	408.	403.	417.
75% Quartile	500.	498.	503.75
Max	709.	709.	701.
Mean	431.713	431.979	431.447
S.D.	107.294	105.275	110.415
Variance	11512.1	11082.8	12191.5

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	6.64894	6.64894	0.000565274	0.981084
firstInt	1	244.524	244.524	0.0207887	0.885675
Error	91	1.07037×10^{6}	11762.3		
Total	93	1.07062×10^{6}			

Cell Means

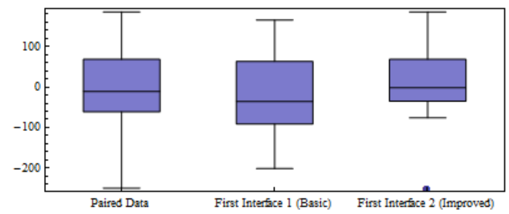
All	431.713
interface[1.]	431.979
interface[2.]	431.447
firstInt[1.]	433.292
firstInt[2.]	430.065

Measure: **DataSecsAll** (Data Entry Seconds All Tasks) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-249.	-201.	-249.
25% Quartile	-60.	-86.	-34.25
Median	-11.	-36.	-2.
75% Quartile	67.25	67.5	67.25
Max	185.	165.	185.
Mean	-0.531915	-17.5	17.1739
S.D.	100.082	104.656	94.0781
Variance	10016.3	10952.9	8850.7

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	14120.4	14120.4	1.42269	0.239213
Error	45	446631.	9925.14		
Total	46	460752.			

Cell Means

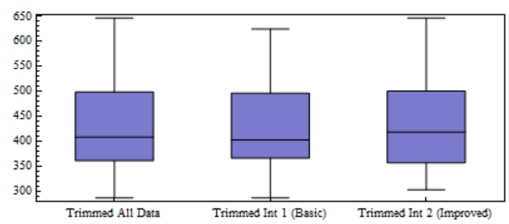
All	-0.531915
firstInt[1.]	-17.5
firstInt[2.]	17.1739

Measure: **DataSecsAll** (Data Entry Seconds All Tasks) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	44	44
Min	287.	287.	303.
25% Quartile	361.5	366.5	359.
Median	408.	402.5	418.
75% Quartile	498.	497.	502.5
Max	646.	624.	646.
Mean	429.784	423.455	436.114
S.D.	89.3195	87.1375	92.0137
Variance	7977.96	7592.95	8466.52

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	3525.56	3525.56	0.44132	0.508284
firstInt	1	11521.1	11521.1	1.44218	0.233123
Error	85	679036.	7988.66		
Total	87	694083.			

Cell Means

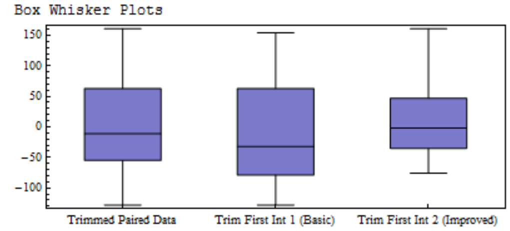
All	429.784
interface[1.]	423.455
interface[2.]	436.114
firstInt[1.]	440.717
firstInt[2.]	417.81

Measure: **DataSecsAll** (Data Entry Seconds All Tasks) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	21	20
Min	-128.	-128.	-76.
25% Quartile	-55.5	-79.5	-33.5
Median	-11.	-32.	-2.
75% Quartile	63.5	65.25	56.
Max	161.	154.	161.
Mean	2.29268	-9.42857	14.6
S.D.	76.52	88.0844	62.036
Variance	5855.31	7758.86	3848.46

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	5914.54	5914.54	1.01038	0.321008
Error	39	228298.	5853.79		
Total	40	234212.			

Cell Means

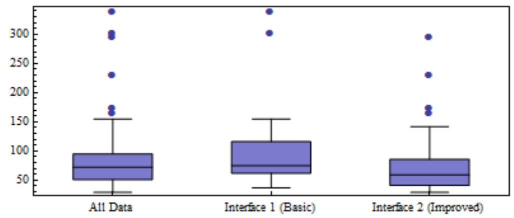
All	2.29268
firstInt[1.]	-9.42857
firstInt[2.]	14.6

Measure: **DataSecsFac** (Data Entry Seconds Factory) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	29.	37.	29.
25% Quartile	51.	62.	41.5
Median	72.	75.	59.
75% Quartile	95.	114.5	86.
Max	341.	341.	296.
Mean	84.1489	92.234	76.0638
S.D.	55.6888	57.1726	53.5502
Variance	3101.25	3268.7	2867.63

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	6144.68	6144.68	2.00585	0.160108
firstInt	1	3503.01	3503.01	1.14351	0.28774
Error	91	278 768.	3063.39		
Total	93	288 416.			

Cell Means

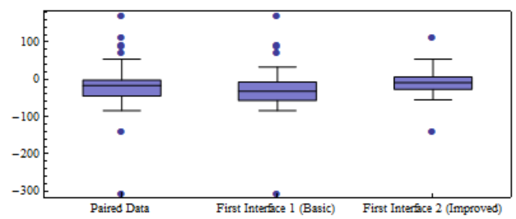
All	84.1489
interface[1.]	92.234
interface[2.]	76.0638
firstInt[1.]	90.125
firstInt[2.]	77.913

Measure: **DataSecsFac** (Data Entry Seconds Factory) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-307.	-307.	-139.
25% Quartile	-44.25	-53.	-26.
Median	-17.	-32.	-9.
75% Quartile	-2.25	-6.5	4.
Max	173.	173.	114.
Mean	-16.1702	-22.0833	-10.
S.D.	68.647	85.9195	45.3602
Variance	4712.41	7382.17	2057.55

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	1714.8	1714.8	0.358819	0.552166
Error	45	215 056.	4779.02		
Total	46	216 771.			

Cell Means

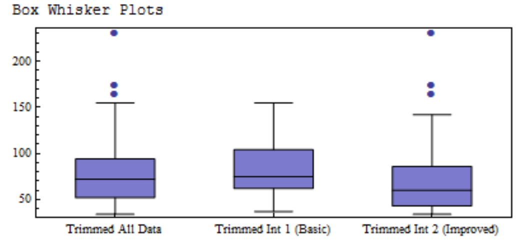
All	-16.1702
firstInt[1.]	-22.0833
firstInt[2.]	-10.

Measure: **DataSecsFac** (Data Entry Seconds Factory) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	45	43
Min	34.	37.	34.
25% Quartile	52.	61.25	43.25
Median	72.	75.	60.
75% Quartile	94.5	105.5	86.
Max	232.	155.	232.
Mean	78.1705	82.	74.1628
S.D.	36.7158	29.7405	42.8207
Variance	1348.05	884.5	1833.62

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	1350.58	1350.58	1.00366	0.319269
firstInt	1	1549.45	1549.45	1.15145	0.286283
Error	85	114 380.	1345.65		
Total	87	117 280.			

Cell Means

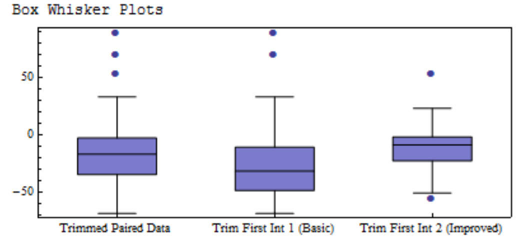
All	78.1705
interface[1.]	82.
interface[2.]	74.1628
firstInt[1.]	82.4545
firstInt[2.]	73.8864

Measure: **DataSecsFac** (Data Entry Seconds Factory) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	20	21
Min	-69.	-69.	-55.
25% Quartile	-36.75	-47.	-24.
Median	-17.	-32.	-9.
75% Quartile	-3.	-9.	0.
Max	90.	90.	54.
Mean	-14.9024	-20.3	-9.7619
S.D.	34.4846	41.7903	25.7369
Variance	1189.19	1746.43	662.39

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	1137.6	1137.6	0.955555	0.334334
Error	39	46 430.	1190.51		
Total	40	47 567.6			

Cell Means

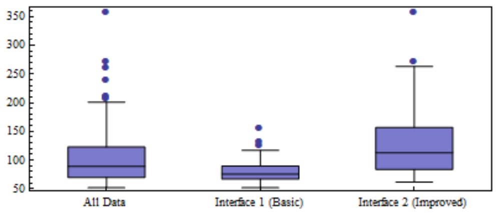
All	-14.9024
firstInt[1.]	-20.3
firstInt[2.]	-9.7619

Measure: **DataSecsDis** (Data Entry Seconds Distributor) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	52.	52.	62.
25% Quartile	70.	67.25	85.25
Median	89.	76.	113.
75% Quartile	123.	89.75	156.75
Max	360.	158.	360.
Mean	107.255	81.6809	132.83
S.D.	54.2834	23.1236	63.9233
Variance	2946.69	534.7	4086.19

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	61481.	61481.	26.5959	1.45481×10^{-6}
firstInt	1	2198.65	2198.65	0.95111	0.332022
Error	91	210362.	2311.67		
Total	93	274042.			

Cell Means

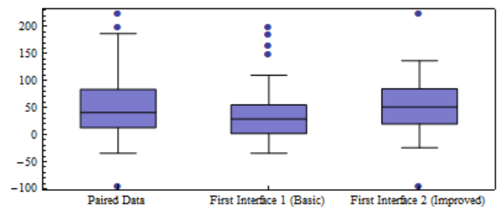
All	107.255
interface[1.]	81.6809
interface[2.]	132.83
firstInt[1.]	102.521
firstInt[2.]	112.196

Measure: **DataSecsDis** (Data Entry Seconds Distributor) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-95.	-34.	-95.
25% Quartile	13.5	3.	21.5
Median	41.	29.	51.
75% Quartile	81.	63.5	84.75
Max	226.	199.	226.
Mean	51.1489	49.875	52.4783
S.D.	62.5574	64.7962	61.5599
Variance	3913.43	4198.55	3789.62

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	79.5933	79.5933	0.0199051	0.888432
Error	45	179938.	3998.63		
Total	46	180018.			

Cell Means

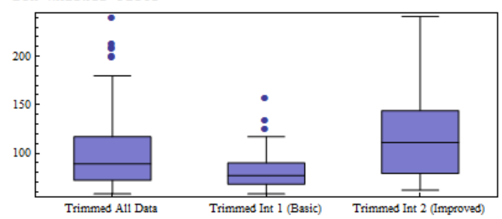
All	51.1489
firstInt[1.]	49.875
firstInt[2.]	52.4783

Measure: **DataSecsDis** (Data Entry Seconds Distributor) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	44	44
Min	58.	58.	62.
25% Quartile	73.	68.5	81.5
Median	89.	77.	111.
75% Quartile	118.5	90.5	145.
Max	241.	158.	241.
Mean	102.58	83.6364	121.523
S.D.	41.2	22.5977	46.7902
Variance	1697.44	510.655	2189.33

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	31578.3	31578.3	23.6326	5.28129×10^{-6}
firstInt	1	2520.92	2520.92	1.88661	0.173196
Error	85	113578.	1336.21		
Total	87	147677.			

Cell Means

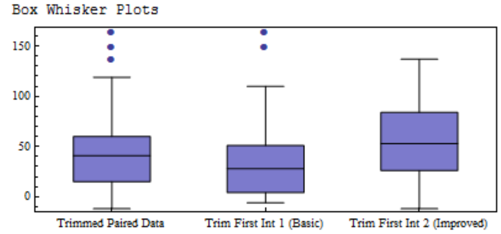
All	102.58
interface[1.]	83.6364
interface[2.]	121.523
firstInt[1.]	97.2273
firstInt[2.]	107.932

Measure: **DataSecsDis** (Data Entry Seconds Distributor) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	21	20
Min	-12.	-6.	-12.
25% Quartile	15.	3.5	31.
Median	41.	28.	53.
75% Quartile	63.	52.	84.5
Max	165.	165.	137.
Mean	47.439	40.2381	55.
S.D.	43.1011	48.2389	36.6606
Variance	1857.7	2326.99	1344.

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	2232.29	2232.29	1.20788	0.27849
Error	39	72075.8	1848.1		
Total	40	74308.1			

Cell Means

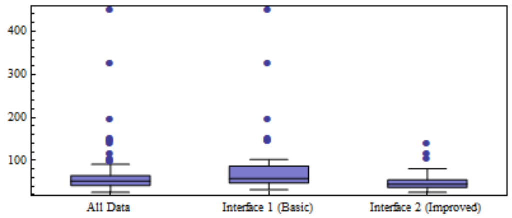
All	47.439
firstInt[1.]	40.2381
firstInt[2.]	55.

Measure: **DataSecsRun** (Data Entry Seconds Run Set) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	26.	32.	26.
25% Quartile	42.	48.5	37.
Median	52.	58.	45.
75% Quartile	65.	86.75	54.75
Max	450.	450.	140.
Mean	67.0213	83.5745	50.4681
S.D.	57.6622	75.2595	22.3206
Variance	3324.92	5663.99	498.211

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	25756.8	25756.8	8.30066	0.00494231
firstInt	1	1090.14	1090.14	0.351322	0.554836
Error	91	282371.	3102.98		
Total	93	309218.			

Cell Means

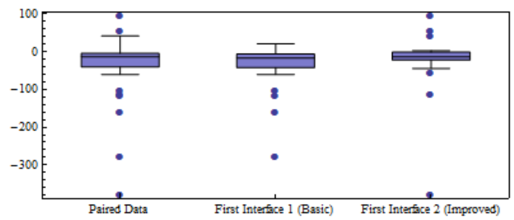
All	67.0213
interface[1.]	83.5745
interface[2.]	50.4681
firstInt[1.]	63.6875
firstInt[2.]	70.5

Measure: **DataSecsRun** (Data Entry Seconds Run Set) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-379.	-278.	-379.
25% Quartile	-38.	-41.	-21.5
Median	-13.	-16.5	-13.
75% Quartile	-4.25	-5.5	-1.75
Max	95.	21.	95.
Mean	-33.1064	-39.7917	-26.1304
S.D.	75.9162	65.642	86.2909
Variance	5763.27	4308.87	7446.12

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	2191.9	2191.9	0.375156	0.54329
Error	45	262919.	5842.63		
Total	46	265110.			

Cell Means

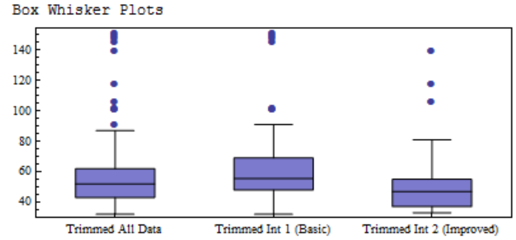
All	-33.1064
firstInt[1.]	-39.7917
firstInt[2.]	-26.1304

Measure: **DataSecsRun** (Data Entry Seconds Run Set) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	44	44
Min	32.	32.	33.
25% Quartile	43.	48.	37.5
Median	52.	55.5	47.
75% Quartile	62.5	71.5	56.
Max	152.	152.	140.
Mean	59.5341	67.1136	51.9545
S.D.	28.048	31.2546	22.2992
Variance	786.688	976.847	497.254

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	5055.56	5055.56	6.92039	0.0101162
firstInt	1	1291.19	1291.19	1.76747	0.187252
Error	85	62095.1	730.531		
Total	87	68441.9			

Cell Means

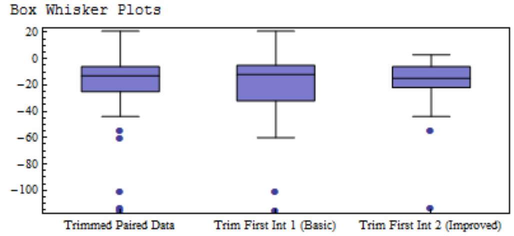
All	59.5341
interface[1.]	67.1136
interface[2.]	51.9545
firstInt[1.]	55.6222
firstInt[2.]	63.6279

Measure: **DataSecsRun** (Data Entry Seconds Run Set) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	22	19
Min	-115.	-115.	-113.
25% Quartile	-26.75	-32.	-21.5
Median	-13.	-12.	-15.
75% Quartile	-5.75	-5.	-6.25
Max	21.	21.	3.
Mean	-22.7561	-23.5455	-21.8421
S.D.	29.6907	32.6186	26.7587
Variance	881.539	1063.97	716.029

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	29.5801	29.5801	0.0327437	0.857342
Error	39	35232.	903.384		
Total	40	35261.6			

Cell Means

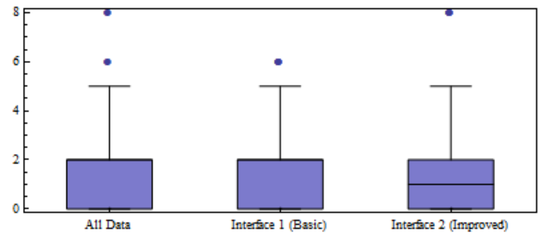
All	-22.7561
firstInt[1.]	-23.5455
firstInt[2.]	-21.8421

Measure: DataErrAll (Data Entry Errors All) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	0.	0.	0.
25% Quartile	0.	0.25	0.
Median	2.	2.	1.
75% Quartile	2.	2.	2.
Max	8.	6.	8.
Mean	1.65957	1.82979	1.48936
S.D.	1.62344	1.47912	1.75539
Variance	2.63555	2.18779	3.08141

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	2.7234	2.7234	1.03612	0.311425
firstInt	1	3.19243	3.19243	1.21456	0.273337
Error	91	239.191	2.62847		
Total	93	245.106			

Cell Means

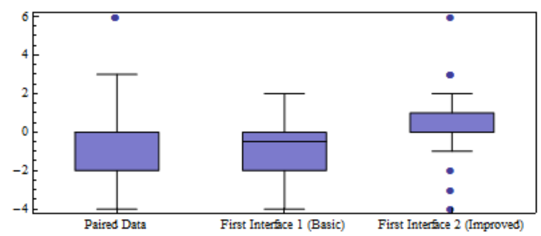
All	1.65957
interface[1.]	1.82979
interface[2.]	1.48936
firstInt[1.]	1.47917
firstInt[2.]	1.84783

Measure: DataErrAll (Data Entry Errors All) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-4.	-4.	-4.
25% Quartile	-2.	-2.	0.
Median	0.	-0.5	0.
75% Quartile	0.	0.	1.
Max	6.	2.	6.
Mean	-0.340426	-0.958333	0.304348
S.D.	1.83299	1.42887	2.00986
Variance	3.35985	2.04167	4.03953

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	18.7253	18.7253	6.20372	0.0165054
Error	45	135.828	3.0184		
Total	46	154.553			

Cell Means

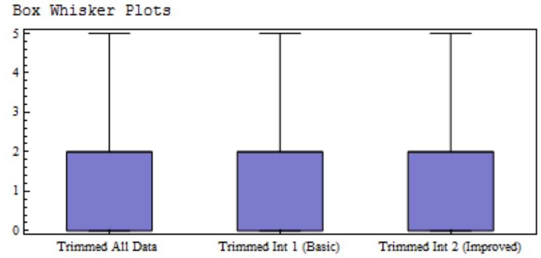
All	-0.340426
firstInt[1.]	-0.958333
firstInt[2.]	0.304348

Measure: DataErrAll (Data Entry Errors All) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	45	43
Min	0.	0.	0.
25% Quartile	0.	0.	0.
Median	2.	2.	2.
75% Quartile	2.	2.	2.
Max	5.	5.	5.
Mean	1.55682	1.66667	1.44186
S.D.	1.38014	1.2792	1.48488
Variance	1.90478	1.63636	2.20487

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	1.11126	1.11126	0.574925	0.450406
firstInt	1	0.310372	0.310372	0.160575	0.689633
Error	85	164.294	1.93287		
Total	87	165.716			

Cell Means

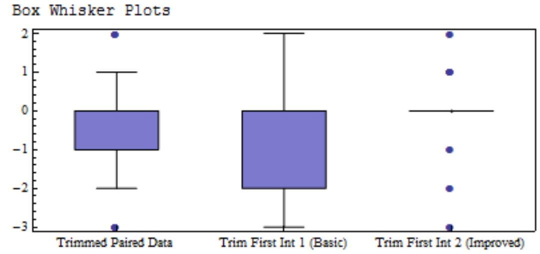
All	1.55682
interface[1.]	1.66667
interface[2.]	1.44186
firstInt[1.]	1.5
firstInt[2.]	1.61364

Measure: DataErrAll (Data Entry Errors All) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	22	19
Min	-3.	-3.	-3.
25% Quartile	-1.25	-2.	0.
Median	0.	0.	0.
75% Quartile	0.	0.	0.
Max	2.	2.	2.
Mean	-0.414634	-0.727273	-0.0526316
S.D.	1.20365	1.24142	1.07877
Variance	1.44878	1.54113	1.16374

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	4.64021	4.64021	3.39458	0.073023
Error	39	53.311	1.36695		
Total	40	57.9512			

Cell Means

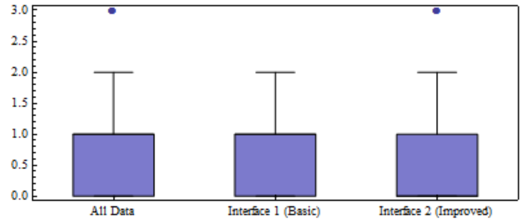
All	-0.414634
firstInt[1.]	-0.727273
firstInt[2.]	-0.0526316

Measure: **DataErrFac** (Data Entry Errors Factory) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	0.	0.	0.
25% Quartile	0.	0.	0.
Median	1.	1.	0.
75% Quartile	1.	1.	1.
Max	3.	2.	3.
Mean	0.638298	0.744681	0.531915
S.D.	0.583852	0.487589	0.654452
Variance	0.340883	0.237743	0.428307

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	1.06383	1.06383	3.25709	0.074423
firstInt	1	0.915896	0.915896	2.80416	0.0974534
Error	91	29.7224	0.32662		
Total	93	31.7021			

Cell Means

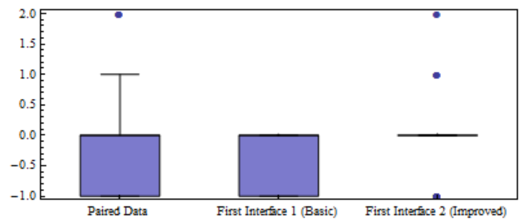
All	0.638298
interface[1.]	0.744681
interface[2.]	0.531915
firstInt[1.]	0.541667
firstInt[2.]	0.73913

Measure: **DataErrFac** (Data Entry Errors Factory) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-1.	-1.	-1.
25% Quartile	-1.	-1.	0.
Median	0.	0.	0.
75% Quartile	0.	0.	0.
Max	2.	0.	2.
Mean	-0.212766	-0.416667	0.
S.D.	0.623321	0.50361	0.6742
Variance	0.388529	0.253623	0.454545

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	2.03901	2.03901	5.79507	0.0202346
Error	45	15.8333	0.351852		
Total	46	17.8723			

Cell Means

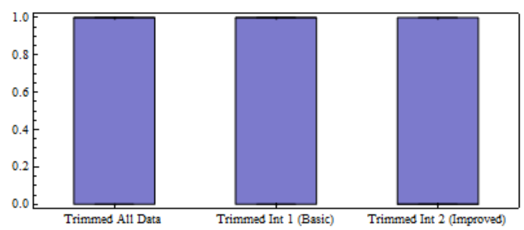
All	-0.212766
firstInt[1.]	-0.416667
firstInt[2.]	0.

Measure: **DataErrFac** (Data Entry Errors Factory) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	46	42
Min	0.	0.	0.
25% Quartile	0.	0.	0.
Median	1.	1.	0.
75% Quartile	1.	1.	1.
Max	1.	1.	1.
Mean	0.602273	0.717391	0.47619
S.D.	0.492233	0.455243	0.505487
Variance	0.242294	0.207246	0.255517

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	1.27727	1.27727	5.50132	0.0213313
firstInt	1	0.0674322	0.0674322	0.290437	0.591349
Error	85	19.7348	0.232175		
Total	87	21.0795			

Cell Means

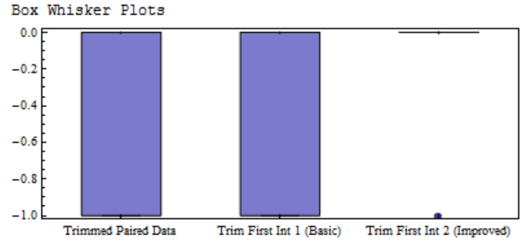
All	0.602273
interface[1.]	0.717391
interface[2.]	0.47619
firstInt[1.]	0.577778
firstInt[2.]	0.627907

Measure: **DataErrFac** (Data Entry Errors Factory) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	21	20
Min	-1.	-1.	-1.
25% Quartile	-1.	-1.	0.
Median	0.	0.	0.
75% Quartile	0.	0.	0.
Max	0.	0.	0.
Mean	-0.268293	-0.333333	-0.2
S.D.	0.448575	0.483046	0.410391
Variance	0.20122	0.233333	0.168421

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	0.182114	0.182114	0.902852	0.34787
Error	39	7.86667	0.201709		
Total	40	8.04878			

Cell Means

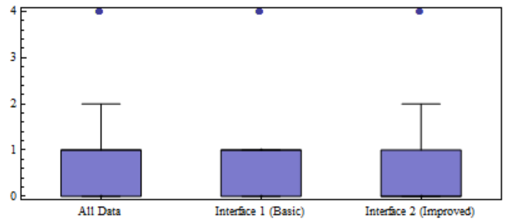
All	-0.268293
firstInt[1.]	-0.333333
firstInt[2.]	-0.2

Measure: **DataErrDis** (Data Entry Errors Distributor) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	0.	0.	0.
25% Quartile	0.	0.	0.
Median	1.	1.	0.
75% Quartile	1.	1.	1.
Max	4.	4.	4.
Mean	0.755319	0.93617	0.574468
S.D.	0.946825	1.05097	0.80067
Variance	0.896477	1.10453	0.641073

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	3.07447	3.07447	3.53601	0.0632482
firstInt	1	1.17578	1.17578	1.35229	0.247918
Error	91	79.1221	0.869474		
Total	93	83.3723			

Cell Means

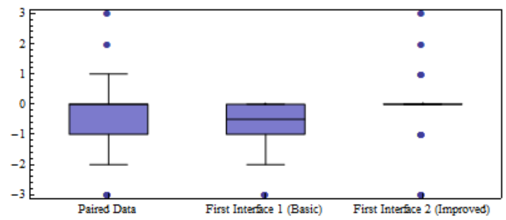
All	0.755319
interface[1.]	0.93617
interface[2.]	0.574468
firstInt[1.]	0.645833
firstInt[2.]	0.869565

Measure: **DataErrDis** (Data Entry Errors Distributor) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-3.	-3.	-3.
25% Quartile	-1.	-1.	0.
Median	0.	-0.5	0.
75% Quartile	0.	0.	0.
Max	3.	0.	3.
Mean	-0.361702	-0.625	-0.0869565
S.D.	1.07188	0.76967	1.27611
Variance	1.14894	0.592391	1.62846

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	3.39998	3.39998	3.09395	0.0853825
Error	45	49.4511	1.09891		
Total	46	52.8511			

Cell Means

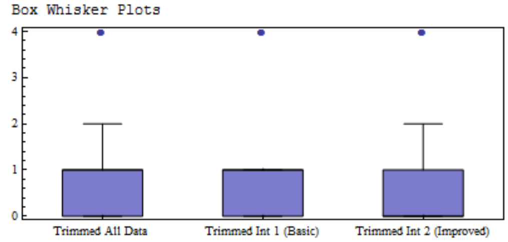
All	-0.361702
firstInt[1.]	-0.625
firstInt[2.]	-0.0869565

Measure: **DataErrDis** (Data Entry Errors Distributor) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	44	44
Min	0.	0.	0.
25% Quartile	0.	0.	0.
Median	1.	1.	0.
75% Quartile	1.	1.	1.
Max	4.	4.	4.
Mean	0.670455	0.727273	0.613636
S.D.	0.753865	0.694284	0.813145
Variance	0.568312	0.48203	0.661205

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	0.284091	0.284091	0.494345	0.483917
firstInt	1	0.311147	0.311147	0.541425	0.463868
Error	85	48.8479	0.574682		
Total	87	49.4432			

Cell Means

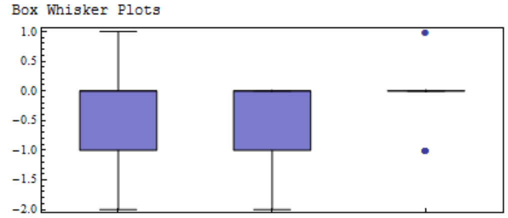
All	0.670455
interface[1.]	0.727273
interface[2.]	0.613636
firstInt[1.]	0.613636
firstInt[2.]	0.727273

Measure: **DataErrDis** (Data Entry Errors Distributor) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	23	18
Min	-2.	-2.	-1.
25% Quartile	-1.	-1.	0.
Median	0.	0.	0.
75% Quartile	0.	0.	0.
Max	1.	0.	1.
Mean	-0.341463	-0.521739	-0.111111
S.D.	0.574881	0.593109	0.471405
Variance	0.330488	0.351779	0.222222

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	1.7026	1.7026	5.76557	0.0212091
Error	39	11.5169	0.295305		
Total	40	13.2195			

Cell Means

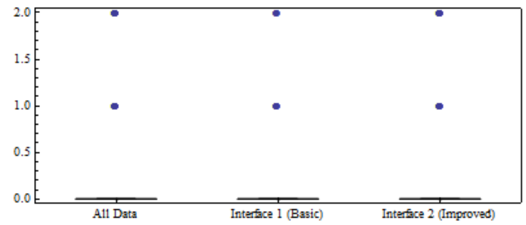
All	-0.341463
firstInt[1.]	-0.521739
firstInt[2.]	-0.111111

Measure: **DataErrRun** (Data Entry Errors Run Set) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	0.	0.	0.
25% Quartile	0.	0.	0.
Median	0.	0.	0.
75% Quartile	0.	0.	0.
Max	2.	2.	2.
Mean	0.265957	0.148936	0.382979
S.D.	0.625197	0.465259	0.738777
Variance	0.390872	0.216466	0.545791

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	1.28723	1.28723	3.3469	0.0706063
firstInt	1	0.0648319	0.0648319	0.168568	0.682353
Error	91	34.999	0.384604		
Total	93	36.3511			

Cell Means

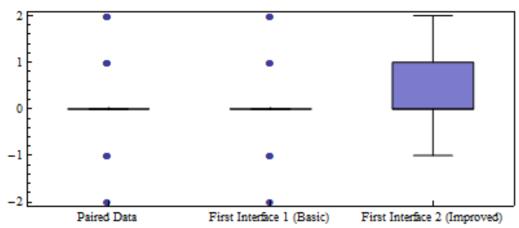
All	0.265957
interface[1.]	0.148936
interface[2.]	0.382979
firstInt[1.]	0.291667
firstInt[2.]	0.23913

Measure: **DataErrRun** (Data Entry Errors Run Set) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-2.	-2.	-1.
25% Quartile	0.	0.	0.
Median	0.	0.	0.
75% Quartile	0.	0.	0.75
Max	2.	2.	2.
Mean	0.234043	0.0833333	0.391304
S.D.	0.839585	0.829702	0.838783
Variance	0.704903	0.688406	0.703557

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	1.11394	1.11394	1.60091	0.212286
Error	45	31.3116	0.695813		
Total	46	32.4255			

Cell Means

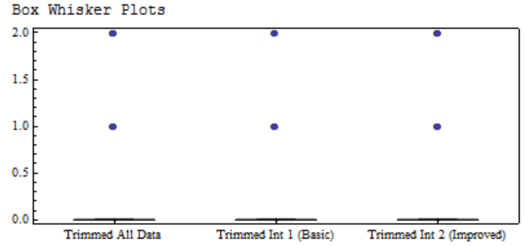
All	0.234043
firstInt[1.]	0.0833333
firstInt[2.]	0.391304

Measure: **DataErrRun** (Data Entry Errors Run Set) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	45	43
Min	0.	0.	0.
25% Quartile	0.	0.	0.
Median	0.	0.	0.
75% Quartile	0.	0.	0.
Max	2.	2.	2.
Mean	0.215909	0.155556	0.27907
S.D.	0.55603	0.474608	0.629648
Variance	0.309169	0.225253	0.396456

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	0.335453	0.335453	1.09975	0.297294
firstInt	1	0.634912	0.634912	2.08149	0.15277
Error	85	25.9274	0.305028		
Total	87	26.8977			

Cell Means

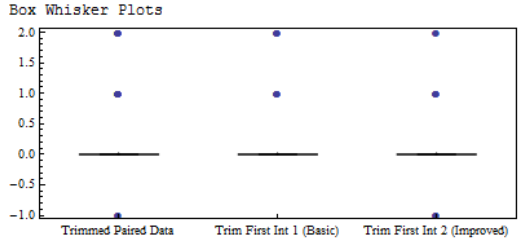
All	0.215909
interface[1.]	0.155556
interface[2.]	0.27907
firstInt[1.]	0.297872
firstInt[2.]	0.121951

Measure: **DataErrRun** (Data Entry Errors Run Set) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	21	20
Min	-1.	0.	-1.
25% Quartile	0.	0.	0.
Median	0.	0.	0.
75% Quartile	0.	0.	0.
Max	2.	2.	2.
Mean	0.219512	0.285714	0.15
S.D.	0.61287	0.64365	0.587143
Variance	0.37561	0.414286	0.344737

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	0.188676	0.188676	0.49599	0.485452
Error	39	14.8357	0.380403		
Total	40	15.0244			

Cell Means

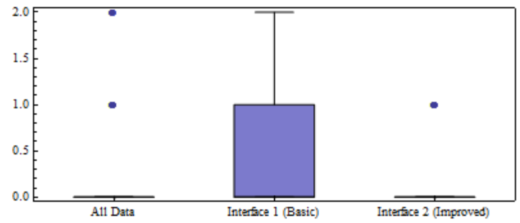
All	0.219512
firstInt[1.]	0.285714
firstInt[2.]	0.15

Measure: **DataTaskFail** (Data Entry Task Failures) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	0.	0.	0.
25% Quartile	0.	0.	0.
Median	0.	0.	0.
75% Quartile	0.	1.	0.
Max	2.	2.	1.
Mean	0.265957	0.361702	0.170213
S.D.	0.511702	0.60525	0.379883
Variance	0.261839	0.366327	0.144311

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	0.861702	0.861702	3.34187	0.0708145
firstInt	1	0.0249769	0.0249769	0.0968658	0.756336
Error	91	23.4644	0.25785		
Total	93	24.3511			

Cell Means

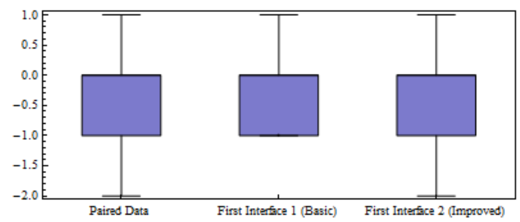
All	0.265957
interface[1.]	0.361702
interface[2.]	0.170213
firstInt[1.]	0.25
firstInt[2.]	0.282609

Measure: **DataTaskFail** (Data Entry Task Failures) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-2.	-1.	-2.
25% Quartile	-1.	-1.	-0.75
Median	0.	0.	0.
75% Quartile	0.	0.	0.
Max	1.	1.	1.
Mean	-0.191489	-0.166667	-0.217391
S.D.	0.647346	0.637022	0.671262
Variance	0.419056	0.405797	0.450593

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	0.0302189	0.0302189	0.070655	0.7916
Error	45	19.2464	0.427697		
Total	46	19.2766			

Cell Means

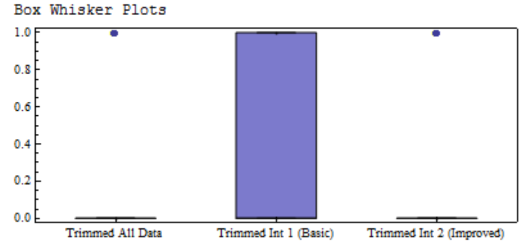
All	-0.191489
firstInt[1.]	-0.166667
firstInt[2.]	-0.217391

Measure: **DataTaskFail** (Data Entry Task Failures) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	43	45
Min	0.	0.	0.
25% Quartile	0.	0.	0.
Median	0.	0.	0.
75% Quartile	0.	0.75	0.
Max	1.	1.	1.
Mean	0.215909	0.255814	0.177778
S.D.	0.413809	0.441481	0.386646
Variance	0.171238	0.194906	0.149495

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	0.133903	0.133903	0.770924	0.382407
firstInt	1	0.000034191	0.000034191	0.000196849	0.988839
Error	85	14.7638	0.173692		
Total	87	14.8977			

Cell Means

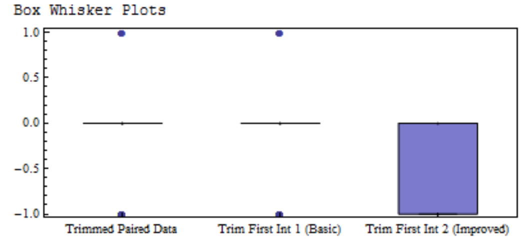
All	0.215909
interface[1.]	0.255814
interface[2.]	0.177778
firstInt[1.]	0.217391
firstInt[2.]	0.214286

Measure: **DataTaskFail** (Data Entry Task Failures) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	21	20
Min	-1.	-1.	-1.
25% Quartile	-0.25	-0.25	-0.5
Median	0.	0.	0.
75% Quartile	0.	0.	0.
Max	1.	1.	0.
Mean	-0.195122	-0.142857	-0.25
S.D.	0.510858	0.573212	0.444262
Variance	0.260976	0.328571	0.197368

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	0.117596	0.117596	0.444341	0.508959
Error	39	10.3214	0.264652		
Total	40	10.439			

Cell Means

All	-0.195122
firstInt[1.]	-0.142857
firstInt[2.]	-0.25

Appendix U2

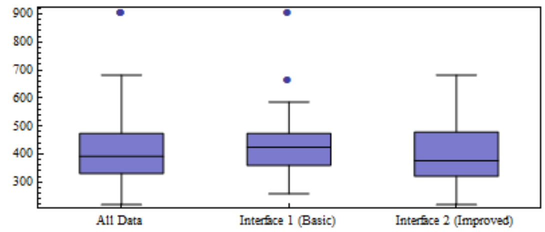
Data Analysis Details – Analysis

Measure: AnaSecsAll (Analysis Seconds All) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	220.	259.	220.
25% Quartile	331.	360.25	321.25
Median	392.	424.	377.
75% Quartile	474.	471.	476.25
Max	909.	909.	682.
Mean	413.915	429.766	398.064
S.D.	111.692	114.756	107.421
Variance	12475.2	13168.8	11539.2

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	23618.1	23618.1	1.89309	0.172231
firstInt	1	1258.22	1258.22	0.100851	0.751538
Error	91	1.13531×10^6	12476.		
Total	93	1.16019×10^6			

Cell Means

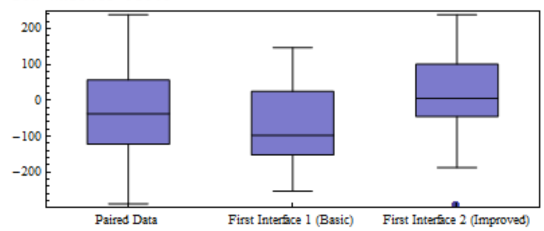
All	413.915
interface[1.]	429.766
interface[2.]	398.064
firstInt[1.]	410.333
firstInt[2.]	417.652

Measure: AnaSecsAll (Analysis Seconds All) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-288.	-253.	-288.
25% Quartile	-119.25	-149.5	-45.
Median	-37.	-97.	6.
75% Quartile	54.75	28.5	96.
Max	239.	147.	239.
Mean	-31.7021	-65.75	3.82609
S.D.	118.919	111.189	118.575
Variance	14141.8	12363.1	14060.

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	56854.	56854.	4.30952	0.0436426
Error	45	593670.	13192.7		
Total	46	650524.			

Cell Means

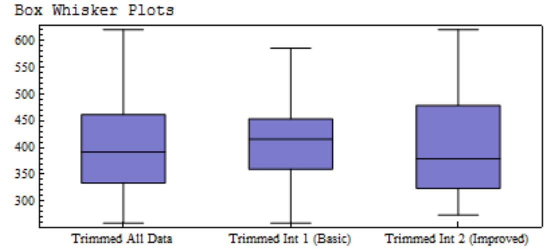
All	-31.7021
firstInt[1.]	-65.75
firstInt[2.]	3.82609

Measure: AnaSecsAll (Analysis Seconds All) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	45	43
Min	259.	259.	274.
25% Quartile	334.5	356.75	325.5
Median	392.	416.	379.
75% Quartile	465.	456.	476.25
Max	621.	586.	621.
Mean	408.216	413.867	402.302
S.D.	88.9304	83.7908	94.6408
Variance	7908.61	7020.89	8956.88

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	2940.63	2940.63	0.367147	0.546178
firstInt	1	4308.37	4308.37	0.537913	0.465317
Error	85	680800.	8009.41		
Total	87	688049.			

Cell Means

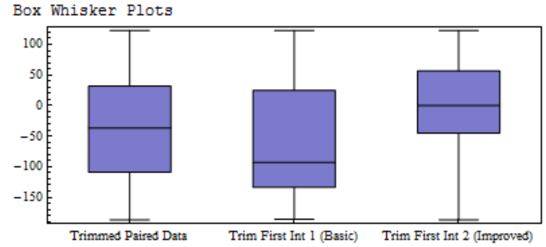
All	408.216
interface[1.]	413.867
interface[2.]	402.302
firstInt[1.]	415.591
firstInt[2.]	400.841

Measure: AnaSecsAll (Analysis Seconds All) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	21	20
Min	-187.	-186.	-187.
25% Quartile	-109.5	-137.25	-45.
Median	-37.	-93.	0.
75% Quartile	36.	26.75	69.
Max	123.	123.	123.
Mean	-30.4878	-59.0952	-0.45
S.D.	94.7748	93.7517	88.3387
Variance	8982.26	8789.39	7803.73

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	35231.5	35231.5	4.24006	0.0462025
Error	39	324059.	8309.2		
Total	40	359290.			

Cell Means

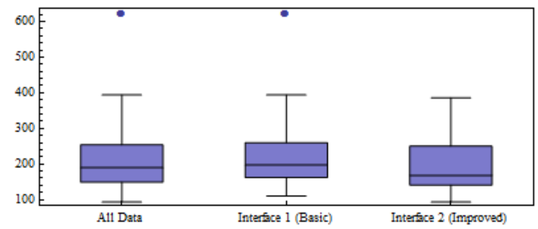
All	-30.4878
firstInt[1.]	-59.0952
firstInt[2.]	-0.45

Measure: AnaSecsTab (Analysis Seconds Table) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	93.	110.	93.
25% Quartile	149.	163.25	141.25
Median	189.5	197.	168.
75% Quartile	254.	258.5	248.
Max	626.	626.	386.
Mean	205.33	219.511	191.149
S.D.	80.2037	86.6941	71.2622
Variance	6432.63	7515.86	5078.3

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	18 903.1	18 903.1	2.96925	0.0882577
firstInt	1	0.0293131	0.0293131	4.60444×10^{-6}	0.998293
Error	91	579 332.	6366.28		
Total	93	598 235.			

Cell Means

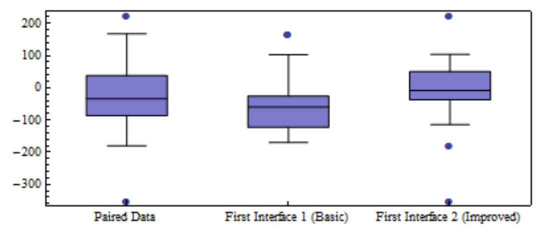
All	205.33
interface[1.]	219.511
interface[2.]	191.149
firstInt[1.]	205.313
firstInt[2.]	205.348

Measure: AnaSecsTab (Analysis Seconds Table) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-354.	-170.	-354.
25% Quartile	-82.25	-106.5	-36.75
Median	-34.	-60.	-8.
75% Quartile	38.	-24.5	49.5
Max	226.	168.	226.
Mean	-28.3617	-51.2083	-4.52174
S.D.	98.6858	81.0598	111.041
Variance	9738.89	6570.69	12 330.2

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	25 599.2	25 599.2	2.72725	0.105612
Error	45	422 390.	9386.44		
Total	46	447 989.			

Cell Means

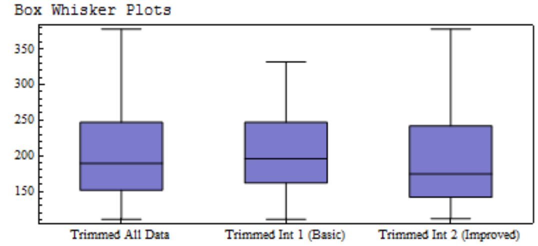
All	-28.3617
firstInt[1.]	-51.2083
firstInt[2.]	-4.52174

Measure: AnaSecsTab (Analysis Seconds Table) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	44	44
Min	111.	111.	112.
25% Quartile	152.	164.5	142.
Median	189.5	196.	174.5
75% Quartile	248.5	250.5	246.
Max	378.	332.	378.
Mean	199.898	208.795	191.
S.D.	60.4434	55.616	64.3164
Variance	3653.4	3093.14	4136.6

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	6966.92	6966.92	1.92296	0.169157
firstInt	1	2922.51	2922.51	0.806649	0.37165
Error	85	307 957.	3623.02		
Total	87	317 846.			

Cell Means

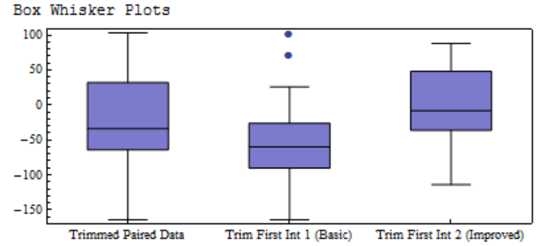
All	199.898
interface[1.]	208.795
interface[2.]	191.
firstInt[1.]	206.111
firstInt[2.]	193.395

Measure: AnaSecsTab (Analysis Seconds Table) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	22	19
Min	-164.	-164.	-114.
25% Quartile	-65.	-90.	-35.5
Median	-34.	-60.	-8.
75% Quartile	33.5	-26.	46.75
Max	103.	103.	88.
Mean	-27.4878	-55.7727	5.26316
S.D.	66.7241	64.9189	53.5411
Variance	4452.11	4214.47	2866.65

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	37 980.7	37 980.7	10.5725	0.00236997
Error	39	140 104.	3592.4		
Total	40	178 084.			

Cell Means

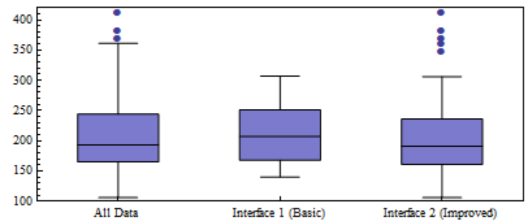
All	-27.4878
firstInt[1.]	-55.7727
firstInt[2.]	5.26316

Measure: **AnaSecsGraph** (Analysis Seconds Graph) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	106.	140.	106.
25% Quartile	165.	168.5	162.
Median	193.	207.	191.
75% Quartile	244.	249.25	231.5
Max	414.	307.	414.
Mean	208.585	210.255	206.915
S.D.	61.3838	47.2608	73.3387
Variance	3767.97	2233.59	5378.56

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	262.223	262.223	0.0683906	0.794286
firstInt	1	1246.1	1246.1	0.324996	0.570025
Error	91	348 912.	3834.2		
Total	93	350 421.			

Cell Means

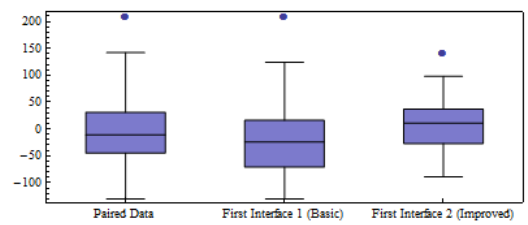
All	208.585
interface[1.]	210.255
interface[2.]	206.915
firstInt[1.]	205.021
firstInt[2.]	212.304

Measure: **AnaSecsGraph** (Analysis Seconds Graph) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-130.	-130.	-89.
25% Quartile	-44.75	-69.	-25.
Median	-11.	-24.	11.
75% Quartile	30.5	18.5	35.5
Max	211.	211.	142.
Mean	-3.34043	-14.5417	8.34783
S.D.	70.6874	81.7541	56.3952
Variance	4996.71	6683.74	3180.42

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	6153.38	6153.38	1.23785	0.271793
Error	45	223 695.	4971.		
Total	46	229 849.			

Cell Means

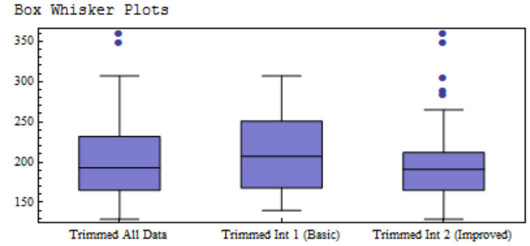
All	-3.34043
firstInt[1.]	-14.5417
firstInt[2.]	8.34783

Measure: **AnaSecsGraph** (Analysis Seconds Graph) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	47	41
Min	129.	140.	129.
25% Quartile	165.	168.5	165.
Median	193.	207.	191.
75% Quartile	234.	249.25	213.5
Max	361.	307.	361.
Mean	205.477	210.255	200.
S.D.	51.1628	47.2608	55.3819
Variance	2617.63	2233.59	3067.15

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	2303.02	2303.02	0.872948	0.352787
firstInt	1	1183.33	1183.33	0.448537	0.504846
Error	85	224 248.	2638.21		
Total	87	227 734.			

Cell Means

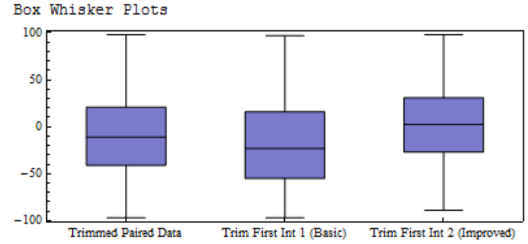
All	205.477
interface[1.]	210.255
interface[2.]	200.
firstInt[1.]	201.977
firstInt[2.]	208.822

Measure: **AnaSecsGraph** (Analysis Seconds Graph) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	19	22
Min	-97.	-97.	-89.
25% Quartile	-41.75	-51.5	-27.
Median	-11.	-23.	2.5
75% Quartile	23.	9.25	31.
Max	98.	97.	98.
Mean	-6.5122	-16.6842	2.27273
S.D.	50.8744	51.9455	49.4226
Variance	2588.21	2698.34	2442.59

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	3663.78	3663.78	1.43081	0.238854
Error	39	99 864.5	2560.63		
Total	40	103 528.			

Cell Means

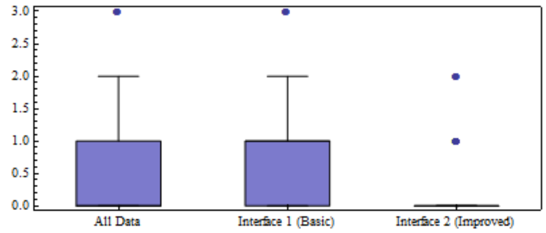
All	-6.5122
firstInt[1.]	-16.6842
firstInt[2.]	2.27273

Measure: **AnaErrAll** (Analysis Errors All) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	0.	0.	0.
25% Quartile	0.	0.	0.
Median	0.	1.	0.
75% Quartile	1.	1.	0.
Max	3.	3.	2.
Mean	0.43617	0.638298	0.234043
S.D.	0.66492	0.735011	0.519731
Variance	0.442119	0.540241	0.27012

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	3.84043	3.84043	9.46851	0.00276155
firstInt	1	0.367021	0.367021	0.904885	0.343995
Error	91	36.9096	0.4056		
Total	93	41.117			

Cell Means

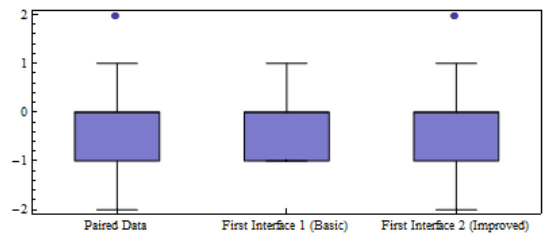
All	0.43617
interface[1.]	0.638298
interface[2.]	0.234043
firstInt[1.]	0.375
firstInt[2.]	0.5

Measure: **AnaErrAll** (Analysis Errors All) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-2.	-1.	-2.
25% Quartile	-1.	-1.	-1.
Median	0.	0.	0.
75% Quartile	0.	0.	0.
Max	2.	1.	2.
Mean	-0.404255	-0.333333	-0.478261
S.D.	0.851075	0.637022	1.03877
Variance	0.724329	0.405797	1.07905

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	0.246685	0.246685	0.335652	0.565239
Error	45	33.0725	0.734944		
Total	46	33.3191			

Cell Means

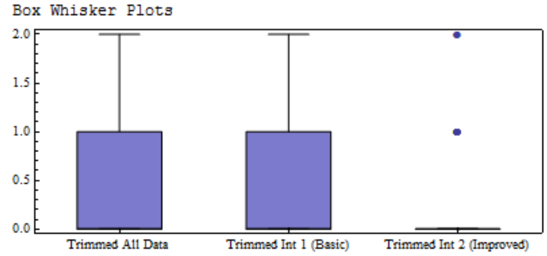
All	-0.404255
firstInt[1.]	-0.333333
firstInt[2.]	-0.478261

Measure: **AnaErrAll** (Analysis Errors All) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	45	43
Min	0.	0.	0.
25% Quartile	0.	0.	0.
Median	0.	0.	0.
75% Quartile	1.	1.	0.
Max	2.	2.	2.
Mean	0.386364	0.555556	0.209302
S.D.	0.575991	0.62361	0.465891
Variance	0.331766	0.388889	0.217054

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	2.63625	2.63625	8.54383	0.0044416
firstInt	1	0.000175259	0.000175259	0.000567999	0.981042
Error	85	26.2272	0.308555		
Total	87	28.8636			

Cell Means

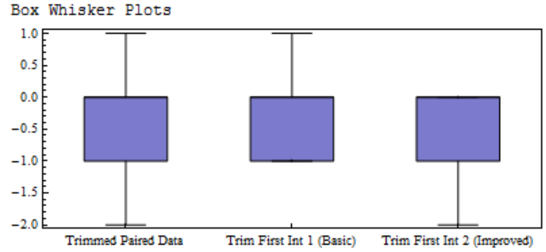
All	0.386364
interface[1.]	0.555556
interface[2.]	0.209302
firstInt[1.]	0.391304
firstInt[2.]	0.380952

Measure: **AnaErrAll** (Analysis Errors All) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	24	17
Min	-2.	-1.	-2.
25% Quartile	-1.	-1.	-1.
Median	0.	0.	0.
75% Quartile	0.	0.	0.
Max	1.	1.	0.
Mean	-0.414634	-0.333333	-0.529412
S.D.	0.631491	0.637022	0.624264
Variance	0.39878	0.405797	0.389706

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	0.382592	0.382592	0.958408	0.333623
Error	39	15.5686	0.399196		
Total	40	15.9512			

Cell Means

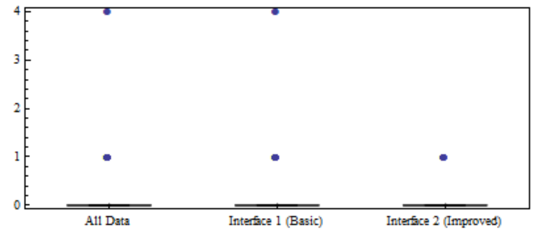
All	-0.414634
firstInt[1.]	-0.333333
firstInt[2.]	-0.529412

Measure: AnaTaskFail (Analysis Task Failures) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	0.	0.	0.
25% Quartile	0.	0.	0.
Median	0.	0.	0.
75% Quartile	0.	0.	0.
Max	4.	4.	1.
Mean	0.148936	0.234043	0.0638298
S.D.	0.507099	0.666358	0.247092
Variance	0.257149	0.444033	0.0610546

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	0.680851	0.680851	2.68351	0.104845
firstInt	1	0.145872	0.145872	0.574941	0.450261
Error	91	23.0882	0.253716		
Total	93	23.9149			

Cell Means

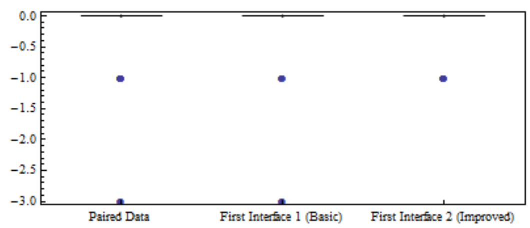
All	0.148936
interface[1.]	0.234043
interface[2.]	0.0638298
firstInt[1.]	0.1875
firstInt[2.]	0.108696

Measure: AnaTaskFail (Analysis Task Failures) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-3.	-3.	-1.
25% Quartile	0.	0.	0.
Median	0.	0.	0.
75% Quartile	0.	0.	0.
Max	0.	0.	0.
Mean	-0.170213	-0.208333	-0.130435
S.D.	0.524162	0.658005	0.34435
Variance	0.274746	0.432971	0.118577

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	0.0712689	0.0712689	0.2552	0.615903
Error	45	12.567	0.279267		
Total	46	12.6383			

Cell Means

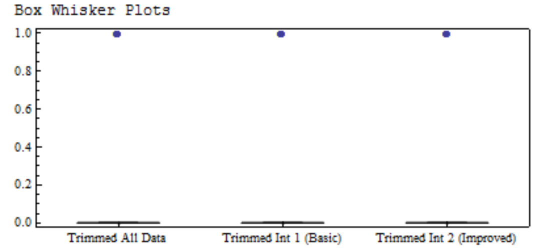
All	-0.170213
firstInt[1.]	-0.208333
firstInt[2.]	-0.130435

Measure: AnaTaskFail (Analysis Task Failures) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	43	45
Min	0.	0.	0.
25% Quartile	0.	0.	0.
Median	0.	0.	0.
75% Quartile	0.	0.	0.
Max	1.	1.	1.
Mean	0.0909091	0.116279	0.0666667
S.D.	0.289127	0.324353	0.252262
Variance	0.0835946	0.105205	0.0636364

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	0.0541226	0.0541226	0.637303	0.426914
firstInt	1	0.0000279848	0.0000279848	0.000329526	0.985559
Error	85	7.21858	0.0849244		
Total	87	7.27273			

Cell Means

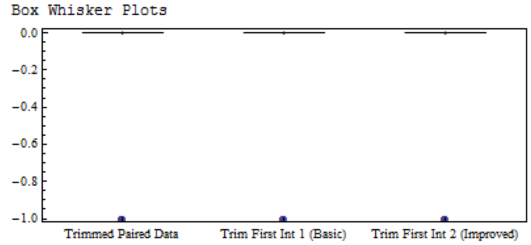
All	0.0909091
interface[1.]	0.116279
interface[2.]	0.0666667
firstInt[1.]	0.0909091
firstInt[2.]	0.0909091

Measure: AnaTaskFail (Analysis Task Failures) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	21	20
Min	-1.	-1.	-1.
25% Quartile	0.	0.	0.
Median	0.	0.	0.
75% Quartile	0.	0.	0.
Max	0.	0.	0.
Mean	-0.0731707	-0.047619	-0.1
S.D.	0.263652	0.218218	0.307794
Variance	0.0695122	0.047619	0.0947368

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	0.0281069	0.0281069	0.398261	0.53167
Error	39	2.75238	0.0705739		
Total	40	2.78049			

Cell Means

All	-0.0731707
firstInt[1.]	-0.047619
firstInt[2.]	-0.1

Appendix U3

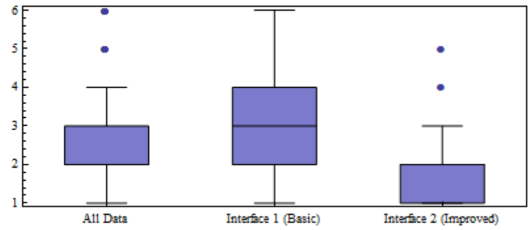
Data Analysis Details – Usability Questionnaire

Measure: Uq1 (PSSUQ: Satisfied w/ease of use) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	1.	1.	1.
25% Quartile	2.	2.	1.25
Median	2.	3.	2.
75% Quartile	3.	4.	2.
Max	6.	6.	5.
Mean	2.48936	3.	1.97872
S.D.	1.36582	1.60163	0.82064
Variance	1.86548	2.56522	0.673451

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	24.5106	24.5106	15.024	0.000200102
firstInt	1	0.518347	0.518347	0.317725	0.574364
Error	91	148.46	1.63143		
Total	93	173.489			

Cell Means

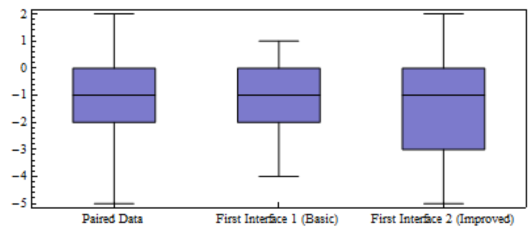
All	2.48936
interface[1.]	3.
interface[2.]	1.97872
firstInt[1.]	2.41667
firstInt[2.]	2.56522

Measure: Uq1 (PSSUQ: Satisfied w/ease of use) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-5.	-4.	-5.
25% Quartile	-2.	-2.	-2.75
Median	-1.	-1.	-1.
75% Quartile	0.	0.	0.
Max	2.	1.	2.
Mean	-1.02128	-1.	-1.04348
S.D.	1.60826	1.25109	1.94184
Variance	2.58649	1.56522	3.77075

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	0.0222017	0.0222017	0.00839866	0.927388
Error	45	118.957	2.64348		
Total	46	118.979			

Cell Means

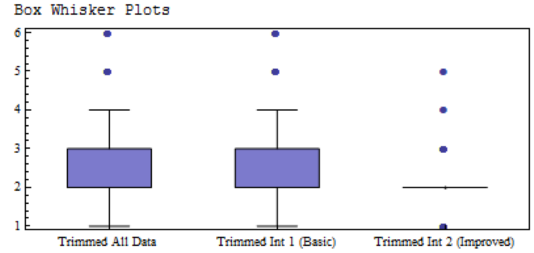
All	-1.02128
firstInt[1.]	-1.
firstInt[2.]	-1.04348

Measure: Uq1 (PSSUQ: Satisfied w/ease of use) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	44	44
Min	1.	1.	1.
25% Quartile	2.	2.	2.
Median	2.	2.	2.
75% Quartile	3.	3.5	2.
Max	6.	6.	5.
Mean	2.42045	2.79545	2.04545
S.D.	1.21978	1.43995	0.805636
Variance	1.48785	2.07347	0.649049

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	12.375	12.375	9.01587	0.00351417
firstInt	1	0.398848	0.398848	0.290583	0.591256
Error	85	116.669	1.37258		
Total	87	129.443			

Cell Means

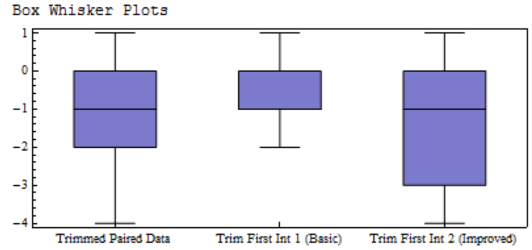
All	2.42045
interface[1.]	2.79545
interface[2.]	2.04545
firstInt[1.]	2.51111
firstInt[2.]	2.32558

Measure: Uq1 (PSSUQ: Satisfied w/ease of use) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	22	19
Min	-4.	-2.	-4.
25% Quartile	-2.	-1.	-2.75
Median	-1.	-1.	-1.
75% Quartile	0.	0.	0.
Max	1.	1.	1.
Mean	-0.95122	-0.727273	-1.21053
S.D.	1.3029	0.882735	1.65257
Variance	1.69756	0.779221	2.73099

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	2.38091	2.38091	1.41717	0.241065
Error	39	65.5215	1.68004		
Total	40	67.9024			

Cell Means

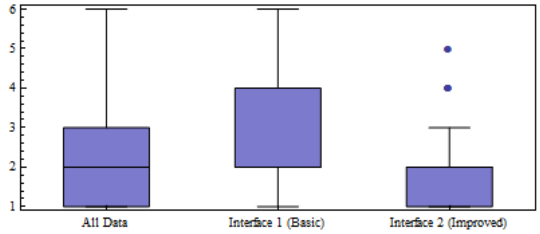
All	-0.95122
firstInt[1.]	-0.727273
firstInt[2.]	-1.21053

Measure: Uq2 (PSSUQ: Simple to use) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	1.	1.	1.
25% Quartile	1.	2.	1.
Median	2.	2.	2.
75% Quartile	3.	4.	2.
Max	6.	6.	5.
Mean	2.34043	2.78723	1.89362
S.D.	1.33242	1.53136	0.914474
Variance	1.77534	2.34505	0.836263

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	18.766	18.766	11.7074	0.000934272
firstInt	1	0.475042	0.475042	0.296361	0.587504
Error	91	145.865	1.60292		
Total	93	165.106			

Cell Means

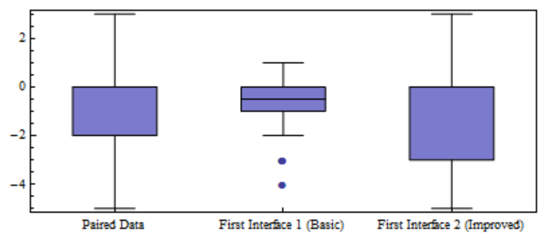
All	2.34043
interface[1.]	2.78723
interface[2.]	1.89362
firstInt[1.]	2.27083
firstInt[2.]	2.41304

Measure: Uq2 (PSSUQ: Simple to use) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-5.	-4.	-5.
25% Quartile	-2.	-1.	-2.75
Median	0.	-0.5	0.
75% Quartile	0.	0.	0.
Max	3.	1.	3.
Mean	-0.893617	-0.875	-0.913043
S.D.	1.6048	1.2619	1.92857
Variance	2.57539	1.59239	3.71937

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	0.0169981	0.0169981	0.00645766	0.936308
Error	45	118.451	2.63225		
Total	46	118.468			

Cell Means

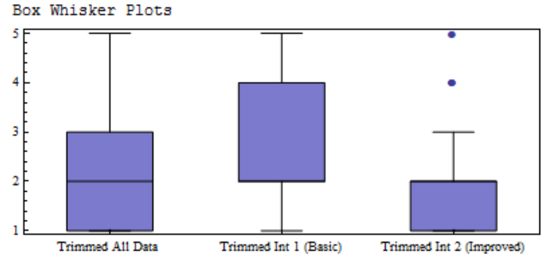
All	-0.893617
firstInt[1.]	-0.875
firstInt[2.]	-0.913043

Measure: Uq2 (PSSUQ: Simple to use) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	43	45
Min	1.	1.	1.
25% Quartile	1.	2.	1.
Median	2.	2.	2.
75% Quartile	3.	4.	2.
Max	5.	5.	5.
Mean	2.26136	2.60465	1.93333
S.D.	1.16948	1.31184	0.914529
Variance	1.36769	1.72093	0.836364

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	9.90957	9.90957	7.72213	0.00671293
firstInt	1	0.00122827	0.00122827	0.000957142	0.975392
Error	85	109.078	1.28327		
Total	87	118.989			

Cell Means

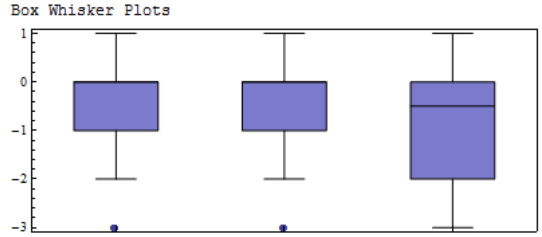
All	2.26136
interface[1.]	2.60465
interface[2.]	1.93333
firstInt[1.]	2.27273
firstInt[2.]	2.25

Measure: Uq2 (PSSUQ: Simple to use) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	23	18
Min	-3.	-3.	-3.
25% Quartile	-1.25	-1.	-2.
Median	0.	0.	-0.5
75% Quartile	0.	0.	0.
Max	1.	1.	1.
Mean	-0.829268	-0.73913	-0.944444
S.D.	1.22275	1.09617	1.39209
Variance	1.49512	1.20158	1.93791

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	0.425651	0.425651	0.279566	0.599983
Error	39	59.3792	1.52254		
Total	40	59.8049			

Cell Means

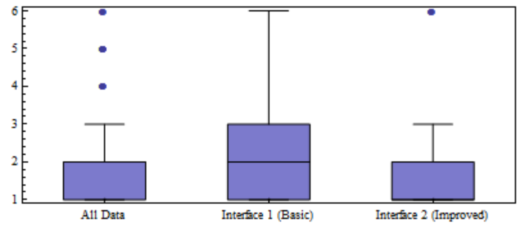
All	-0.829268
firstInt[1.]	-0.73913
firstInt[2.]	-0.944444

Measure: Uq3 (PSSUQ: Effectively complete tasks) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	1.	1.	1.
25% Quartile	1.	1.25	1.
Median	2.	2.	1.
75% Quartile	2.	3.	2.
Max	6.	6.	6.
Mean	2.04255	2.44681	1.6383
S.D.	1.20853	1.34824	0.895048
Variance	1.46054	1.81776	0.80111

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	15.3617	15.3617	11.6078	0.000979626
firstInt	1	0.0390264	0.0390264	0.0294896	0.864035
Error	91	120.429	1.3234		
Total	93	135.83			

Cell Means

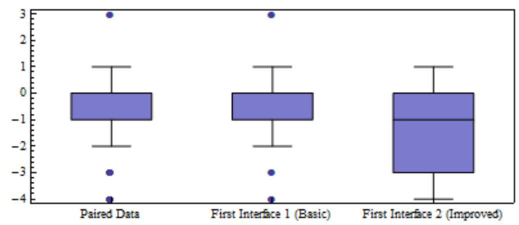
All	2.04255
interface[1.]	2.44681
interface[2.]	1.6383
firstInt[1.]	2.0625
firstInt[2.]	2.02174

Measure: Uq3 (PSSUQ: Effectively complete tasks) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-4.	-4.	-4.
25% Quartile	-1.	-1.	-3.
Median	0.	0.	-1.
75% Quartile	0.	0.	0.
Max	3.	3.	1.
Mean	-0.808511	-0.375	-1.26087
S.D.	1.54129	1.34528	1.62976
Variance	2.37558	1.80978	2.65613

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	9.21681	9.21681	4.14509	0.0476677
Error	45	100.06	2.22355		
Total	46	109.277			

Cell Means

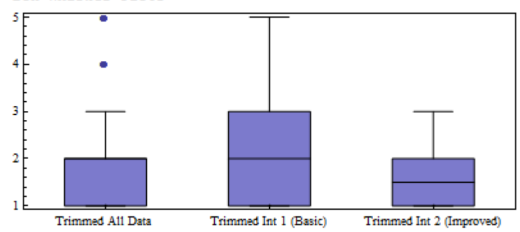
All	-0.808511
firstInt[1.]	-0.375
firstInt[2.]	-1.26087

Measure: Uq3 (PSSUQ: Effectively complete tasks) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	44	44
Min	1.	1.	1.
25% Quartile	1.	1.5	1.
Median	2.	2.	1.5
75% Quartile	2.	3.	2.
Max	5.	5.	3.
Mean	1.95455	2.34091	1.56818
S.D.	1.02732	1.19967	0.624974
Variance	1.05538	1.43922	0.390592

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	13.1364	13.1364	14.2773	0.000291975
firstInt	1	0.474402	0.474402	0.515606	0.474691
Error	85	78.2074	0.920087		
Total	87	91.8182			

Cell Means

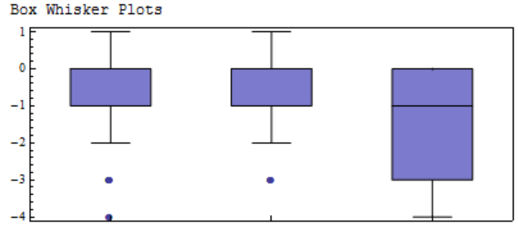
All	1.95455
interface[1.]	2.34091
interface[2.]	1.56818
firstInt[1.]	2.04545
firstInt[2.]	1.86364

Measure: Uq3 (PSSUQ: Effectively complete tasks) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	22	19
Min	-4.	-3.	-4.
25% Quartile	-1.	-1.	-2.75
Median	0.	0.	-1.
75% Quartile	0.	0.	0.
Max	1.	1.	0.
Mean	-0.756098	-0.363636	-1.21053
S.D.	1.19959	0.902138	1.35724
Variance	1.43902	0.813853	1.84211

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	7.31217	7.31217	5.67525	0.0221783
Error	39	50.2488	1.28843		
Total	40	57.561			

Cell Means

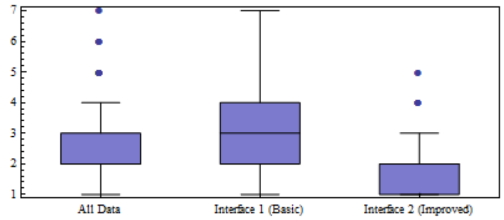
All	-0.756098
firstInt[1.]	-0.363636
firstInt[2.]	-1.21053

Measure: **Uq4** (PSSUQ: Able to complete tasks quickly) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	1.	1.	1.
25% Quartile	2.	2.	1.
Median	2.	3.	2.
75% Quartile	3.	4.	2.
Max	7.	7.	5.
Mean	2.47872	3.	1.95745
S.D.	1.31761	1.47442	0.883605
Variance	1.7361	2.17391	0.780759

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	25.5426	25.5426	17.1227	0.0000780766
firstInt	1	0.166686	0.166686	0.111739	0.738942
Error	91	135.748	1.49174		
Total	93	161.457			

Cell Means

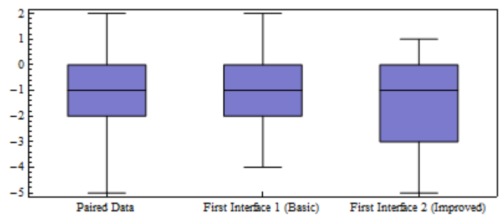
All	2.47872
interface[1.]	3.
interface[2.]	1.95745
firstInt[1.]	2.4375
firstInt[2.]	2.52174

Measure: **Uq4** (PSSUQ: Able to complete tasks quickly) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-5.	-4.	-5.
25% Quartile	-2.	-2.	-2.75
Median	-1.	-1.	-1.
75% Quartile	0.	0.	0.
Max	2.	2.	1.
Mean	-1.04255	-0.958333	-1.13043
S.D.	1.61457	1.36666	1.86607
Variance	2.60685	1.86775	3.48221

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	0.347865	0.347865	0.130922	0.719172
Error	45	119.567	2.65705		
Total	46	119.915			

Cell Means

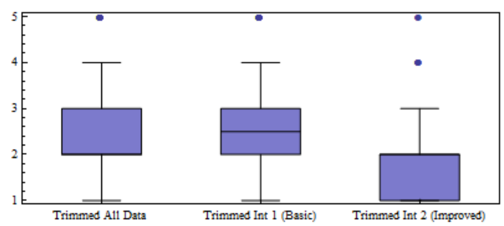
All	-1.04255
firstInt[1.]	-0.958333
firstInt[2.]	-1.13043

Measure: **Uq4** (PSSUQ: Able to complete tasks quickly) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	44	44
Min	1.	1.	1.
25% Quartile	2.	2.	1.5
Median	2.	2.5	2.
75% Quartile	3.	3.5	2.
Max	5.	5.	5.
Mean	2.39773	2.77273	2.02273
S.D.	1.11973	1.21739	0.875736
Variance	1.25379	1.48203	0.766913

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	12.375	12.375	10.8929	0.00141215
firstInt	1	0.139493	0.139493	0.122786	0.726899
Error	85	96.5651	1.13606		
Total	87	109.08			

Cell Means

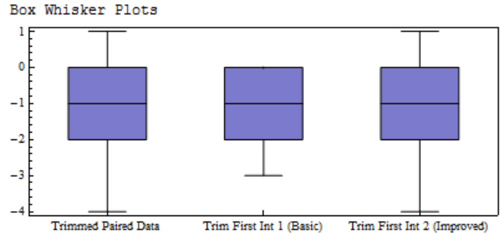
All	2.39773
interface[1.]	2.77273
interface[2.]	2.02273
firstInt[1.]	2.45455
firstInt[2.]	2.34091

Measure: **Uq4** (PSSUQ: Able to complete tasks quickly) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	22	19
Min	-4.	-3.	-4.
25% Quartile	-2.	-2.	-1.75
Median	-1.	-1.	-1.
75% Quartile	0.	0.	0.
Max	1.	0.	1.
Mean	-0.95122	-0.954545	-0.947368
S.D.	1.24401	1.0901	1.4327
Variance	1.54756	1.18831	2.05263

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	0.000525149	0.000525149	0.000330859	0.98558
Error	39	61.9019	1.58723		
Total	40	61.9024			

Cell Means

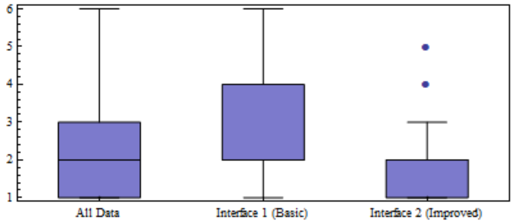
All	-0.95122
firstInt[1.]	-0.954545
firstInt[2.]	-0.947368

Measure: Uq5 (PSSUQ: Efficiently complete tasks) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	1.	1.	1.
25% Quartile	1.	2.	1.
Median	2.	2.	2.
75% Quartile	3.	4.	2.
Max	6.	6.	5.
Mean	2.24468	2.70213	1.78723
S.D.	1.24163	1.4129	0.832392
Variance	1.54164	1.9963	0.692877

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	19.6702	19.6702	14.5831	0.000244618
firstInt	1	0.958391	0.958391	0.710534	0.401477
Error	91	122.744	1.34883		
Total	93	143.372			

Cell Means

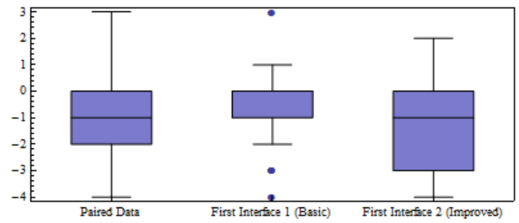
All	2.24468
interface[1.]	2.70213
interface[2.]	1.78723
firstInt[1.]	2.14583
firstInt[2.]	2.34783

Measure: Uq5 (PSSUQ: Efficiently complete tasks) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-4.	-4.	-4.
25% Quartile	-2.	-1.	-2.75
Median	-1.	0.	-1.
75% Quartile	0.	0.	0.
Max	3.	3.	2.
Mean	-0.914894	-0.625	-1.21739
S.D.	1.54399	1.52693	1.53613
Variance	2.3839	2.33152	2.35968

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	4.12153	4.12153	1.75737	0.191644
Error	45	105.538	2.34529		
Total	46	109.66			

Cell Means

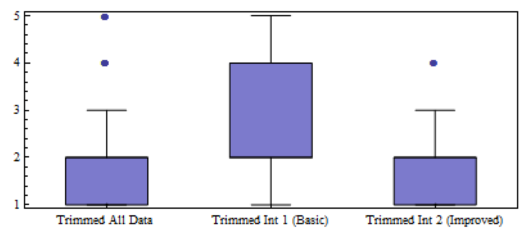
All	-0.914894
firstInt[1.]	-0.625
firstInt[2.]	-1.21739

Measure: Uq5 (PSSUQ: Efficiently complete tasks) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	43	45
Min	1.	1.	1.
25% Quartile	1.	2.	1.
Median	2.	2.	2.
75% Quartile	2.5	4.	2.
Max	5.	5.	4.
Mean	2.17045	2.62791	1.73333
S.D.	1.08513	1.23488	0.687552
Variance	1.17751	1.52492	0.472727

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	17.5967	17.5967	17.8066	0.00006093
firstInt	1	0.848486	0.848486	0.858607	0.356752
Error	85	83.998	0.988212		
Total	87	102.443			

Cell Means

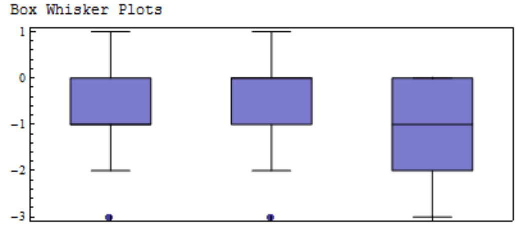
All	2.17045
interface[1.]	2.62791
interface[2.]	1.73333
firstInt[1.]	2.06977
firstInt[2.]	2.26667

Measure: Uq5 (PSSUQ: Efficiently complete tasks) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	21	20
Min	-3.	-3.	-3.
25% Quartile	-1.25	-1.	-2.
Median	-1.	0.	-1.
75% Quartile	0.	0.	0.
Max	1.	1.	0.
Mean	-0.902439	-0.714286	-1.1
S.D.	1.15769	1.14642	1.16529
Variance	1.34024	1.31429	1.35789

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	1.52404	1.52404	1.14115	0.291977
Error	39	52.0857	1.33553		
Total	40	53.6098			

Cell Means

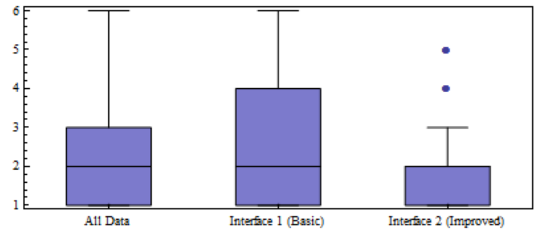
All	-0.902439
firstInt[1.]	-0.714286
firstInt[2.]	-1.1

Measure: **Uq6** (PSSUQ: Felt comfortable using) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	1.	1.	1.
25% Quartile	1.	1.25	1.
Median	2.	2.	2.
75% Quartile	3.	4.	2.
Max	6.	6.	5.
Mean	2.31915	2.78723	1.85106
S.D.	1.39286	1.53136	1.06278
Variance	1.94006	2.34505	1.12951

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	20.5957	20.5957	11.896	0.0008542
firstInt	1	2.2806	2.2806	1.31727	0.254091
Error	91	157.549	1.73131		
Total	93	180.426			

Cell Means

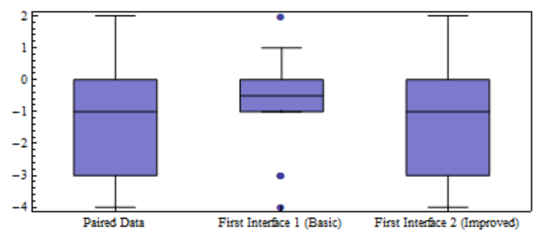
All	2.31915
interface[1.]	2.78723
interface[2.]	1.85106
firstInt[1.]	2.16667
firstInt[2.]	2.47826

Measure: **Uq6** (PSSUQ: Felt comfortable using) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-4.	-4.	-4.
25% Quartile	-2.75	-1.	-3.
Median	-1.	-0.5	-1.
75% Quartile	0.	0.	0.
Max	2.	2.	2.
Mean	-0.93617	-0.75	-1.13043
S.D.	1.52379	1.35935	1.68696
Variance	2.32192	1.84783	2.84585

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	1.69981	1.69981	0.727739	0.398135
Error	45	105.109	2.33575		
Total	46	106.809			

Cell Means

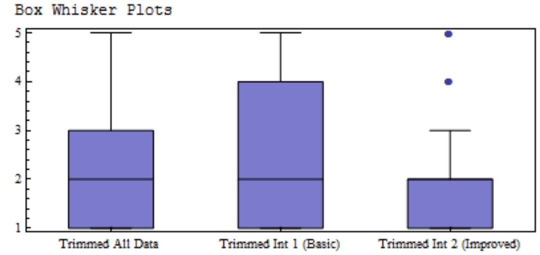
All	-0.93617
firstInt[1.]	-0.75
firstInt[2.]	-1.13043

Measure: **Uq6** (PSSUQ: Felt comfortable using) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	43	45
Min	1.	1.	1.
25% Quartile	1.	1.25	1.
Median	2.	2.	2.
75% Quartile	3.	4.	2.
Max	5.	5.	5.
Mean	2.25	2.62791	1.88889
S.D.	1.2708	1.36318	1.07073
Variance	1.61494	1.85825	1.14646

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	12.009	12.009	7.99833	0.00583818
firstInt	1	0.868295	0.868295	0.578307	0.449081
Error	85	127.623	1.50144		
Total	87	140.5			

Cell Means

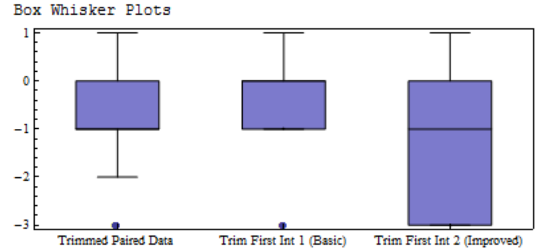
All	2.25
interface[1.]	2.62791
interface[2.]	1.88889
firstInt[1.]	2.15909
firstInt[2.]	2.34091

Measure: **Uq6** (PSSUQ: Felt comfortable using) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	21	20
Min	-3.	-3.	-3.
25% Quartile	-1.25	-1.	-3.
Median	-1.	0.	-1.
75% Quartile	0.	0.	0.
Max	1.	1.	1.
Mean	-0.926829	-0.619048	-1.25
S.D.	1.2528	0.973457	1.44641
Variance	1.56951	0.947619	2.09211

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	4.07811	4.07811	2.70936	0.107797
Error	39	58.7024	1.50519		
Total	40	62.7805			

Cell Means

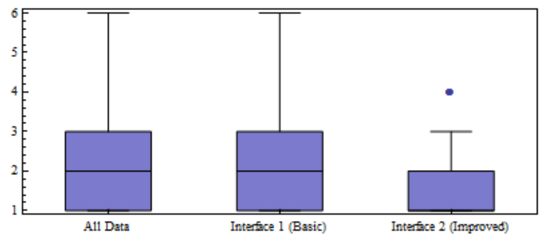
All	-0.926829
firstInt[1.]	-0.619048
firstInt[2.]	-1.25

Measure: **Uq7** (PSSUQ: Easy to learn to use) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	1.	1.	1.
25% Quartile	1.	1.	1.
Median	2.	2.	1.
75% Quartile	3.	3.	2.
Max	6.	6.	4.
Mean	2.06383	2.44681	1.68085
S.D.	1.24269	1.45675	0.836826
Variance	1.54427	2.12211	0.700278

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	13.7872	13.7872	9.71306	0.00244846
firstInt	1	0.659594	0.659594	0.464682	0.497175
Error	91	129.17	1.41945		
Total	93	143.617			

Cell Means

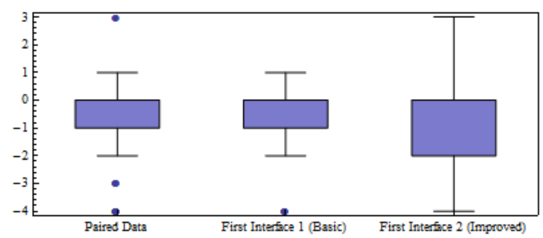
All	2.06383
interface[1.]	2.44681
interface[2.]	1.68085
firstInt[1.]	2.14583
firstInt[2.]	1.97826

Measure: **Uq7** (PSSUQ: Easy to learn to use) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-4.	-4.	-4.
25% Quartile	-1.	-1.	-2.
Median	0.	0.	0.
75% Quartile	0.	0.	0.
Max	3.	1.	3.
Mean	-0.765957	-0.541667	-1.
S.D.	1.53528	1.28466	1.7581
Variance	2.35708	1.65036	3.09091

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	2.4672	2.4672	1.04781	0.311484
Error	45	105.958	2.35463		
Total	46	108.426			

Cell Means

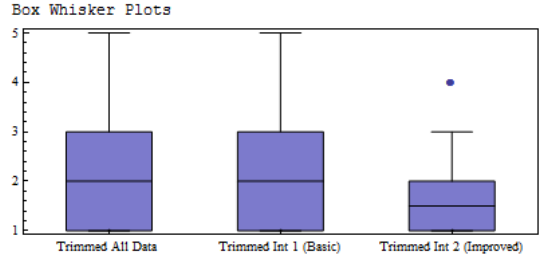
All	-0.765957
firstInt[1.]	-0.541667
firstInt[2.]	-1.

Measure: **Uq7** (PSSUQ: Easy to learn to use) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	42	46
Min	1.	1.	1.
25% Quartile	1.	1.	1.
Median	2.	2.	1.5
75% Quartile	3.	3.	2.
Max	5.	5.	4.
Mean	1.97727	2.28571	1.69565
S.D.	1.07187	1.21546	0.83983
Variance	1.1489	1.47735	0.705314

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	7.64399	7.64399	7.07628	0.00933535
firstInt	1	0.491255	0.491255	0.45477	0.501908
Error	85	91.8193	1.08023		
Total	87	99.9545			

Cell Means

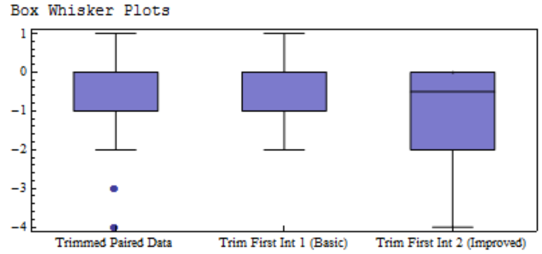
All	1.97727
interface[1.]	2.28571
interface[2.]	1.69565
firstInt[1.]	2.04651
firstInt[2.]	1.91111

Measure: **Uq7** (PSSUQ: Easy to learn to use) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	21	20
Min	-4.	-2.	-4.
25% Quartile	-1.	-1.	-2.
Median	0.	0.	-0.5
75% Quartile	0.	0.	0.
Max	1.	1.	0.
Mean	-0.707317	-0.285714	-1.15
S.D.	1.18836	0.717137	1.42441
Variance	1.4122	0.514286	2.02895

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	7.65209	7.65209	6.11093	0.0179039
Error	39	48.8357	1.2522		
Total	40	56.4878			

Cell Means

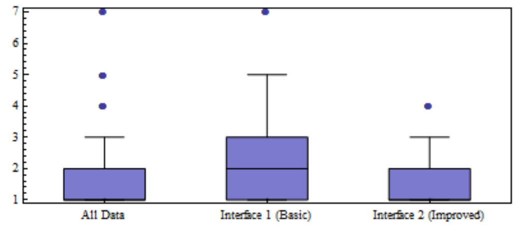
All	-0.707317
firstInt[1.]	-0.285714
firstInt[2.]	-1.15

Measure: Uq8 (PSSUQ: Could be productive quickly) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	1.	1.	1.
25% Quartile	1.	1.	1.
Median	1.	2.	1.
75% Quartile	2.	3.	2.
Max	7.	7.	4.
Mean	1.89362	2.31915	1.46809
S.D.	1.28237	1.54788	0.74749
Variance	1.64447	2.39593	0.558742

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	17.0213	17.0213	11.5217	0.00102065
firstInt	1	1.47874	1.47874	1.00096	0.319731
Error	91	134.436	1.47732		
Total	93	152.936			

Cell Means

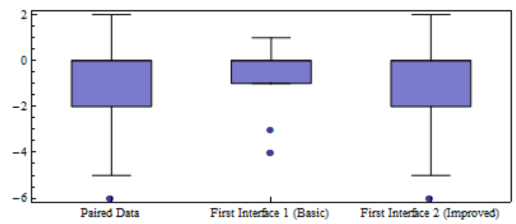
All	1.89362
interface[1.]	2.31915
interface[2.]	1.46809
firstInt[1.]	1.77083
firstInt[2.]	2.02174

Measure: Uq8 (PSSUQ: Could be productive quickly) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-6.	-4.	-6.
25% Quartile	-1.75	-1.	-2.
Median	0.	0.	0.
75% Quartile	0.	0.	0.
Max	2.	1.	2.
Mean	-0.851064	-0.541667	-1.17391
S.D.	1.64156	1.31807	1.89862
Variance	2.69473	1.73732	3.60474

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	4.69477	4.69477	1.77142	0.189911
Error	45	119.263	2.65028		
Total	46	123.957			

Cell Means

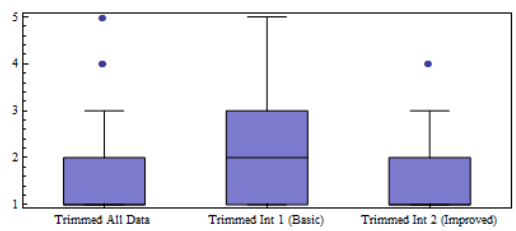
All	-0.851064
firstInt[1.]	-0.541667
firstInt[2.]	-1.17391

Measure: Uq8 (PSSUQ: Could be productive quickly) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	43	45
Min	1.	1.	1.
25% Quartile	1.	1.	1.
Median	1.	2.	1.
75% Quartile	2.	3.	2.
Max	5.	5.	4.
Mean	1.77273	2.06977	1.48889
S.D.	1.00261	1.14216	0.757455
Variance	1.00522	1.30454	0.573737

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	7.4194	7.4194	7.88712	0.00617518
firstInt	1	0.0757316	0.0757316	0.0805056	0.777303
Error	85	79.9594	0.940699		
Total	87	87.4545			

Cell Means

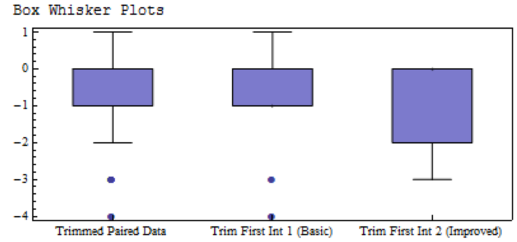
All	1.77273
interface[1.]	2.06977
interface[2.]	1.48889
firstInt[1.]	1.75
firstInt[2.]	1.79545

Measure: Uq8 (PSSUQ: Could be productive quickly) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	22	19
Min	-4.	-4.	-3.
25% Quartile	-1.	-1.	-2.
Median	0.	0.	0.
75% Quartile	0.	0.	0.
Max	1.	1.	0.
Mean	-0.707317	-0.454545	-1.
S.D.	1.16713	1.10096	1.20185
Variance	1.3622	1.21212	1.44444

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	3.03326	3.03326	2.29906	0.137517
Error	39	51.4545	1.31935		
Total	40	54.4878			

Cell Means

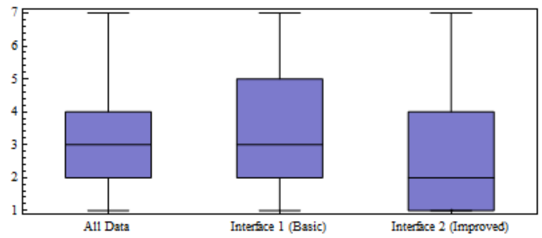
All	-0.707317
firstInt[1.]	-0.454545
firstInt[2.]	-1.

Measure: Uq9 (PSSUQ: Clear error messages) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	70	33	37
Min	1.	1.	1.
25% Quartile	2.	2.	1.
Median	3.	3.	2.
75% Quartile	4.	5.	4.
Max	7.	7.	7.
Mean	3.12857	3.63636	2.67568
S.D.	1.81716	1.83402	1.70056
Variance	3.30207	3.36364	2.89189

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	16.0984	16.0984	5.1456	0.0265329
firstInt	1	2.13017	2.13017	0.680876	0.412214
Error	67	209.614	3.12857		
Total	69	227.843			

Cell Means

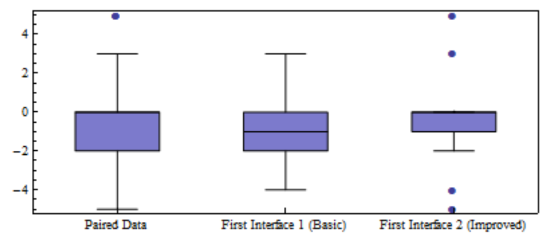
All	3.12857
interface[1.]	3.63636
interface[2.]	2.67568
firstInt[1.]	3.31579
firstInt[2.]	2.90625

Measure: Uq9 (PSSUQ: Clear error messages) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	31	16	15
Min	-5.	-4.	-5.
25% Quartile	-2.	-2.	-1.
Median	0.	-1.	0.
75% Quartile	0.	0.	0.
Max	5.	3.	5.
Mean	-0.645161	-0.9375	-0.333333
S.D.	2.05829	1.73085	2.38048
Variance	4.23656	2.99583	5.66667

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	2.82594	2.82594	0.659465	0.423365
Error	29	124.271	4.2852		
Total	30	127.097			

Cell Means

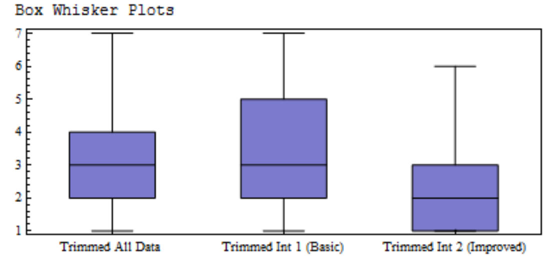
All	-0.645161
firstInt[1.]	-0.9375
firstInt[2.]	-0.333333

Measure: Uq9 (PSSUQ: Clear error messages) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	64	32	32
Min	1.	1.	1.
25% Quartile	2.	2.	1.5
Median	3.	3.	2.
75% Quartile	4.	5.	3.5
Max	7.	7.	6.
Mean	3.04688	3.53125	2.5625
S.D.	1.63716	1.75948	1.36636
Variance	2.68031	3.09577	1.86694

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	15.0156	15.0156	6.07593	0.0165344
firstInt	1	3.0927	3.0927	1.25143	0.267665
Error	61	150.751	2.47133		
Total	63	168.859			

Cell Means

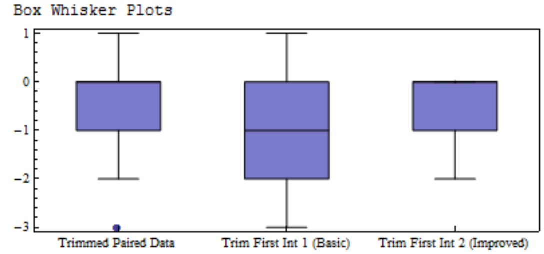
All	3.04688
interface[1.]	3.53125
interface[2.]	2.5625
firstInt[1.]	3.30303
firstInt[2.]	2.77419

Measure: Uq9 (PSSUQ: Clear error messages) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	25	14	11
Min	-3.	-3.	-2.
25% Quartile	-1.25	-2.	-0.75
Median	0.	-1.	0.
75% Quartile	0.	0.	0.
Max	1.	1.	0.
Mean	-0.72	-1.	-0.363636
S.D.	1.06145	1.24035	0.6742
Variance	1.12667	1.53846	0.454545

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	2.49455	2.49455	2.33748	0.139931
Error	23	24.5455	1.06719		
Total	24	27.04			

Cell Means

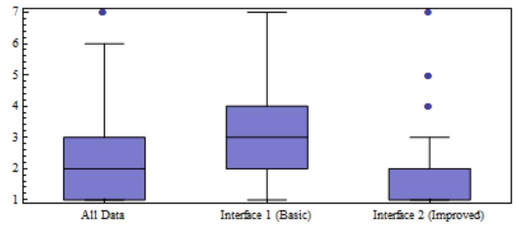
All	-0.72
firstInt[1.]	-1.
firstInt[2.]	-0.363636

Measure: **Uq10** (PSSUQ: Recover easily from errors) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	81	37	44
Min	1.	1.	1.
25% Quartile	1.	2.	1.
Median	2.	3.	2.
75% Quartile	3.	4.	2.
Max	7.	7.	7.
Mean	2.45679	2.91892	2.06818
S.D.	1.47521	1.55239	1.30112
Variance	2.17623	2.40991	1.69292

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	14.5466	14.5466	7.11544	0.00929013
firstInt	1	0.0918674	0.0918674	0.0449369	0.832673
Error	78	159.46	2.04436		
Total	80	174.099			

Cell Means

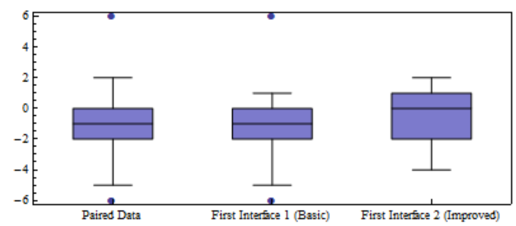
All	2.45679
interface[1.]	2.91892
interface[2.]	2.06818
firstInt[1.]	2.53488
firstInt[2.]	2.36842

Measure: **Uq10** (PSSUQ: Recover easily from errors) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	34	19	15
Min	-6.	-6.	-4.
25% Quartile	-2.	-2.	-1.75
Median	-1.	-1.	0.
75% Quartile	0.	0.	1.
Max	6.	6.	2.
Mean	-0.794118	-1.10526	-0.4
S.D.	2.12887	2.42429	1.68184
Variance	4.53209	5.87719	2.82857

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	4.16935	4.16935	0.917668	0.34527
Error	32	145.389	4.54342		
Total	33	149.559			

Cell Means

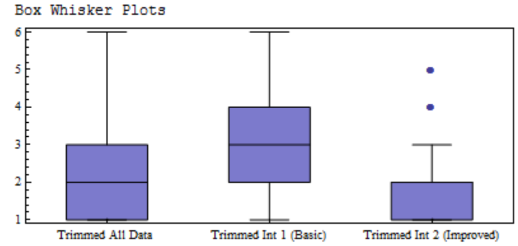
All	-0.794118
firstInt[1.]	-1.10526
firstInt[2.]	-0.4

Measure: **Uq10** (PSSUQ: Recover easily from errors) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	75	34	41
Min	1.	1.	1.
25% Quartile	1.	2.	1.
Median	2.	3.	2.
75% Quartile	3.	4.	2.
Max	6.	6.	5.
Mean	2.34667	2.76471	2.
S.D.	1.23566	1.30405	1.07238
Variance	1.52685	1.70053	1.15

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	10.869	10.869	7.68948	0.00706718
firstInt	1	0.34621	0.34621	0.244932	0.622173
Error	72	101.771	1.41349		
Total	74	112.987			

Cell Means

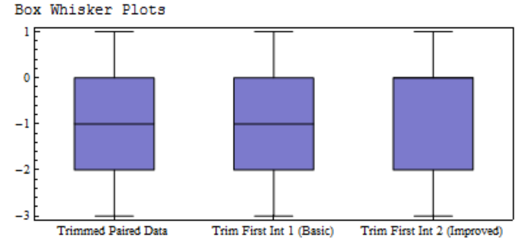
All	2.34667
interface[1.]	2.76471
interface[2.]	2.
firstInt[1.]	2.32432
firstInt[2.]	2.36842

Measure: **Uq10** (PSSUQ: Recover easily from errors) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	28	16	12
Min	-3.	-3.	-3.
25% Quartile	-2.	-2.	-1.5
Median	-1.	-1.	0.
75% Quartile	0.	0.	0.5
Max	1.	1.	1.
Mean	-0.75	-1.	-0.416667
S.D.	1.17458	1.0328	1.31137
Variance	1.37963	1.06667	1.7197

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	2.33333	2.33333	1.73747	0.198955
Error	26	34.9167	1.34295		
Total	27	37.25			

Cell Means

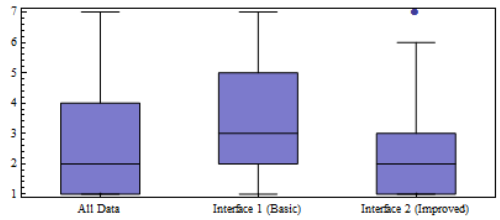
All	-0.75
firstInt[1.]	-1.
firstInt[2.]	-0.416667

Measure: **Uq11** (PSSUQ: Information provided was clear) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	71	36	35
Min	1.	1.	1.
25% Quartile	1.	2.	1.
Median	2.	3.	2.
75% Quartile	4.	5.	3.
Max	7.	7.	7.
Mean	2.90141	3.5	2.28571
S.D.	1.86819	2.07709	1.40527
Variance	3.49014	4.31429	1.97479

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	26.167	26.167	8.16073	0.00567384
firstInt	1	0.10397	0.10397	0.0324252	0.857633
Error	68	218.039	3.20645		
Total	70	244.31			

Cell Means

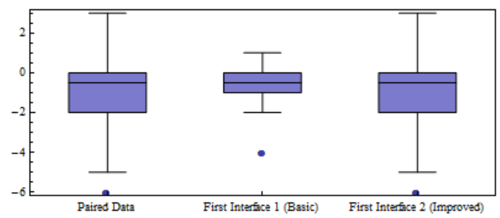
All	2.90141
interface[1.]	3.5
interface[2.]	2.28571
firstInt[1.]	2.85294
firstInt[2.]	2.94595

Measure: **Uq11** (PSSUQ: Information provided was clear) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	34	16	18
Min	-6.	-4.	-6.
25% Quartile	-2.	-1.	-2.
Median	-0.5	-0.5	-0.5
75% Quartile	0.	0.5	0.
Max	3.	1.	3.
Mean	-0.970588	-0.6875	-1.22222
S.D.	1.97692	1.57982	2.2895
Variance	3.9082	2.49583	5.24183

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	2.42198	2.42198	0.612439	0.439624
Error	32	126.549	3.95464		
Total	33	128.971			

Cell Means

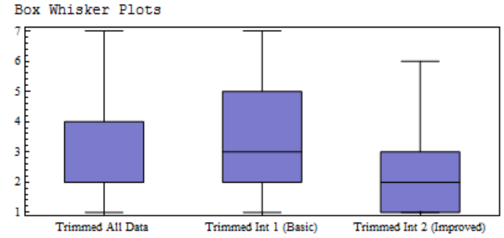
All	-0.970588
firstInt[1.]	-0.6875
firstInt[2.]	-1.22222

Measure: **Uq11** (PSSUQ: Information provided was clear) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	65	33	32
Min	1.	1.	1.
25% Quartile	1.75	2.	1.
Median	2.	3.	2.
75% Quartile	4.	5.	3.
Max	7.	7.	6.
Mean	2.8	3.36364	2.21875
S.D.	1.68819	1.93356	1.15659
Variance	2.85	3.73864	1.3377

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	21.2949	21.2949	8.34736	0.00531493
firstInt	1	2.93735	2.93735	1.15141	0.287414
Error	62	158.168	2.55109		
Total	64	182.4			

Cell Means

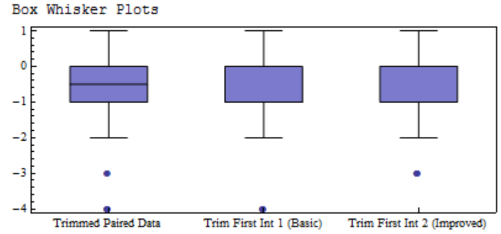
All	2.8
interface[1.]	3.36364
interface[2.]	2.21875
firstInt[1.]	3.03226
firstInt[2.]	2.58824

Measure: **Uq11** (PSSUQ: Information provided was clear) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	28	14	14
Min	-4.	-4.	-3.
25% Quartile	-1.	-1.	-1.
Median	-0.5	-1.	0.
75% Quartile	0.	0.	0.
Max	1.	1.	1.
Mean	-0.785714	-0.928571	-0.642857
S.D.	1.31535	1.54244	1.08182
Variance	1.73016	2.37912	1.17033

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	0.571429	0.571429	0.321981	0.575287
Error	26	46.1429	1.77473		
Total	27	46.7143			

Cell Means

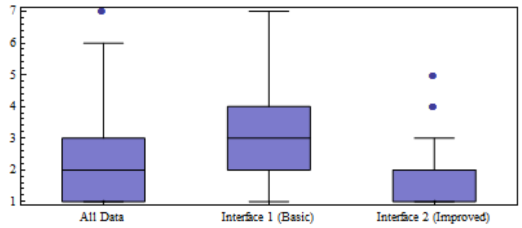
All	-0.785714
firstInt[1.]	-0.928571
firstInt[2.]	-0.642857

Measure: Uq12 (PSSUQ: Easy to find information) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	91	45	46
Min	1.	1.	1.
25% Quartile	1.	2.	1.
Median	2.	3.	2.
75% Quartile	3.	4.	2.
Max	7.	7.	5.
Mean	2.52747	3.08889	1.97826
S.D.	1.57297	1.83182	1.02174
Variance	2.47424	3.35556	1.04396

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	28.0586	28.0586	12.7212	0.000587501
firstInt	1	0.525001	0.525001	0.238025	0.62685
Error	88	194.098	2.20566		
Total	90	222.681			

Cell Means

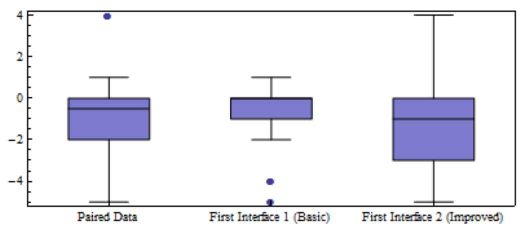
All	2.52747
interface[1.]	3.08889
interface[2.]	1.97826
firstInt[1.]	2.44444
firstInt[2.]	2.6087

Measure: Uq12 (PSSUQ: Easy to find information) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	44	21	23
Min	-5.	-5.	-5.
25% Quartile	-2.	-1.	-2.75
Median	-0.5	0.	-1.
75% Quartile	0.	0.	0.
Max	4.	1.	4.
Mean	-1.06818	-0.904762	-1.21739
S.D.	1.89734	1.6095	2.1523
Variance	3.59989	2.59048	4.63241

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	1.07289	1.07289	0.293134	0.59108
Error	42	153.723	3.66006		
Total	43	154.795			

Cell Means

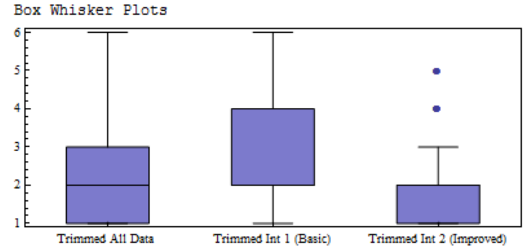
All	-1.06818
firstInt[1.]	-0.904762
firstInt[2.]	-1.21739

Measure: Uq12 (PSSUQ: Easy to find information) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	85	41	44
Min	1.	1.	1.
25% Quartile	1.	2.	1.
Median	2.	2.	2.
75% Quartile	3.	4.	2.
Max	6.	6.	5.
Mean	2.43529	2.87805	2.02273
S.D.	1.39256	1.59992	1.02273
Variance	1.93922	2.55976	1.04598

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	15.5266	15.5266	8.6395	0.00427183
firstInt	1	0.0000689375	0.0000689375	0.0000383591	0.995073
Error	82	147.367	1.79716		
Total	84	162.894			

Cell Means

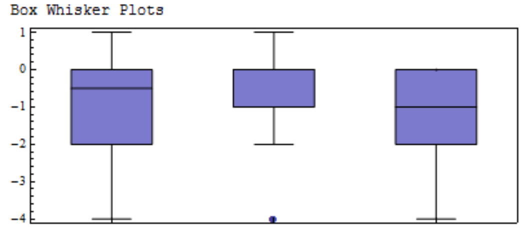
All	2.43529
interface[1.]	2.87805
interface[2.]	2.02273
firstInt[1.]	2.43902
firstInt[2.]	2.43182

Measure: Uq12 (PSSUQ: Easy to find information) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	38	20	18
Min	-4.	-4.	-4.
25% Quartile	-2.	-1.	-2.
Median	-0.5	0.	-1.
75% Quartile	0.	0.	0.
Max	1.	1.	0.
Mean	-1.	-0.7	-1.33333
S.D.	1.41421	1.34164	1.45521
Variance	2.	1.8	2.11765

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	3.8	3.8	1.94872	0.171275
Error	36	70.2	1.95		
Total	37	74.			

Cell Means

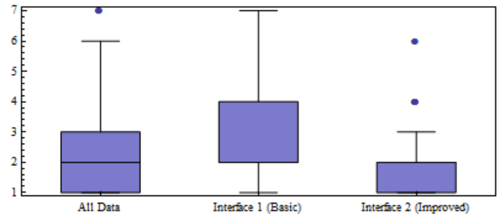
All	-1.
firstInt[1.]	-0.7
firstInt[2.]	-1.33333

Measure: Uq13 (PSSUQ: Information easy to understand) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	93	47	46
Min	1.	1.	1.
25% Quartile	1.	2.	1.
Median	2.	2.	2.
75% Quartile	3.	4.	2.
Max	7.	7.	6.
Mean	2.39785	2.82979	1.95652
S.D.	1.49011	1.64606	1.17296
Variance	2.22043	2.70953	1.37585

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	17.7282	17.7282	8.56006	0.00434878
firstInt	1	0.157749	0.157749	0.0761688	0.783191
Error	90	186.394	2.07104		
Total	92	204.28			

Cell Means

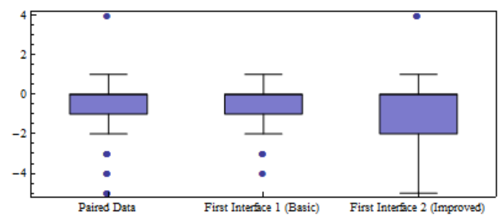
All	2.39785
interface[1.]	2.82979
interface[2.]	1.95652
firstInt[1.]	2.3617
firstInt[2.]	2.43478

Measure: Uq13 (PSSUQ: Information easy to understand) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	46	23	23
Min	-5.	-4.	-5.
25% Quartile	-1.	-1.	-1.75
Median	0.	0.	0.
75% Quartile	0.	0.	0.
Max	4.	1.	4.
Mean	-0.782609	-0.695652	-0.869565
S.D.	1.64537	1.25896	1.98413
Variance	2.70725	1.58498	3.93676

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	0.347826	0.347826	0.125984	0.724328
Error	44	121.478	2.76087		
Total	45	121.826			

Cell Means

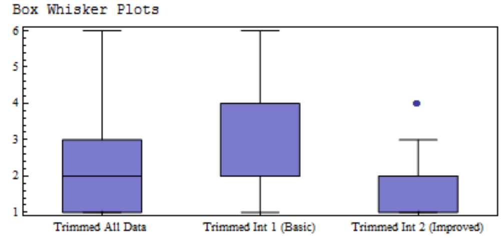
All	-0.782609
firstInt[1.]	-0.695652
firstInt[2.]	-0.869565

Measure: Uq13 (PSSUQ: Information easy to understand) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	87	43	44
Min	1.	1.	1.
25% Quartile	1.	2.	1.
Median	2.	2.	2.
75% Quartile	3.	4.	2.
Max	6.	6.	4.
Mean	2.31034	2.74419	1.88636
S.D.	1.32341	1.46536	1.01651
Variance	1.7514	2.14729	1.0333

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	16.0028	16.0028	9.99755	0.00218121
firstInt	1	0.16118	0.16118	0.100695	0.751784
Error	84	134.457	1.60067		
Total	86	150.621			

Cell Means

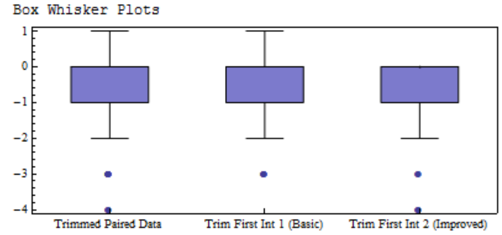
All	2.31034
interface[1.]	2.74419
interface[2.]	1.88636
firstInt[1.]	2.34884
firstInt[2.]	2.27273

Measure: Uq13 (PSSUQ: Information easy to understand) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	40	21	19
Min	-4.	-3.	-4.
25% Quartile	-1.	-1.	-1.
Median	0.	0.	0.
75% Quartile	0.	0.	0.
Max	1.	1.	0.
Mean	-0.7	-0.619048	-0.789474
S.D.	1.09075	1.02353	1.18223
Variance	1.18974	1.04762	1.39766

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	0.289724	0.289724	0.238765	0.627908
Error	38	46.1103	1.21343		
Total	39	46.4			

Cell Means

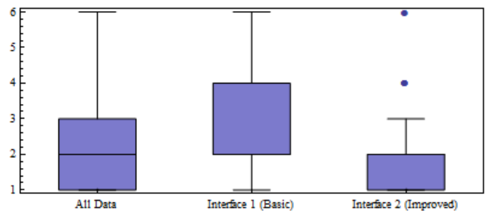
All	-0.7
firstInt[1.]	-0.619048
firstInt[2.]	-0.789474

Measure: **Uq14** (PSSUQ: Information helped complete tasks) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	92	46	46
Min	1.	1.	1.
25% Quartile	1.	2.	1.
Median	2.	2.	2.
75% Quartile	3.	4.	2.
Max	6.	6.	6.
Mean	2.36957	2.8913	1.84783
S.D.	1.43517	1.59483	1.03209
Variance	2.05972	2.54348	1.06522

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	25.0435	25.0435	13.7609	0.000360874
firstInt	1	0.420571	0.420571	0.231096	0.631892
Error	89	161.971	1.8199		
Total	91	187.435			

Cell Means

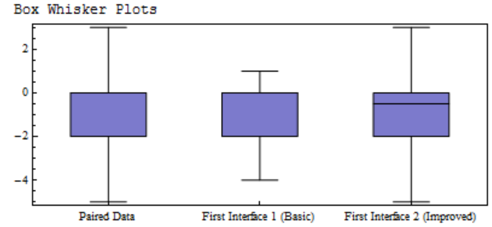
All	2.36957
interface[1.]	2.8913
interface[2.]	1.84783
firstInt[1.]	2.44681
firstInt[2.]	2.28889

Measure: **Uq14** (PSSUQ: Information helped complete tasks) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	45	23	22
Min	-5.	-4.	-5.
25% Quartile	-2.	-1.75	-2.
Median	0.	0.	-0.5
75% Quartile	0.	0.	0.
Max	3.	1.	3.
Mean	-0.977778	-0.913043	-1.04545
S.D.	1.68535	1.44326	1.939
Variance	2.8404	2.083	3.75974

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	0.197145	0.197145	0.0679372	0.795608
Error	43	124.781	2.90188		
Total	44	124.978			

Cell Means

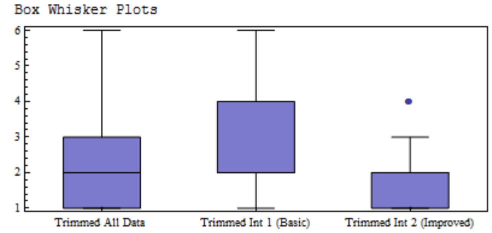
All	-0.977778
firstInt[1.]	-0.913043
firstInt[2.]	-1.04545

Measure: **Uq14** (PSSUQ: Information helped complete tasks) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	86	44	42
Min	1.	1.	1.
25% Quartile	1.	2.	1.
Median	2.	2.	2.
75% Quartile	3.	4.	2.
Max	6.	6.	4.
Mean	2.2907	2.75	1.80952
S.D.	1.29129	1.48049	0.833391
Variance	1.66744	2.19186	0.694541

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	19.0064	19.0064	13.3433	0.000452958
firstInt	1	4.49967	4.49967	3.15896	0.0791745
Error	83	118.227	1.42442		
Total	85	141.733			

Cell Means

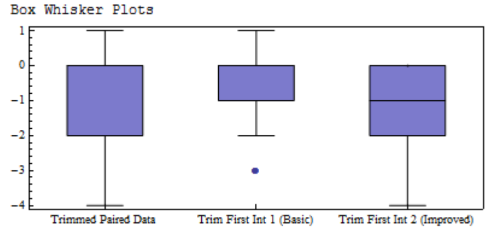
All	2.2907
interface[1.]	2.75
interface[2.]	1.80952
firstInt[1.]	2.54545
firstInt[2.]	2.02381

Measure: **Uq14** (PSSUQ: Information helped complete tasks) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	39	20	19
Min	-4.	-3.	-4.
25% Quartile	-2.	-1.	-2.
Median	0.	0.	-1.
75% Quartile	0.	0.	0.
Max	1.	1.	0.
Mean	-0.948718	-0.7	-1.21053
S.D.	1.27628	1.08094	1.43678
Variance	1.62888	1.16842	2.06433

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	2.53954	2.53954	1.58299	0.216212
Error	37	59.3579	1.60427		
Total	38	61.8974			

Cell Means

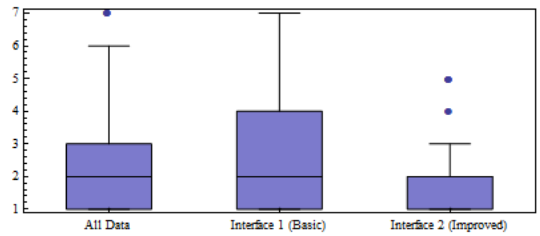
All	-0.948718
firstInt[1.]	-0.7
firstInt[2.]	-1.21053

Measure: Uq15 (PSSUQ: System screens clear) **All Data**

Descriptive Statistics

	All	Interface 1	Interface 2
Statistic	Data	(Basic)	(Improved)
Count	94	47	47
Min	1.	1.	1.
25% Quartile	1.	1.25	1.
Median	2.	2.	2.
75% Quartile	3.	4.	2.
Max	7.	7.	5.
Mean	2.38298	2.76596	2.
S.D.	1.43764	1.72214	0.955533
Variance	2.0668	2.96577	0.913043

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	13.7872	13.7872	7.03611	0.00942511
firstInt	1	0.111317	0.111317	0.0568088	0.812149
Error	91	178.314	1.9595		
Total	93	192.213			

Cell Means

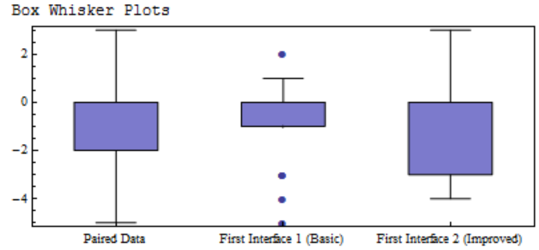
All	2.38298
interface[1.]	2.76596
interface[2.]	2.
firstInt[1.]	2.41667
firstInt[2.]	2.34783

Measure: Uq15 (PSSUQ: System screens clear) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

	Paired	First Interface 1	First Interface 2
Statistic	Data	(Basic)	(Improved)
Count	47	24	23
Min	-5.	-5.	-4.
25% Quartile	-1.75	-1.	-3.
Median	0.	0.	0.
75% Quartile	0.	0.5	0.
Max	3.	2.	3.
Mean	-0.765957	-0.5	-1.04348
S.D.	1.82033	1.69398	1.94184
Variance	3.3136	2.86957	3.77075

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	3.46901	3.46901	1.04799	0.311442
Error	45	148.957	3.31014		
Total	46	152.426			

Cell Means

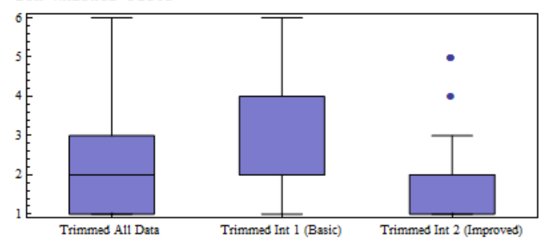
All	-0.765957
firstInt[1.]	-0.5
firstInt[2.]	-1.04348

Measure: Uq15 (PSSUQ: System screens clear) **Trimmed All Data**

Descriptive Statistics

	Trimmed	Trimmed Interface 1	Trimmed Interface 2
Statistic	All Data	(Basic)	(Improved)
Count	88	42	46
Min	1.	1.	1.
25% Quartile	1.	2.	1.
Median	2.	2.	2.
75% Quartile	3.	4.	2.
Max	6.	6.	5.
Mean	2.28409	2.57143	2.02174
S.D.	1.22192	1.41668	0.954268
Variance	1.49308	2.00697	0.910628

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	6.63375	6.63375	4.62609	0.0343281
firstInt	1	1.375	1.375	0.958864	0.330252
Error	85	121.889	1.43399		
Total	87	129.898			

Cell Means

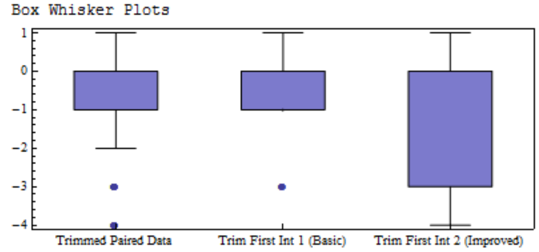
All	2.28409
interface[1.]	2.57143
interface[2.]	2.02174
firstInt[1.]	2.40909
firstInt[2.]	2.15909

Measure: Uq15 (PSSUQ: System screens clear) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

	Trimmed	Trim First Int 1	Trim First Int 2
Statistic	Paired Data	(Basic)	(Improved)
Count	41	20	21
Min	-4.	-3.	-4.
25% Quartile	-1.	-1.	-3.
Median	0.	0.	0.
75% Quartile	0.	0.	0.
Max	1.	1.	1.
Mean	-0.707317	-0.3	-1.09524
S.D.	1.48734	1.12858	1.70014
Variance	2.2122	1.27368	2.89048

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	6.47828	6.47828	3.08078	0.0870759
Error	39	82.0095	2.10281		
Total	40	88.4878			

Cell Means

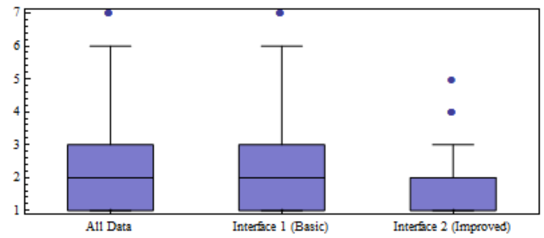
All	-0.707317
firstInt[1.]	-0.3
firstInt[2.]	-1.09524

Measure: Uq16 (PSSUQ: Interface pleasant) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	1.	1.	1.
25% Quartile	1.	1.25	1.
Median	2.	2.	2.
75% Quartile	3.	3.	2.
Max	7.	7.	5.
Mean	2.25532	2.61702	1.89362
S.D.	1.31113	1.52591	0.937945
Variance	1.71906	2.3284	0.879741

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	12.2979	12.2979	7.62315	0.00696957
firstInt	1	0.770891	0.770891	0.477857	0.491154
Error	91	146.804	1.61323		
Total	93	159.872			

Cell Means

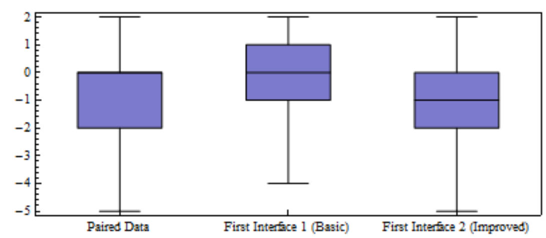
All	2.25532
interface[1.]	2.61702
interface[2.]	1.89362
firstInt[1.]	2.16667
firstInt[2.]	2.34783

Measure: Uq16 (PSSUQ: Interface pleasant) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-5.	-4.	-5.
25% Quartile	-2.	-1.	-2.
Median	0.	0.	-1.
75% Quartile	0.	1.	0.
Max	2.	2.	2.
Mean	-0.723404	-0.333333	-1.13043
S.D.	1.66423	1.46456	1.7915
Variance	2.76966	2.14493	3.20949

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	7.46223	7.46223	2.79969	0.101222
Error	45	119.942	2.66538		
Total	46	127.404			

Cell Means

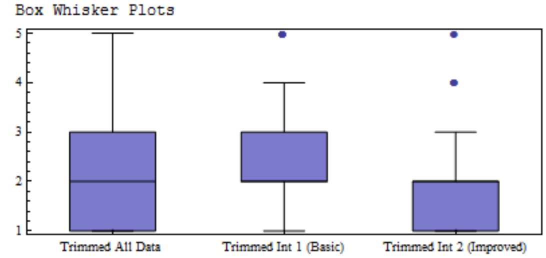
All	-0.723404
firstInt[1.]	-0.333333
firstInt[2.]	-1.13043

Measure: Uq16 (PSSUQ: Interface pleasant) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	42	46
Min	1.	1.	1.
25% Quartile	1.	2.	1.
Median	2.	2.	2.
75% Quartile	3.	3.	2.
Max	5.	5.	5.
Mean	2.15909	2.42857	1.91304
S.D.	1.09215	1.19231	0.938701
Variance	1.19279	1.4216	0.881159

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	5.83484	5.83484	5.06404	0.0270093
firstInt	1	0.	0.	0.	1.
Error	85	97.9379	1.15221		
Total	87	103.773			

Cell Means

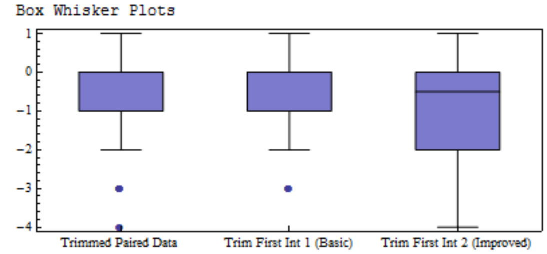
All	2.15909
interface[1.]	2.42857
interface[2.]	1.91304
firstInt[1.]	2.15909
firstInt[2.]	2.15909

Measure: Uq16 (PSSUQ: Interface pleasant) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	21	20
Min	-4.	-3.	-4.
25% Quartile	-1.25	-1.	-2.
Median	0.	0.	-0.5
75% Quartile	0.	0.25	0.
Max	1.	1.	1.
Mean	-0.658537	-0.380952	-0.95
S.D.	1.27691	1.11697	1.39454
Variance	1.63049	1.24762	1.94474

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	3.31713	3.31713	2.08987	0.156267
Error	39	61.9024	1.58724		
Total	40	65.2195			

Cell Means

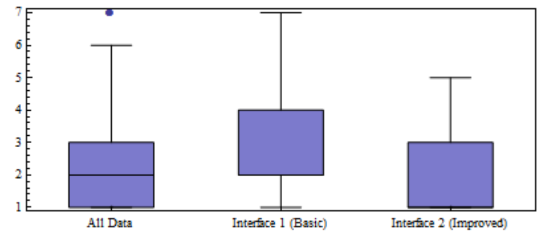
All	-0.658537
firstInt[1.]	-0.380952
firstInt[2.]	-0.95

Measure: Uq17 (PSSUQ: Liked using interface) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	1.	1.	1.
25% Quartile	1.	2.	1.
Median	2.	2.	1.
75% Quartile	3.	4.	2.75
Max	7.	7.	5.
Mean	2.37234	2.85106	1.89362
S.D.	1.55877	1.69371	1.25515
Variance	2.42976	2.86864	1.57539

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	21.5426	21.5426	9.61971	0.0025634
firstInt	1	0.638375	0.638375	0.285063	0.594704
Error	91	203.787	2.23942		
Total	93	225.968			

Cell Means

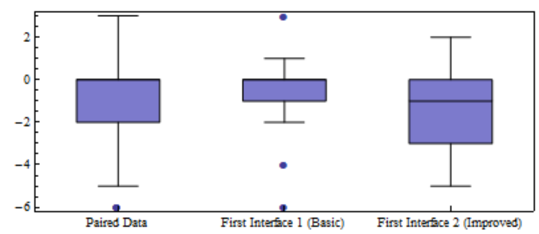
All	2.37234
interface[1.]	2.85106
interface[2.]	1.89362
firstInt[1.]	2.29167
firstInt[2.]	2.45652

Measure: Uq17 (PSSUQ: Liked using interface) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-6.	-6.	-5.
25% Quartile	-2.	-1.	-2.75
Median	0.	0.	-1.
75% Quartile	0.	0.	0.
Max	3.	3.	2.
Mean	-0.957447	-0.666667	-1.26087
S.D.	1.92193	1.76109	2.07183
Variance	3.6938	3.10145	4.29249

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	4.14678	4.14678	1.1257	0.294356
Error	45	165.768	3.68374		
Total	46	169.915			

Cell Means

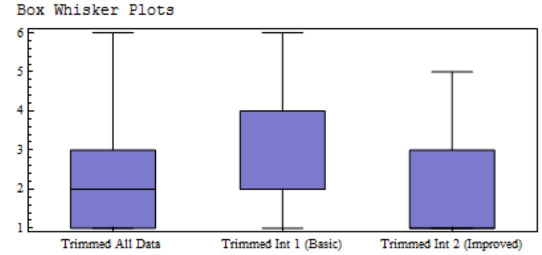
All	-0.957447
firstInt[1.]	-0.666667
firstInt[2.]	-1.26087

Measure: Uq17 (PSSUQ: Liked using interface) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	43	45
Min	1.	1.	1.
25% Quartile	1.	2.	1.
Median	2.	2.	1.
75% Quartile	3.	3.75	3.
Max	6.	6.	5.
Mean	2.27273	2.62791	1.93333
S.D.	1.37069	1.39767	1.2685
Variance	1.87879	1.95349	1.60909

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	10.608	10.608	5.89948	0.0172526
firstInt	1	0.00548502	0.00548502	0.0030504	0.956084
Error	85	152.841	1.79813		
Total	87	163.455			

Cell Means

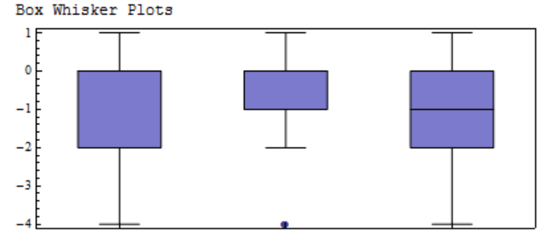
All	2.27273
interface[1.]	2.62791
interface[2.]	1.93333
firstInt[1.]	2.27273
firstInt[2.]	2.27273

Measure: Uq17 (PSSUQ: Liked using interface) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	22	19
Min	-4.	-4.	-4.
25% Quartile	-2.	-1.	-2.
Median	0.	0.	-1.
75% Quartile	0.	0.	0.
Max	1.	1.	1.
Mean	-0.878049	-0.590909	-1.21053
S.D.	1.39991	1.18157	1.58391
Variance	1.95976	1.3961	2.50877

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	3.91417	3.91417	2.04969	0.160203
Error	39	74.4761	1.90964		
Total	40	78.3902			

Cell Means

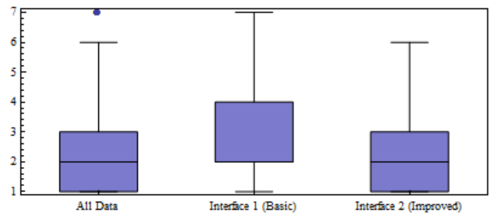
All	-0.878049
firstInt[1.]	-0.590909
firstInt[2.]	-1.21053

Measure: Uq18 (PSSUQ: All functions expected available) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	91	46	45
Min	1.	1.	1.
25% Quartile	1.	2.	1.
Median	2.	2.	2.
75% Quartile	3.	4.	3.
Max	7.	7.	6.
Mean	2.51648	2.8913	2.13333
S.D.	1.56605	1.81632	1.15994
Variance	2.4525	3.29903	1.34545

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	13.0688	13.0688	5.66889	0.0194253
firstInt	1	4.78598	4.78598	2.07603	0.153177
Error	88	202.871	2.30535		
Total	90	220.725			

Cell Means

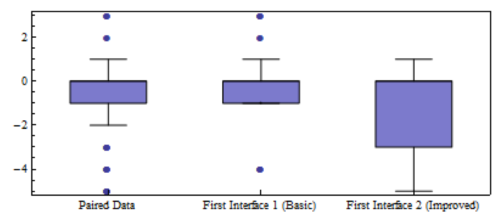
All	2.51648
interface[1.]	2.8913
interface[2.]	2.13333
firstInt[1.]	2.28889
firstInt[2.]	2.73913

Measure: Uq18 (PSSUQ: All functions expected available) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	46	23	23
Min	-5.	-4.	-5.
25% Quartile	-1.	-1.	-3.
Median	0.	0.	0.
75% Quartile	0.	0.	0.
Max	3.	3.	1.
Mean	-0.73913	-0.173913	-1.30435
S.D.	1.90245	1.64184	2.00986
Variance	3.61932	2.69565	4.03953

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	14.6957	14.6957	4.36385	0.0425263
Error	44	148.174	3.36759		
Total	45	162.87			

Cell Means

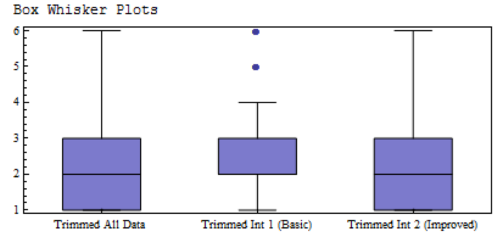
All	-0.73913
firstInt[1.]	-0.173913
firstInt[2.]	-1.30435

Measure: Uq18 (PSSUQ: All functions expected available) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	85	42	43
Min	1.	1.	1.
25% Quartile	1.	2.	1.
Median	2.	2.	2.
75% Quartile	3.	3.	3.
Max	6.	6.	6.
Mean	2.41176	2.64286	2.18605
S.D.	1.34779	1.49506	1.15996
Variance	1.81653	2.23519	1.34551

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	4.43375	4.43375	2.48459	0.118816
firstInt	1	1.82567	1.82567	1.02307	0.314767
Error	82	146.329	1.7845		
Total	84	152.588			

Cell Means

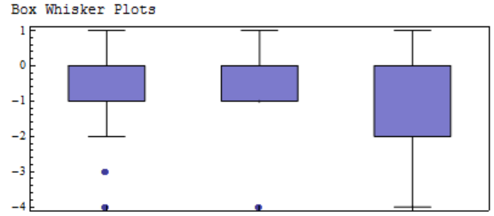
All	2.41176
interface[1.]	2.64286
interface[2.]	2.18605
firstInt[1.]	2.26829
firstInt[2.]	2.54545

Measure: Uq18 (PSSUQ: All functions expected available) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	40	20	20
Min	-4.	-4.	-4.
25% Quartile	-1.	-1.	-1.5
Median	0.	0.	0.
75% Quartile	0.	0.	0.
Max	1.	1.	1.
Mean	-0.675	-0.6	-0.75
S.D.	1.36603	1.27321	1.48235
Variance	1.86603	1.62105	2.19737

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	0.225	0.225	0.11785	0.73327
Error	38	72.55	1.90921		
Total	39	72.775			

Cell Means

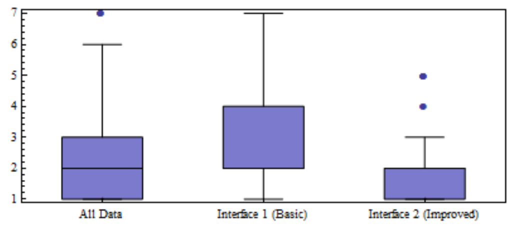
All	-0.675
firstInt[1.]	-0.6
firstInt[2.]	-0.75

Measure: **Uq19** (PSSUQ: Overall system satisfaction) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	1.	1.	1.
25% Quartile	1.	2.	1.
Median	2.	2.	2.
75% Quartile	3.	4.	2.
Max	7.	7.	5.
Mean	2.34043	2.82979	1.85106
S.D.	1.44098	1.65922	0.977546
Variance	2.07641	2.75301	0.955597

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	22.5106	22.5106	12.0131	0.000808104
firstInt	1	0.0764917	0.0764917	0.0408209	0.840335
Error	91	170.519	1.87384		
Total	93	193.106			

Cell Means

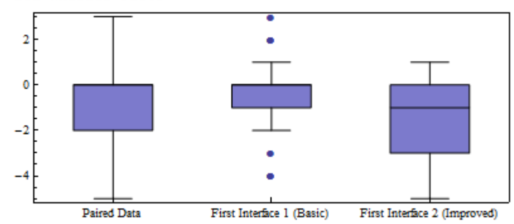
All	2.34043
interface[1.]	2.82979
interface[2.]	1.85106
firstInt[1.]	2.3125
firstInt[2.]	2.36957

Measure: **Uq19** (PSSUQ: Overall system satisfaction) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-5.	-4.	-5.
25% Quartile	-2.	-1.	-3.
Median	0.	0.	-1.
75% Quartile	0.	0.	0.
Max	3.	3.	1.
Mean	-0.978723	-0.458333	-1.52174
S.D.	1.83551	1.66757	1.87979
Variance	3.3691	2.7808	3.5336

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	13.2813	13.2813	4.21784	0.045839
Error	45	141.697	3.14883		
Total	46	154.979			

Cell Means

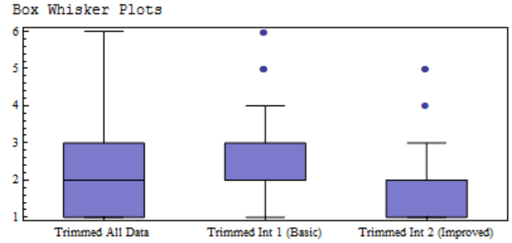
All	-0.978723
firstInt[1.]	-0.458333
firstInt[2.]	-1.52174

Measure: **Uq19** (PSSUQ: Overall system satisfaction) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	43	45
Min	1.	1.	1.
25% Quartile	1.	2.	1.
Median	2.	2.	2.
75% Quartile	3.	3.	2.
Max	6.	6.	5.
Mean	2.25	2.62791	1.88889
S.D.	1.26173	1.41461	0.982164
Variance	1.59195	2.00111	0.964646

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	12.009	12.009	8.17604	0.00533891
firstInt	1	1.64209	1.64209	1.11798	0.293351
Error	85	124.849	1.46881		
Total	87	138.5			

Cell Means

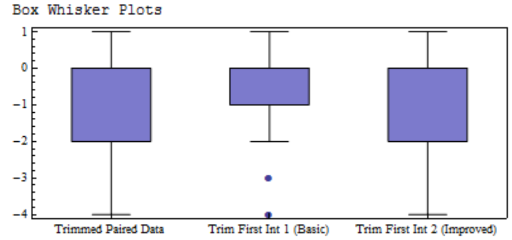
All	2.25
interface[1.]	2.62791
interface[2.]	1.88889
firstInt[1.]	2.4
firstInt[2.]	2.09302

Measure: **Uq19** (PSSUQ: Overall system satisfaction) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	20	21
Min	-4.	-4.	-4.
25% Quartile	-2.	-1.	-2.25
Median	0.	0.	0.
75% Quartile	0.	0.	0.
Max	1.	1.	1.
Mean	-0.95122	-0.7	-1.19048
S.D.	1.41335	1.17429	1.6006
Variance	1.99756	1.37895	2.5619

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	2.46434	2.46434	1.24111	0.272076
Error	39	77.4381	1.98559		
Total	40	79.9024			

Cell Means

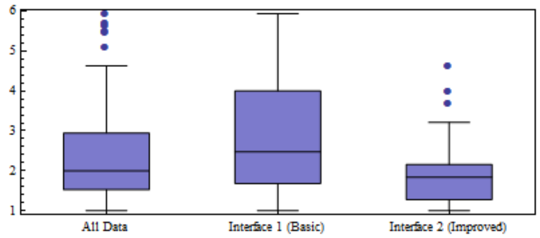
All	-0.95122
firstInt[1.]	-0.7
firstInt[2.]	-1.19048

Measure: **UqOverall** (PSSUQ: Overall) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	1.	1.	1.
25% Quartile	1.52632	1.7076	1.28728
Median	2.	2.47368	1.84211
75% Quartile	2.94737	3.92105	2.15789
Max	5.9375	5.9375	4.63158
Mean	2.38477	2.84713	1.92242
S.D.	1.23928	1.41364	0.818404
Variance	1.5358	1.99837	0.669785

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	20.0946	20.0946	14.9224	0.000209559
firstInt	1	0.194077	0.194077	0.144123	0.7051
Error	91	122.541	1.34661		
Total	93	142.83			

Cell Means

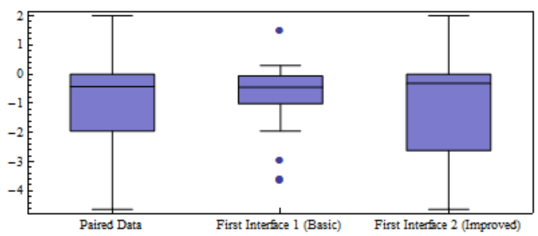
All	2.38477
interface[1.]	2.84713
interface[2.]	1.92242
firstInt[1.]	2.34029
firstInt[2.]	2.43119

Measure: **UqOverall** (PSSUQ: Overall) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-4.63158	-3.59608	-4.63158
25% Quartile	-1.80857	-0.978386	-2.5688
Median	-0.430341	-0.452012	-0.315789
75% Quartile	-0.00928793	-0.0263158	-0.00928793
Max	2.	1.52632	2.
Mean	-0.924711	-0.750528	-1.10647
S.D.	1.44255	1.21652	1.65415
Variance	2.08094	1.47992	2.73623

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	1.48797	1.48797	0.710547	0.403721
Error	45	94.2352	2.09412		
Total	46	95.7232			

Cell Means

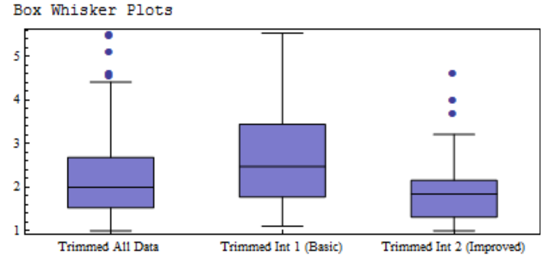
All	-0.924711
firstInt[1.]	-0.750528
firstInt[2.]	-1.10647

Measure: **UqOverall** (PSSUQ: Overall) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	42	46
Min	1.	1.10526	1.
25% Quartile	1.52632	1.77778	1.31579
Median	2.	2.47214	1.84211
75% Quartile	2.72446	3.44444	2.15789
Max	5.52941	5.52941	4.63158
Mean	2.31697	2.72715	1.94247
S.D.	1.08532	1.1998	0.81569
Variance	1.17792	1.43953	0.66535

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	13.5177	13.5177	12.9163	0.000545149
firstInt	1	0.00318359	0.00318359	0.00304194	0.956145
Error	85	88.9582	1.04657		
Total	87	102.479			

Cell Means

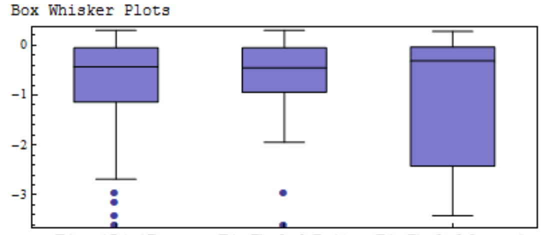
All	2.31697
interface[1.]	2.72715
interface[2.]	1.94247
firstInt[1.]	2.34029
firstInt[2.]	2.28899

Measure: **UqOverall** (PSSUQ: Overall) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	22	19
Min	-3.5848	-3.5848	-3.41118
25% Quartile	-1.2033	-0.944272	-2.35526
Median	-0.430341	-0.452012	-0.315789
75% Quartile	-0.0487616	-0.0526316	-0.0410217
Max	0.298611	0.298611	0.277778
Mean	-0.862682	-0.724678	-1.02248
S.D.	1.12753	0.993846	1.27381
Variance	1.27133	0.98773	1.62259

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	0.904153	0.904153	0.70596	0.40591
Error	39	49.949	1.28074		
Total	40	50.8531			

Cell Means

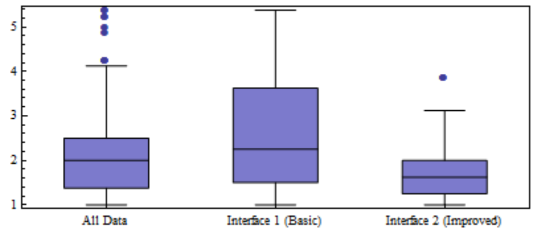
All	-0.862682
firstInt[1.]	-0.724678
firstInt[2.]	-1.02248

Measure: UqUseful (PSSUQ: System Usefulness) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	1.	1.	1.
25% Quartile	1.375	1.5625	1.25
Median	2.	2.25	1.625
75% Quartile	2.5	3.59375	2.
Max	5.375	5.375	3.875
Mean	2.23404	2.68617	1.78191
S.D.	1.14773	1.32438	0.701061
Variance	1.31728	1.75399	0.491486

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	19.2154	19.2154	16.9811	0.0000831323
firstInt	1	0.318229	0.318229	0.281225	0.597191
Error	91	102.974	1.13158		
Total	93	122.507			

Cell Means

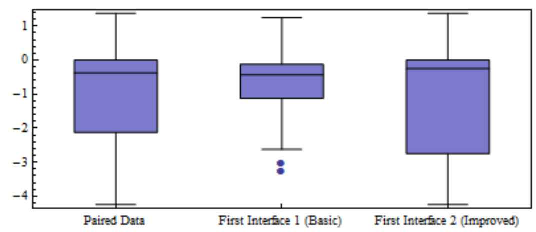
All	2.23404
interface[1.]	2.68617
interface[2.]	1.78191
firstInt[1.]	2.17708
firstInt[2.]	2.29348

Measure: UqUseful (PSSUQ: System Usefulness) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-4.25	-3.25	-4.25
25% Quartile	-1.96875	-1.	-2.59375
Median	-0.375	-0.4375	-0.25
75% Quartile	0.	-0.0625	0.
Max	1.375	1.25	1.375
Mean	-0.904255	-0.708333	-1.1087
S.D.	1.34786	1.08702	1.57407
Variance	1.81672	1.18161	2.47771

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	1.88255	1.88255	1.03707	0.313947
Error	45	81.6866	1.81526		
Total	46	83.5691			

Cell Means

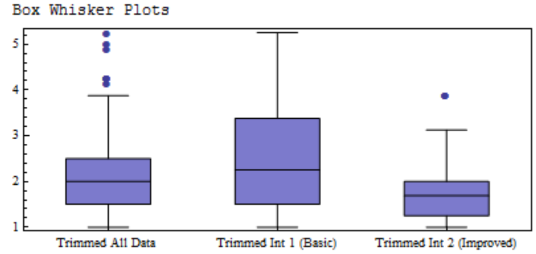
All	-0.904255
firstInt[1.]	-0.708333
firstInt[2.]	-1.1087

Measure: UqUseful (PSSUQ: System Usefulness) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	44	44
Min	1.	1.	1.
25% Quartile	1.5	1.5	1.25
Median	2.	2.25	1.6875
75% Quartile	2.5	3.375	2.
Max	5.25	5.25	3.875
Mean	2.17045	2.50568	1.83523
S.D.	1.01004	1.16357	0.692974
Variance	1.02018	1.35389	0.480213

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	9.8892	9.8892	10.7078	0.00154301
firstInt	1	0.364346	0.364346	0.394504	0.531625
Error	85	78.5021	0.923554		
Total	87	88.7557			

Cell Means

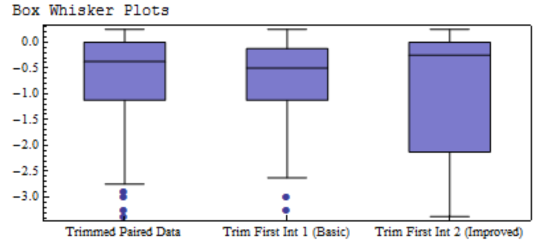
All	2.17045
interface[1.]	2.50568
interface[2.]	1.83523
firstInt[1.]	2.25556
firstInt[2.]	2.0814

Measure: UqUseful (PSSUQ: System Usefulness) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	23	18
Min	-3.375	-3.25	-3.375
25% Quartile	-1.21875	-1.0625	-2.125
Median	-0.375	-0.5	-0.25
75% Quartile	0.	-0.125	0.
Max	0.25	0.25	0.25
Mean	-0.832317	-0.793478	-0.881944
S.D.	1.08958	1.02636	1.19394
Variance	1.1872	1.05342	1.4255

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	0.0790262	0.0790262	0.0650095	0.800086
Error	39	47.4088	1.21561		
Total	40	47.4878			

Cell Means

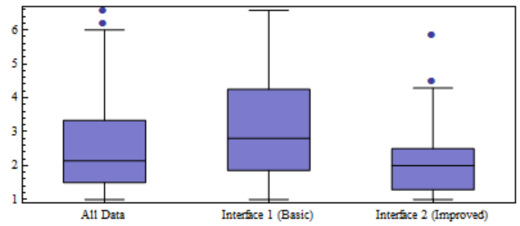
All	-0.832317
firstInt[1.]	-0.793478
firstInt[2.]	-0.881944

Measure: **UqInfoQual** (PSSUQ: Information Quality) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	1.	1.	1.
25% Quartile	1.5	1.89286	1.28571
Median	2.14286	2.8	2.
75% Quartile	3.33333	4.15179	2.5
Max	6.57143	6.57143	5.85714
Mean	2.59121	3.0848	2.09762
S.D.	1.3929	1.55022	1.01067
Variance	1.94017	2.40319	1.02146

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	22.9015	22.9015	13.2326	0.000455948
firstInt	1	0.0416032	0.0416032	0.0240386	0.87713
Error	91	157.493	1.73069		
Total	93	180.436			

Cell Means

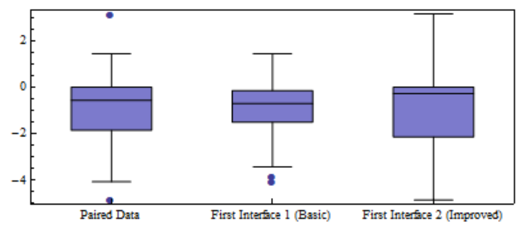
All	2.59121
interface[1.]	3.0848
interface[2.]	2.09762
firstInt[1.]	2.61181
firstInt[2.]	2.56972

Measure: **UqInfoQual** (PSSUQ: Information Quality) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-4.85714	-4.07143	-4.85714
25% Quartile	-1.83036	-1.47143	-2.07143
Median	-0.571429	-0.714286	-0.285714
75% Quartile	0.	-0.075	0.
Max	3.14286	1.42857	3.14286
Mean	-0.987183	-0.986111	-0.988302
S.D.	1.54394	1.38989	1.7218
Variance	2.38374	1.93178	2.96459

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	0.0000563887	0.0000563887	0.0000231413	0.996183
Error	45	109.652	2.43671		
Total	46	109.652			

Cell Means

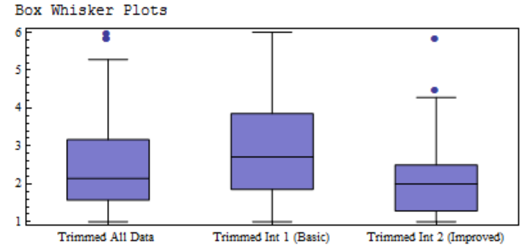
All	-0.987183
firstInt[1.]	-0.986111
firstInt[2.]	-0.988302

Measure: **UqInfoQual** (PSSUQ: Information Quality) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	43	45
Min	1.	1.	1.
25% Quartile	1.57143	1.89286	1.28571
Median	2.14286	2.71429	2.
75% Quartile	3.22619	3.85119	2.51786
Max	6.	6.	5.85714
Mean	2.52048	2.91196	2.1464
S.D.	1.23136	1.33235	1.00533
Variance	1.51626	1.77516	1.01069

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	12.8871	12.8871	9.23439	0.00315531
firstInt	1	0.405098	0.405098	0.290278	0.591451
Error	85	118.622	1.39555		
Total	87	131.914			

Cell Means

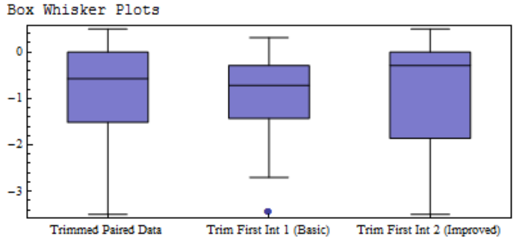
All	2.52048
interface[1.]	2.91196
interface[2.]	2.1464
firstInt[1.]	2.44772
firstInt[2.]	2.60017

Measure: **UqInfoQual** (PSSUQ: Information Quality) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	20	21
Min	-3.5	-3.42857	-3.5
25% Quartile	-1.57321	-1.35714	-1.92857
Median	-0.571429	-0.714286	-0.285714
75% Quartile	0.	-0.217857	0.
Max	0.5	0.314286	0.5
Mean	-0.947329	-0.89119	-1.00079
S.D.	1.13113	0.969852	1.28809
Variance	1.27945	0.940613	1.65917

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	0.123059	0.123059	0.0940022	0.760781
Error	39	51.055	1.3091		
Total	40	51.1781			

Cell Means

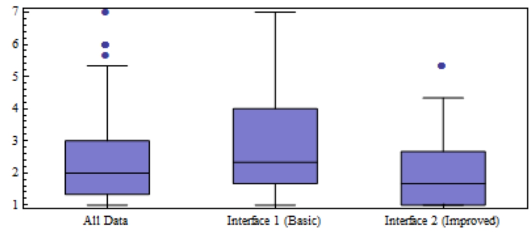
All	-0.947329
firstInt[1.]	-0.89119
firstInt[2.]	-1.00079

Measure: UqIntQual (PSSUQ: Interface Quality) **All Data**

Descriptive Statistics

Statistic	All Data	Interface 1 (Basic)	Interface 2 (Improved)
Count	94	47	47
Min	1.	1.	1.
25% Quartile	1.33333	1.66667	1.
Median	2.	2.33333	1.66667
75% Quartile	3.	3.91667	2.66667
Max	7.	7.	5.33333
Mean	2.37234	2.78014	1.96454
S.D.	1.3988	1.59146	1.0408
Variance	1.95665	2.53274	1.08326

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	15.6324	15.6324	8.6469	0.0041535
firstInt	1	1.82034	1.82034	1.0069	0.318307
Error	91	164.515	1.80786		
Total	93	181.968			

Cell Means

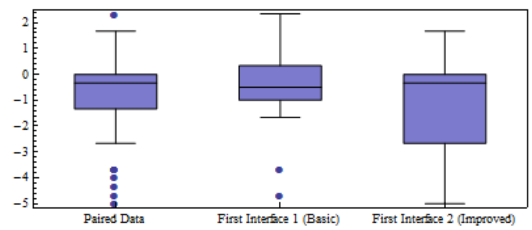
All	2.37234
interface[1.]	2.78014
interface[2.]	1.96454
firstInt[1.]	2.23611
firstInt[2.]	2.51449

Measure: UqIntQual (PSSUQ: Interface Quality) **Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Paired Data	First Interface 1 (Basic)	First Interface 2 (Improved)
Count	47	24	23
Min	-5.	-4.66667	-5.
25% Quartile	-1.33333	-1.	-2.58333
Median	-0.333333	-0.5	-0.333333
75% Quartile	0.	0.5	0.
Max	2.33333	2.33333	1.66667
Mean	-0.815603	-0.416667	-1.23188
S.D.	1.72899	1.52357	1.86254
Variance	2.98941	2.32126	3.46904

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	7.80527	7.80527	2.70791	0.10682
Error	45	129.708	2.88239		
Total	46	137.513			

Cell Means

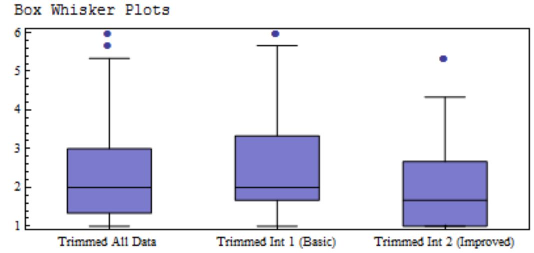
All	-0.815603
firstInt[1.]	-0.416667
firstInt[2.]	-1.23188

Measure: UqIntQual (PSSUQ: Interface Quality) **Trimmed All Data**

Descriptive Statistics

Statistic	Trimmed All Data	Trimmed Interface 1 (Basic)	Trimmed Interface 2 (Improved)
Count	88	43	45
Min	1.	1.	1.
25% Quartile	1.33333	1.66667	1.
Median	2.	2.	1.66667
75% Quartile	3.	3.25	2.66667
Max	6.	6.	5.33333
Mean	2.28409	2.57364	2.00741
S.D.	1.21247	1.31802	1.04323
Variance	1.47009	1.73717	1.08833

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
interface	1	7.05007	7.05007	4.96055	0.0285746
firstInt	1	0.043464	0.043464	0.0305821	0.861592
Error	85	120.804	1.42123		
Total	87	127.898			

Cell Means

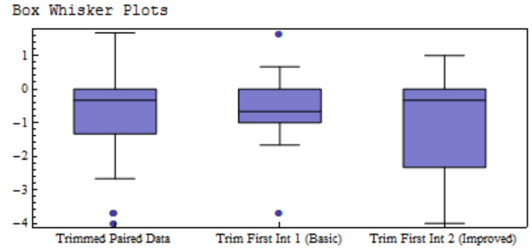
All	2.28409
interface[1.]	2.57364
interface[2.]	2.00741
firstInt[1.]	2.31852
firstInt[2.]	2.24806

Measure: UqIntQual (PSSUQ: Interface Quality) **Trimmed Paired Data** (Test of interface 2 - test of interface 1, by subject)

Descriptive Statistics

Statistic	Trimmed Paired Data	Trim First Int 1 (Basic)	Trim First Int 2 (Improved)
Count	41	21	20
Min	-4.	-3.66667	-4.
25% Quartile	-1.33333	-1.	-2.16667
Median	-0.333333	-0.666667	-0.333333
75% Quartile	0.	0.0833333	0.
Max	1.66667	1.66667	1.
Mean	-0.731707	-0.444444	-1.03333
S.D.	1.32543	1.08184	1.50981
Variance	1.75678	1.17037	2.27953

Box Whisker Plots



ANOVA Results

	DF	SumOfSq	MeanSq	FRatio	PValue
firstInt	1	3.55248	3.55248	2.07659	0.157555
Error	39	66.7185	1.71073		
Total	40	70.271			

Cell Means

All	-0.731707
firstInt[1.]	-0.444444
firstInt[2.]	-1.03333

Appendix V

Summary of Data Analysis Significance and Means Comparison

Significance and Means for difference in Interface measures (from all data)

Items marked in RED are significantly different at a 90% confidence level.

Measure	Description	All Data PValue	Interface 1 Mean	Interface 2 Mean	Trimmed All Data PValue	Interface 1 Mean	Interface 2 Mean
DataSecsAll	Data Entry Seconds All Tasks	0.981084	431.979	431.447	0.508284	423.455	436.114
DataSecsFac	Data Entry Seconds Factory	0.160108	92.234	76.0638	0.319269	82.	74.1628
DataSecsDis	Data Entry Seconds Distributor	1.45481×10^{-6}	81.6809	132.83	5.28129×10^{-6}	83.6364	121.523
DataSecsRun	Data Entry Seconds Run Set	0.00494231	83.5745	50.4681	0.0101162	67.1136	51.9545
DataErrAll	Data Entry Errors All	0.311425	1.82979	1.48936	0.450406	1.66667	1.44186
DataErrFac	Data Entry Errors Factory	0.074423	0.744681	0.531915	0.0213313	0.717391	0.47619
DataErrDis	Data Entry Errors Distributor	0.0632482	0.93617	0.574468	0.483917	0.727273	0.613636
DataErrRun	Data Entry Errors Run Set	0.0706063	0.148936	0.382979	0.297294	0.155556	0.27907
DataTaskFail	Data Entry Task Failures	0.0708145	0.361702	0.170213	0.382407	0.255814	0.177778
AnaSecsAll	Analysis Seconds All	0.172231	429.766	398.064	0.546178	413.867	402.302
AnaSecsTab	Analysis Seconds Table	0.0882577	219.511	191.149	0.169157	208.795	191.
AnaSecsGraph	Analysis Seconds Graph	0.794286	210.255	206.915	0.352787	210.255	200.
AnaErrAll	Analysis Errors All	0.00276155	0.638298	0.234043	0.0044416	0.555556	0.209302
AnaTaskFail	Analysis Task Failures	0.104845	0.234043	0.0638298	0.426914	0.116279	0.0666667
Uq1	PSSUQ: Satisfied w/ease of use	0.000200102	3.	1.97872	0.00351417	2.79545	2.04545
Uq2	PSSUQ: Simple to use	0.000934272	2.78723	1.89362	0.00671293	2.60465	1.93333
Uq3	PSSUQ: Effectively complete tasks	0.000979626	2.44681	1.6383	0.000291975	2.34091	1.56818
Uq4	PSSUQ: Able to complete tasks quickly	0.0000780766	3.	1.95745	0.00141215	2.77273	2.02273
Uq5	PSSUQ: Efficiently complete tasks	0.000244618	2.70213	1.78723	0.00006093	2.62791	1.73333
Uq6	PSSUQ: Felt comfortable using	0.0008542	2.78723	1.85106	0.00583818	2.62791	1.88889
Uq7	PSSUQ: Easy to learn to use	0.00244846	2.44681	1.68085	0.00933535	2.28571	1.69565
Uq8	PSSUQ: Could be productive quickly	0.00102065	2.31915	1.46809	0.00617518	2.06977	1.48889
Uq9	PSSUQ: Clear error messages	0.0265329	3.63636	2.67568	0.0165344	3.53125	2.5625
Uq10	PSSUQ: Recover easily from errors	0.00929013	2.91892	2.06818	0.00706718	2.76471	2.
Uq11	PSSUQ: Information provided was clear	0.00567384	3.5	2.28571	0.00531493	3.36364	2.21875
Uq12	PSSUQ: Easy to find information	0.000587501	3.08889	1.97826	0.00427183	2.87805	2.02273
Uq13	PSSUQ: Information easy to understand	0.00434878	2.82979	1.95652	0.00218121	2.74419	1.88636
Uq14	PSSUQ: Information helped complete tasks	0.000360874	2.8913	1.84783	0.000452958	2.75	1.80952
Uq15	PSSUQ: System screens clear	0.00942511	2.76596	2.	0.0343281	2.57143	2.02174
Uq16	PSSUQ: Interface pleasant	0.00696957	2.61702	1.89362	0.0270093	2.42857	1.91304
Uq17	PSSUQ: Liked using interface	0.0025634	2.85106	1.89362	0.0172526	2.62791	1.93333
Uq18	PSSUQ: All functions expected available	0.0194253	2.8913	2.13333	0.118816	2.64286	2.18605
Uq19	PSSUQ: Overall system satisfaction	0.000808104	2.82979	1.85106	0.00533891	2.62791	1.88889
UqOverall	PSSUQ: Overall	0.000209559	2.84713	1.92242	0.000545149	2.72715	1.94247
UqUseful	PSSUQ: System Usefulness	0.0000831323	2.68617	1.78191	0.00154301	2.50568	1.83523
UqInfoQual	PSSUQ: Information Quality	0.000455948	3.0848	2.09762	0.00315531	2.91196	2.1464
UqIntQual	PSSUQ: Interface Quality	0.0041535	2.78014	1.96454	0.0285746	2.57364	2.00741

Significance and Means for difference in First Interface measures (from data paired by subject)

Items marked in RED are significantly different at a 90% confidence level.

Measure	Description	Paired Data PValue	First Interface 1 Mean	First Interface 2 Mean	Trimmed Paired Data PValue	First Interface 1 Mean	First Interface 2 Mean
DataSecsAll	Data Entry Seconds All Tasks	0.239213	-17.5	17.1739	0.321008	-9.42857	14.6
DataSecsFac	Data Entry Seconds Factory	0.552166	-22.0833	-10.	0.334334	-20.3	-9.7619
DataSecsDis	Data Entry Seconds Distributor	0.888432	49.875	52.4783	0.27849	40.2381	55.
DataSecsRun	Data Entry Seconds Run Set	0.54329	-39.7917	-26.1304	0.857342	-23.5455	-21.8421
DataErrAll	Data Entry Errors All	0.0165054	-0.958333	0.304348	0.073023	-0.727273	-0.0526316
DataErrFac	Data Entry Errors Factory	0.0202346	-0.416667	0.	0.34787	-0.333333	-0.2
DataErrDis	Data Entry Errors Distributor	0.0853825	-0.625	-0.0869565	0.0212091	-0.521739	-0.111111
DataErrRun	Data Entry Errors Run Set	0.212286	0.0833333	0.391304	0.485452	0.285714	0.15
DataTaskFail	Data Entry Task Failures	0.7916	-0.166667	-0.217391	0.508959	-0.142857	-0.25
AnaSecsAll	Analysis Seconds All	0.0436426	-65.75	3.82609	0.0462025	-59.0952	-0.45
AnaSecsTab	Analysis Seconds Table	0.105612	-51.2083	-4.52174	0.00236997	-55.7727	5.26316
AnaSecsGraph	Analysis Seconds Graph	0.271793	-14.5417	8.34783	0.238854	-16.6842	2.27273
AnaErrAll	Analysis Errors All	0.565239	-0.333333	-0.478261	0.333623	-0.333333	-0.529412
AnaTaskFail	Analysis Task Failures	0.615903	-0.208333	-0.130435	0.53167	-0.047619	-0.1
Uq1	PSSUQ: Satisfied w/ease of use	0.927388	-1.	-1.04348	0.241065	-0.727273	-1.21053
Uq2	PSSUQ: Simple to use	0.936308	-0.875	-0.913043	0.599983	-0.73913	-0.944444
Uq3	PSSUQ: Effectively complete tasks	0.0476677	-0.375	-1.26087	0.0221783	-0.363636	-1.21053
Uq4	PSSUQ: Able to complete tasks quickly	0.719172	-0.958333	-1.13043	0.98558	-0.954545	-0.947368
Uq5	PSSUQ: Efficiently complete tasks	0.191644	-0.625	-1.21739	0.291977	-0.714286	-1.1
Uq6	PSSUQ: Felt comfortable using	0.398135	-0.75	-1.13043	0.107797	-0.619048	-1.25
Uq7	PSSUQ: Easy to learn to use	0.311484	-0.541667	-1.	0.0179039	-0.285714	-1.15
Uq8	PSSUQ: Could be productive quickly	0.189911	-0.541667	-1.17391	0.137517	-0.454545	-1.
Uq9	PSSUQ: Clear error messages	0.423365	-0.9375	-0.333333	0.139931	-1.	-0.363636
Uq10	PSSUQ: Recover easily from errors	0.34527	-1.10526	-0.4	0.198955	-1.	-0.416667
Uq11	PSSUQ: Information provided was clear	0.439624	-0.6875	-1.22222	0.575287	-0.928571	-0.642857
Uq12	PSSUQ: Easy to find information	0.59108	-0.904762	-1.21739	0.171275	-0.7	-1.33333
Uq13	PSSUQ: Information easy to understand	0.724328	-0.695652	-0.869565	0.627908	-0.619048	-0.789474
Uq14	PSSUQ: Information helped complete tasks	0.795608	-0.913043	-1.04545	0.216212	-0.7	-1.21053
Uq15	PSSUQ: System screens clear	0.311442	-0.5	-1.04348	0.0870759	-0.3	-1.09524
Uq16	PSSUQ: Interface pleasant	0.101222	-0.333333	-1.13043	0.156267	-0.380952	-0.95
Uq17	PSSUQ: Liked using interface	0.294356	-0.666667	-1.26087	0.160203	-0.590909	-1.21053
Uq18	PSSUQ: All functions expected available	0.0425263	-0.173913	-1.30435	0.73327	-0.6	-0.75
Uq19	PSSUQ: Overall system satisfaction	0.045839	-0.458333	-1.52174	0.272076	-0.7	-1.19048
UqOverall	PSSUQ: Overall	0.403721	-0.750528	-1.10647	0.40591	-0.724678	-1.02248
UqUseful	PSSUQ: System Usefulness	0.313947	-0.708333	-1.1087	0.800086	-0.793478	-0.881944
UqInfoQual	PSSUQ: Information Quality	0.996183	-0.986111	-0.988302	0.760781	-0.89119	-1.00079
UqIntQual	PSSUQ: Interface Quality	0.10682	-0.416667	-1.23188	0.157555	-0.444444	-1.03333

Appendix W

Mathematica Source Code for Data Analysis

```
raw = Import["C:/Users/brmjr9/Documents/Data Analysis/StudyData-Final-040311-forMM.xls"] [[1]];
dLongLabels = raw[[1]];
d = Drop[raw, 1]; (* drop the labels from the data list*)
dLabels = d[[1]];
d = Drop[d, 1]; (* drop the labels from the data list*)
dT = Transpose[d];
dT = Drop[dT, 1]; (* drop the trial number *)
dLabels = Drop[dLabels, 1];
dLongLabels = Drop[dLongLabels, 1];
dT = Drop[dT, 1]; (* drop the subject number *)
dLabels = Drop[dLabels, 1];
dLongLabels = Drop[dLongLabels, 1];
d = Transpose[dT];                    (* d is the whole data set, by interface and first interface *)
dInt1 = Select[d, Part[#, 1] == 1 &] ; (* dInt1 is only tests on the 1st "basic" interface *)
dInt2 = Select[d, Part[#, 1] == 2 &] ;(* dInt2 is only tests on the 2nd "improved" interface *)
dP = dInt2 - dInt1;
dP = Drop[Transpose[dP], {1, 2}];
dI = Take[Transpose[dInt1], {2}];
dPaired = Transpose[Join[dI, dP]] ;  (* dPaired is test by subject = "improved" interface - "basic" interface *)
dPairedFI1 = Select[dPaired, Part[#, 1] == 1 &] ; (* dPairedFI1 is dPaired for the first interface "basic" *)
dPairedFI2 = Select[dPaired, Part[#, 1] == 2 &] ; (* dPairedFI2 is dPaired for the first interface "improved" *)
sll[ll_, elem_] := ll[[Ordering[ll[[All, elem]]]]] (* from ref/Ordering - sorts at a position, maintains original order *)
allPvalues1 = {{"Measure", "Description", "All Data", "Interface 1", "Interface 2", "Trimmed All Data", "Interface 1", "Interface 2"},
   {"", "", "PValue", "Mean", "Mean", "PValue", "Mean", "Mean"}};
allPvalues2 = {{" ", " ", "Paired", "First", "First", "Trimmed", "First", "First"},
   {"Measure", "Description", "Data", "Interface 1", "Interface 2", "Paired Data", "Interface 1", "Interface 2"},
   {"", "", "PValue", "Mean", "Mean", "PValue", "Mean", "Mean"}};
graphScale = .22;
graphRatio = .4;

Needs["ANOVA`"];
Needs["StatisticalPlots`"];

For[ i = 3, i < 40, i++,
 dTa = Join[Take[Transpose[d], {1, 2}], Take[Transpose[d], {i}]];
 da = Transpose[dTa];
 If[17 ≤ i ≤ 35, da = Select[da, Part[#, 3] ≠ "n" &]; dTa = Transpose[da];]; (* Drop Missing Data = n *)
 dTInt1a = Join[Take[Transpose[dInt1], {1, 2}], Take[Transpose[dInt1], {i}]];
 dInt1a = Transpose[dTInt1a];
 If[17 ≤ i ≤ 35, dInt1a = Select[dInt1a, Part[#, 3] ≠ "n" &]; dTInt1a = Transpose[dInt1a];]; (* Drop Missing Data = n *)
 dTInt2a = Join[Take[Transpose[dInt2], {1, 2}], Take[Transpose[dInt2], {i}]];
 dInt2a = Transpose[dTInt2a];
 If[17 ≤ i ≤ 35, dInt2a = Select[dInt2a, Part[#, 3] ≠ "n" &]; dTInt2a = Transpose[dInt2a];]; (* Drop Missing Data = n *)
 dTPaireda = Join[Take[Transpose[dPaired], {1}], Take[Transpose[dPaired], {i - 1}]];
```

```
dPaireda = Transpose[dTPaireda];
If[17 ≤ i ≤ 35, dPaireda = Select[dPaireda, Part[#, 2] ≠ "n" &]; dTPaireda = Transpose[dPaireda];]; (* Drop Missing Data = n *)
dTPairedFI1a = Join[Take[Transpose[dPairedFI1], {1}], Take[Transpose[dPairedFI1], {i - 1}]];
dPairedFI1a = Transpose[dTPairedFI1a];
If[17 ≤ i ≤ 35, dPairedFI1a = Select[dPairedFI1a, Part[#, 2] ≠ "n" &]; dTPairedFI1a = Transpose[dPairedFI1a];]; (* Drop Missing Data = n *)
dTPairedFI2a = Join[Take[Transpose[dPairedFI2], {1}], Take[Transpose[dPairedFI2], {i - 1}]];
dPairedFI2a = Transpose[dTPairedFI2a];
If[17 ≤ i ≤ 35, dPairedFI2a = Select[dPairedFI2a, Part[#, 2] ≠ "n" &]; dTPairedFI2a = Transpose[dPairedFI2a];]; (* Drop Missing Data = n *)
allPvalues1 = Append[allPvalues1, {dLabels[[i]], dLongLabels[[i]], 0, 0, 0, 0, 0, 0}];
allPvalues2 = Append[allPvalues2, {dLabels[[i]], dLongLabels[[i]], 0, 0, 0, 0, 0, 0}];


Print["Measure: ", Style[dLabels[[i]], Bold], " (", dLongLabels[[i]], ")      ", Style["All Data", Bold]];
t = {{"", "All", "Interface 1", "Interface 2"},
    {"Statistic", "Data", "(Basic)", "(Improved)"},
     {"Count", Length[dTa[[3]]], Length[dTInt1a[[3]]], Length[dTInt2a[[3]]]},
     {"Min", Min[dTa[[3]]], Min[dTInt1a[[3]]], Min[dTInt2a[[3]]]},
     {"25% Quartile", Quartiles[dTa[[3]]][[1]], Quartiles[dTInt1a[[3]]][[1]], Quartiles[dTInt2a[[3]]][[1]]},
     {"Median", Median[dTa[[3]]], Median[dTInt1a[[3]]], Median[dTInt2a[[3]]]},
     {"75% Quartile", Quartiles[dTa[[3]]][[3]], Quartiles[dTInt1a[[3]]][[3]], Quartiles[dTInt2a[[3]]][[3]]},
     {"Max", Max[dTa[[3]]],  Max[dTInt1a[[3]]], Max[dTInt2a[[3]]]},
     {"Mean", Mean[dTa[[3]]], Mean[dTInt1a[[3]]], Mean[dTInt2a[[3]]]},
     {"S.D.", StandardDeviation[dTa[[3]]], StandardDeviation[dTInt1a[[3]]], StandardDeviation[dTInt2a[[3]]]},
     {"Variance", Variance[dTa[[3]]], Variance[dTInt1a[[3]]], Variance[dTInt2a[[3]]]}};
p1 = BoxWhiskerPlot[dTa[[3]], dTInt1a[[3]], dTInt2a[[3]], BoxOutliers → All,
  BoxLabels → {"All Data", "Interface 1 (Basic)", "Interface 2 (Improved)"}, ImageSize → Scaled[graphScale], AspectRatio → graphRatio];
Print[Grid[{{"Descriptive Statistics", " ", "Box Whisker Plots"}, {TableForm[t], "  ", p1}}, Alignment → {Left, Top}]];
a = ANOVA[da, {interface, firstInt}, {interface, firstInt}];
Print[Grid[{{"ANOVA Results", "   ", "Cell Means"}, {a[[1, 2]], "    ", a[[2, 2]]}}, Alignment → {Left, Top}]];
allPvalues1[[i, 3]] = a[[1, 2]][[1]][[1, 5]]; (*PValue*)
allPvalues1[[i, 4]] = a[[2, 2]][[1]][[2, 2]]; (*Mean 1*)
allPvalues1[[i, 5]] = a[[2, 2]][[1]][[3, 2]]; (*Mean 2*)

Print[""];

Print["Measure: ", Style[dLabels[[i]], Bold], " (", dLongLabels[[i]], ")      ", Style["Paired Data", Bold],
 " (Test of interface 2 - test of interface 1, by subject)"];
t = {{"", "Paired", "First Interface 1", "First Interface 2"}, {"Statistic", "Data", "(Basic)", "(Improved)"},
     {"Count", Length[dTPaireda[[2]]], Length[dTPairedFI1a[[2]]], Length[dTPairedFI2a[[2]]]},
     {"Min", Min[dTPaireda[[2]]], Min[dTPairedFI1a[[2]]], Min[dTPairedFI2a[[2]]]},
     {"25% Quartile", Quartiles[dTPaireda[[2]]][[1]], Quartiles[dTPairedFI1a[[2]]][[1]], Quartiles[dTPairedFI2a[[2]]][[1]]},
     {"Median", Median[dTPaireda[[2]]], Median[dTPairedFI1a[[2]]], Median[dTPairedFI2a[[2]]]},
     {"75% Quartile", Quartiles[dTPaireda[[2]]][[3]], Quartiles[dTPairedFI1a[[2]]][[3]], Quartiles[dTPairedFI2a[[2]]][[3]]},
     {"Max", Max[dTPaireda[[2]]], Max[dTPairedFI1a[[2]]], Max[dTPairedFI2a[[2]]]},
```

```
        {"Mean", Mean[dTPaireda[[2]]], Mean[dTPairedFI1a[[2]]], Mean[dTPairedFI2a[[2]]]},
        {"S.D.", StandardDeviation[dTPaireda[[2]]], StandardDeviation[dTPairedFI1a[[2]]], StandardDeviation[dTPairedFI2a[[2]]]},
        {"Variance", Variance[dTPaireda[[2]]], Variance[dTPairedFI1a[[2]]], Variance[dTPairedFI2a[[2]]]}};
p1 = BoxWhiskerPlot[dTPaireda[[2]], dTPairedFI1a[[2]], dTPairedFI2a[[2]], BoxOutliers → All,
  BoxLabels → {"Paired Data", "First Interface 1 (Basic)", "First Interface 2 (Improved)"}, ImageSize → Scaled[graphScale],
  AspectRatio → graphRatio];
Print[Grid[{{"Descriptive Statistics", " ", "Box Whisker Plots"}, {TableForm[t], "  ", p1}}, Alignment → {Left, Top}]];
a = ANOVA[dPaireda, {firstInt}, {firstInt}];
Print[Grid[{{"ANOVA Results", "  ", "Cell Means"}, {a[[1, 2]], "   ", a[[2, 2]]}}, Alignment → {Left, Top}]];
allPvalues2[[i + 1, 3]] = a[[1, 2]][[1]][[1, 5]]; (*PValue*)
allPvalues2[[i + 1, 4]] = a[[2, 2]][[1]][[2, 2]]; (*Mean 1*)
allPvalues2[[i + 1, 5]] = a[[2, 2]][[1]][[3, 2]]; (*Mean 2*)

Print[""];

Print["Measure: ", Style[dLabels[[i]], Bold], " (", dLongLabels[[i]], ")     ", Style["Trimmed All Data", Bold]];
trimCount = 3;
trimDa = Drop[Drop[sll[da, 3], trimCount], -trimCount];
trimD1 = Transpose[trimDa][[3]];
trimD2 = Transpose[Select[trimDa, Part[#, 1] == 1 &]][[3]];
trimD3 = Transpose[Select[trimDa, Part[#, 1] == 2 &]][[3]];
t = {{"", "Trimmed", "Trimmed Interface 1", "Trimmed Interface 2"}, {"Statistic", "All Data", "(Basic)", "(Improved)"},
        {"Count", Length[trimD1], Length[trimD2], Length[trimD3]},
        {"Min", Min[trimD1], Min[trimD2], Min[trimD3]},
        {"25% Quartile", Quartiles[trimD1][[1]], Quartiles[trimD2][[1]], Quartiles[trimD3][[1]]},
        {"Median", Median[trimD1], Median[trimD2], Median[trimD3]},
        {"75% Quartile", Quartiles[trimD1][[3]], Quartiles[trimD2][[3]], Quartiles[trimD3][[3]]},
        {"Max", Max[trimD1], Max[trimD2], Max[trimD3]},
        {"Mean", Mean[trimD1], Mean[trimD2], Mean[trimD3]},
        {"S.D.", StandardDeviation[trimD1], StandardDeviation[trimD2], StandardDeviation[trimD3]},
        {"Variance", Variance[trimD1], Variance[trimD2], Variance[trimD3]}};
p1 = BoxWhiskerPlot[trimD1, trimD2, trimD3, BoxOutliers → All,
  BoxLabels → {"Trimmed All Data", "Trimmed Int 1 (Basic)", "Trimmed Int 2 (Improved)"}, ImageSize → Scaled[graphScale],
  AspectRatio → graphRatio];
Print[Grid[{{"Descriptive Statistics", " ", "Box Whisker Plots"}, {TableForm[t], "  ", p1}}, Alignment → {Left, Top}]];
a = ANOVA[trimDa, {interface, firstInt}, {interface, firstInt}];
Print[Grid[{{"ANOVA Results", "  ", "Cell Means"}, {a[[1, 2]], "   ", a[[2, 2]]}}, Alignment → {Left, Top}]];
allPvalues1[[i, 6]] = a[[1, 2]][[1]][[1, 5]]; (*PValue*)
allPvalues1[[i, 7]] = a[[2, 2]][[1]][[2, 2]]; (*Mean 1*)
allPvalues1[[i, 8]] = a[[2, 2]][[1]][[3, 2]]; (*Mean 2*)

Print[""];

Print["Measure: ", Style[dLabels[[i]], Bold], " (", dLongLabels[[i]], ")     ", Style["Trimmed Paired Data", Bold],
 " (Test of interface 2 - test of interface 1, by subject)"];
trimCount = 3;
trimDa = Drop[Drop[sll[dPaireda, 2], trimCount], -trimCount];
trimD1 = Transpose[trimDa][[2]];
trimD2 = Transpose[Select[trimDa, Part[#, 1] == 1 &]][[2]];
trimD3 = Transpose[Select[trimDa, Part[#, 1] == 2 &]][[2]];
t = {{"", "Trimmed", "Trim First Int 1", "Trim First Int 2"}, {"Statistic", "Paired Data", "(Basic)", "(Improved)"},
        {"Count", Length[trimD1], Length[trimD2], Length[trimD3]},
        {"Min", Min[trimD1], Min[trimD2], Min[trimD3]},
        {"25% Quartile", Quartiles[trimD1][[1]], Quartiles[trimD2][[1]], Quartiles[trimD3][[1]]},
        {"Median", Median[trimD1], Median[trimD2], Median[trimD3]},
        {"75% Quartile", Quartiles[trimD1][[3]], Quartiles[trimD2][[3]], Quartiles[trimD3][[3]]},
        {"Max", Max[trimD1], Max[trimD2], Max[trimD3]},
        {"Mean", Mean[trimD1], Mean[trimD2], Mean[trimD3]},
        {"S.D.", StandardDeviation[trimD1], StandardDeviation[trimD2], StandardDeviation[trimD3]},
        {"Variance", Variance[trimD1], Variance[trimD2], Variance[trimD3]}};
p1 = BoxWhiskerPlot[trimD1, trimD2, trimD3, BoxOutliers → All,
  BoxLabels → {"Trimmed Paired Data", "Trim First Int 1 (Basic)", "Trim First Int 2 (Improved)"}, ImageSize → Scaled[graphScale],
  AspectRatio → graphRatio];
Print[Grid[{{"Descriptive Statistics", " ", "Box Whisker Plots"}, {TableForm[t], "  ", p1}}, Alignment → {Left, Top}]];
a = ANOVA[trimDa, {firstInt}, {firstInt}];
Print[Grid[{{"ANOVA Results", "  ", "Cell Means"}, {a[[1, 2]], "   ", a[[2, 2]]}}, Alignment → {Left, Top}]];
allPvalues2[[i + 1, 6]] = a[[1, 2]][[1]][[1, 5]]; (*PValue*)
allPvalues2[[i + 1, 7]] = a[[2, 2]][[1]][[2, 2]]; (*Mean 1*)
allPvalues2[[i + 1, 8]] = a[[2, 2]][[1]][[3, 2]]; (*Mean 2*)

CellPrint[Cell[" ", "Text", PageBreakBelow → True]];

]
```

Appendix X

Subject Comments on Usability Questionnaires

Subject comments from questionnaire – Basic Interface

- "Need save feedback, highlight lines in table."
- "Some selections not obvious”
- "Like to have save or overwrite confirmation. More explanation of what was wrong in errors."
- "Tasks easier if menus were task oriented - verbs for tasks to complete"
- "Resize of fields in data charts and cross-hairs for graphs would improve interface. Overall, very easy to use."
- "Column headers not fully visible", "Tab order for data entry"
- "Is there an undo?"
- "Down & dirty UI - feels homegrown to support immediate need. Would want more from tool."
- "It is great!"
- "Error message did not say which textbox was wrong"
- "No feedback for save", "Table should have floating row headlines", "Didn't try help."
- "Lot of data on spreadsheets. Freeze option would help. More tick lines on graphs, also 3d and multi plots.
- "Fix tab order to reflect inputs"
- "Prefer to see two graphs at once, need feedback after saving"
- "Could be quicker with repeated use. Don't recall error text shown. Found organization difficult. Would prefer New->Factory vs. Factory->New"
- "System was easy to use for the first time."

- "I liked the simpler interface, I can't recall any questions the graphical interface would have answered more simply. Comfort grew once I understood the scheme of it. Initial learning and experiment required to determine value formats. Lack of critical feedback from system functions. Missing positive and negative feedback. Help was without a guiding structure. Screen prompts were missing. I derive pleasure from efficient minimalism, so that pleased me."
- "Would be nice to see two graphs. Did it save? Should be feedback."
- "Much more difficult to use this interface than the 1st test. Not user-friendly."
- "Intuitive system. Could use a prompt to let me know I've saved. Didn't need to use help."
- "No indication for saved settings. Initialy, there is no information on the screen to explain the tool or menu structure. However, the tool is relatively easy to navigate."
- "Tables were confusing. Had to make sure I was in right category by increasing width. Top & bottom tables not linked increased chance of error. Could not see weeks in all settings. Graphic interface for connections helps to catch mistakes more quickly. Graphs terrible, hard to make estimates. System was not very intuitive, frustrating."
- "I wouldn't buy it unless I had to. Couldn't display multiple graphs on one screen. Very sparse - small and not intuitive."
- "Needed % indicators when % requested."
- "If the user must complete several tasks, it is time consuming because you have to go to the menus for everything. Too many clicks to do tasks. Not much

information on the screen, x/y coordinates, labels, etc. Just a menu bar as a main window is not a good way to allow users to see what options they have. There should be shortcuts for common tasks."

Subject comments – Improved Interface

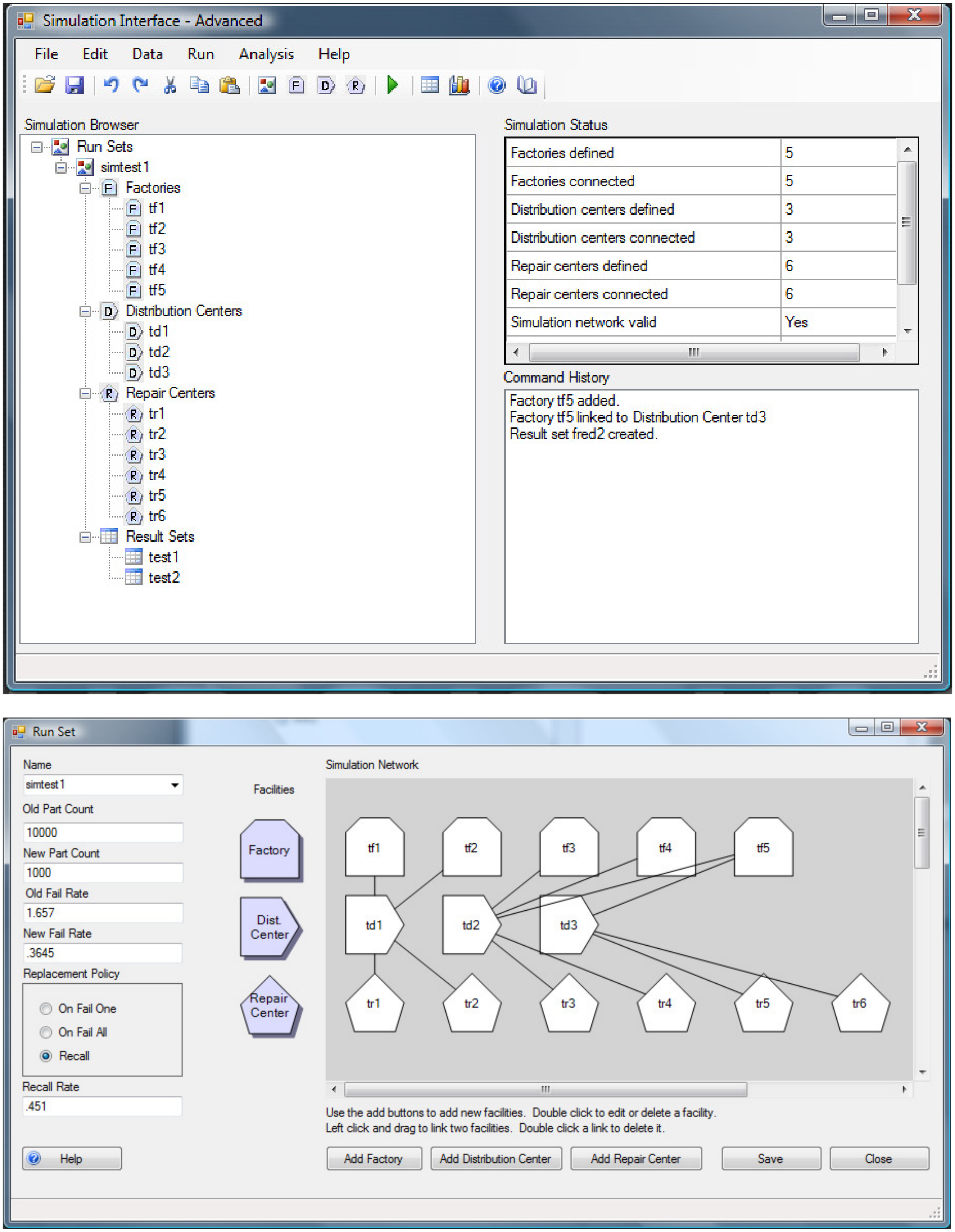
- "Easy to navigate through."
- "Good mouse over tips"
- "Close not cancel"
- "Fairly easy to use once I became familiar with the structure"
- "Excellent, easy to use"
- "I liked the more graphical interface - made the information easier to read and visualize - felt familiar. Hard to find individual help items as presented."
- "Like error indication, hover over tips useful"
- "Preferred 1st UI, had a hard time finding how to edit a run set."
- "Alphabetic order for options, Run Set form didn't clear to save. More graphical, easier to understand."
- "Nice GUI"
- "Alphabetize table headings", "Close on forms", "Slow tooltips"
- "Combination of graphics for data entry and menus/icons for results not intuitive."
- "For being able to just open & start using with little instruction it was very productive."
- "Conventional or reasonable extensions of standard windows controls and operations. Learning involved, hunting - experimentation, but minimal. Didn't

prevent input of invalid data or show "fix". Not always aware of having made mistake until error message. Didn't look at help - control and tool tip labels fine. Suprisingly simple given no application knowledge. Clean, spacious. Prefer modeless edit dialogs. Given no application knowledge, it was surprising how much specific info I got with simple instructions. "Null" icon for topmost tree made me gloss over it at first."

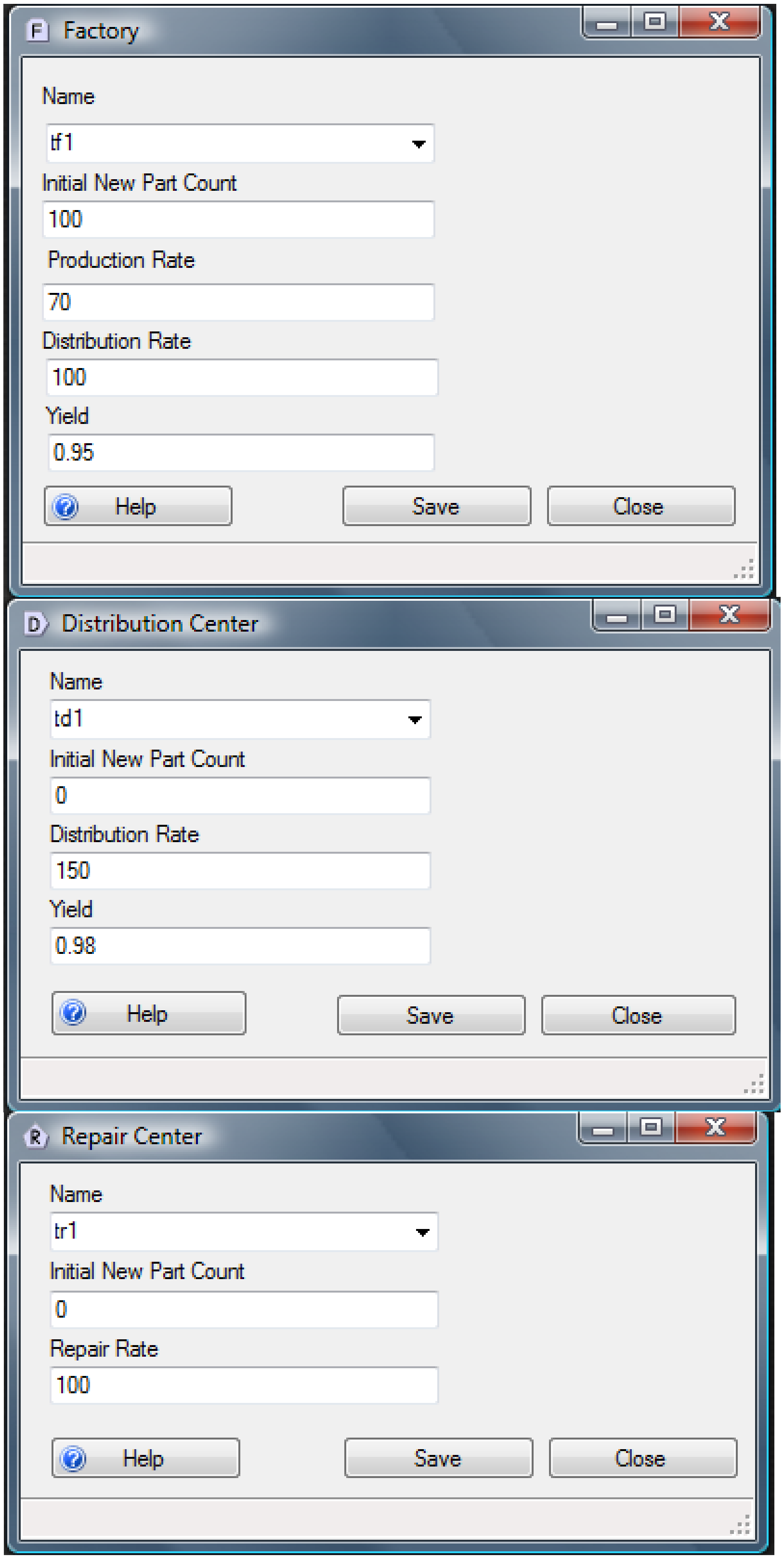
- "Prefer close to cancel in forms."
- "Very easy to use navigation. Clearly defined tabs and option make this easy to learn. Colors, backgrounds made it easy to view screen. Great job, impressive."
- "More help functions."
- "Like to see alphabetic order for choices"
- "Needs alphabetically sorted lists"
- "No message stating changes are saved."
- "Very straightforward, after getting a feel for program - would be easy to utilize. Intuitive things such as drag on symbols nice. Standard right clicks were available. Flagged error, but did not state what was wrong."
- "Notify that graph needs to be regenerated"
- “More confusing than the first interface."
- "Save button should close the window. I would increase the font. Lists should be alphabetically sorted."

Appendix Y

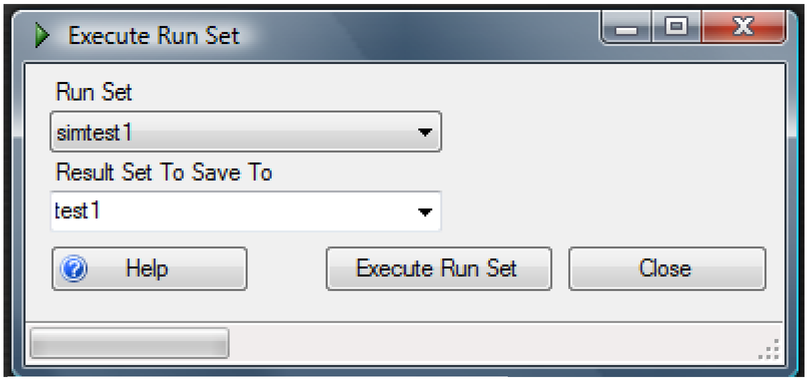
High-fidelity Prototypes for Heuristic Analysis



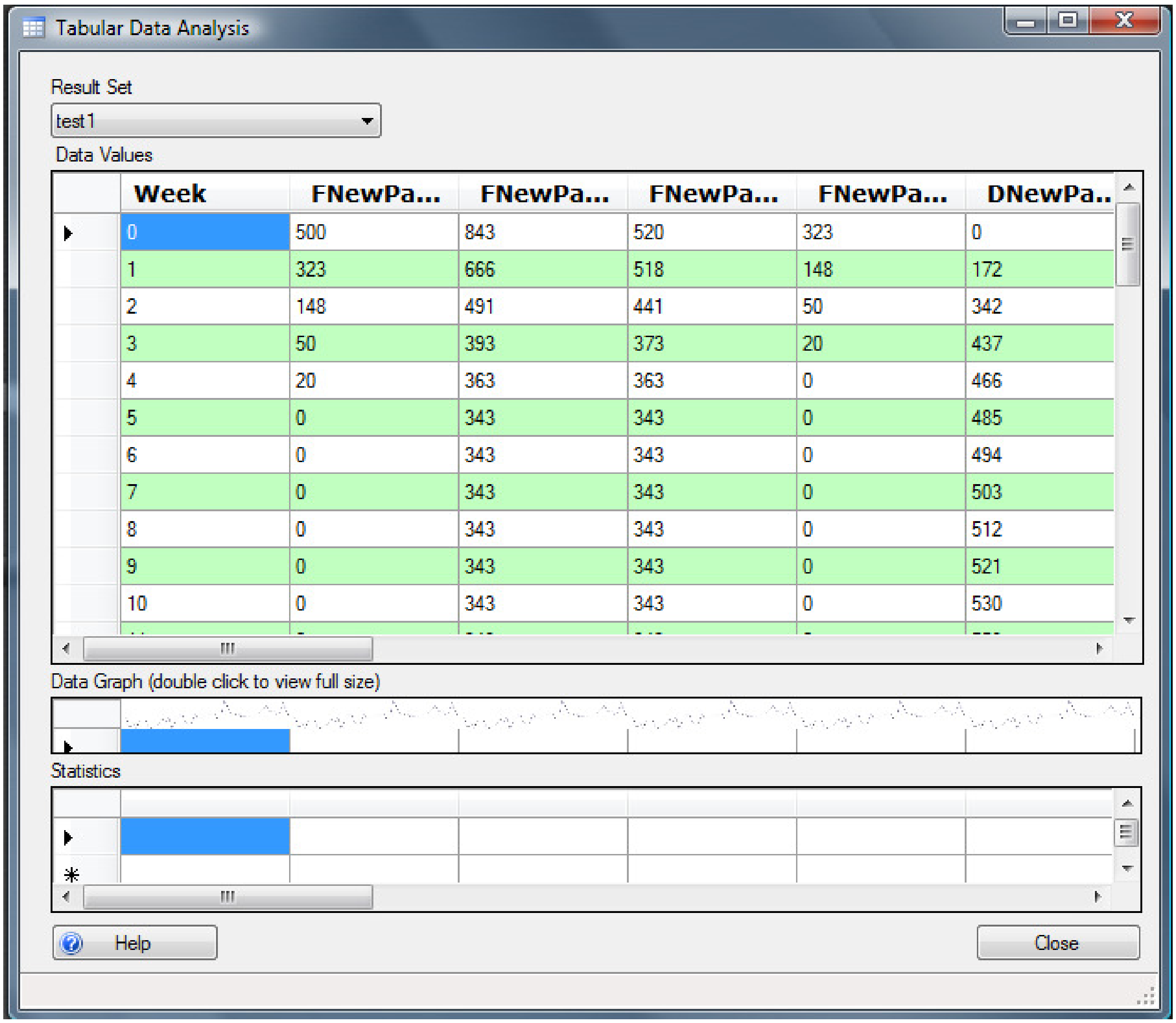
Improved main menu and run set forms.



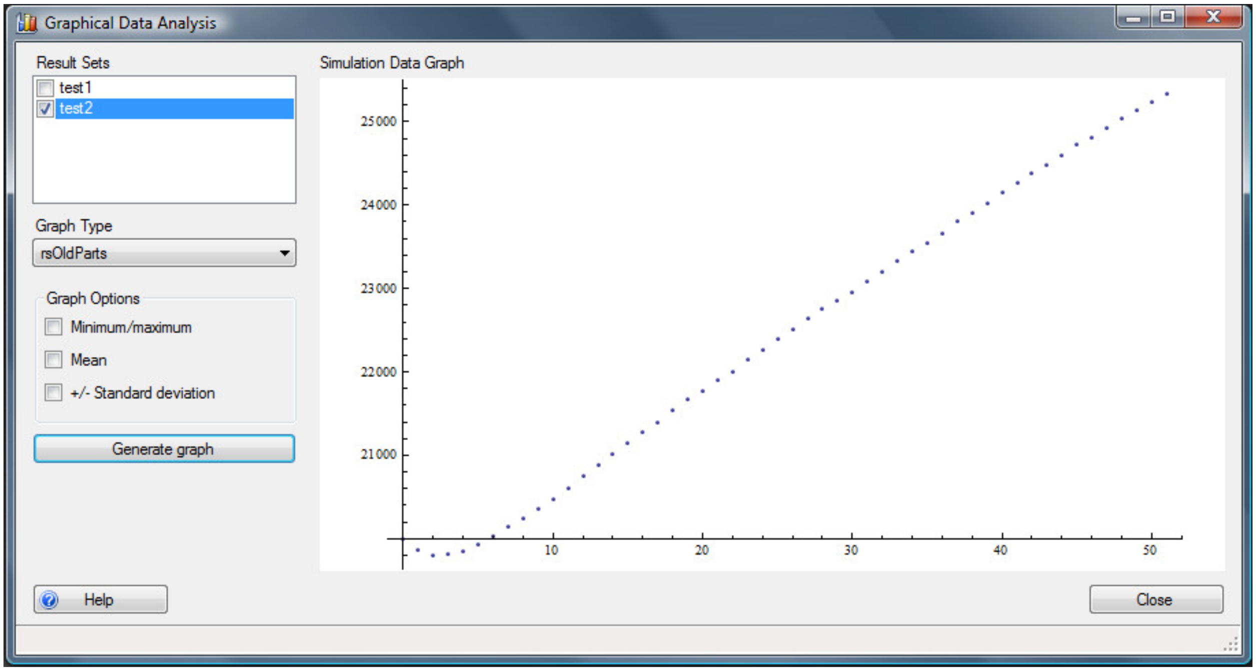
Improved factory, distribution, and repair center data forms.



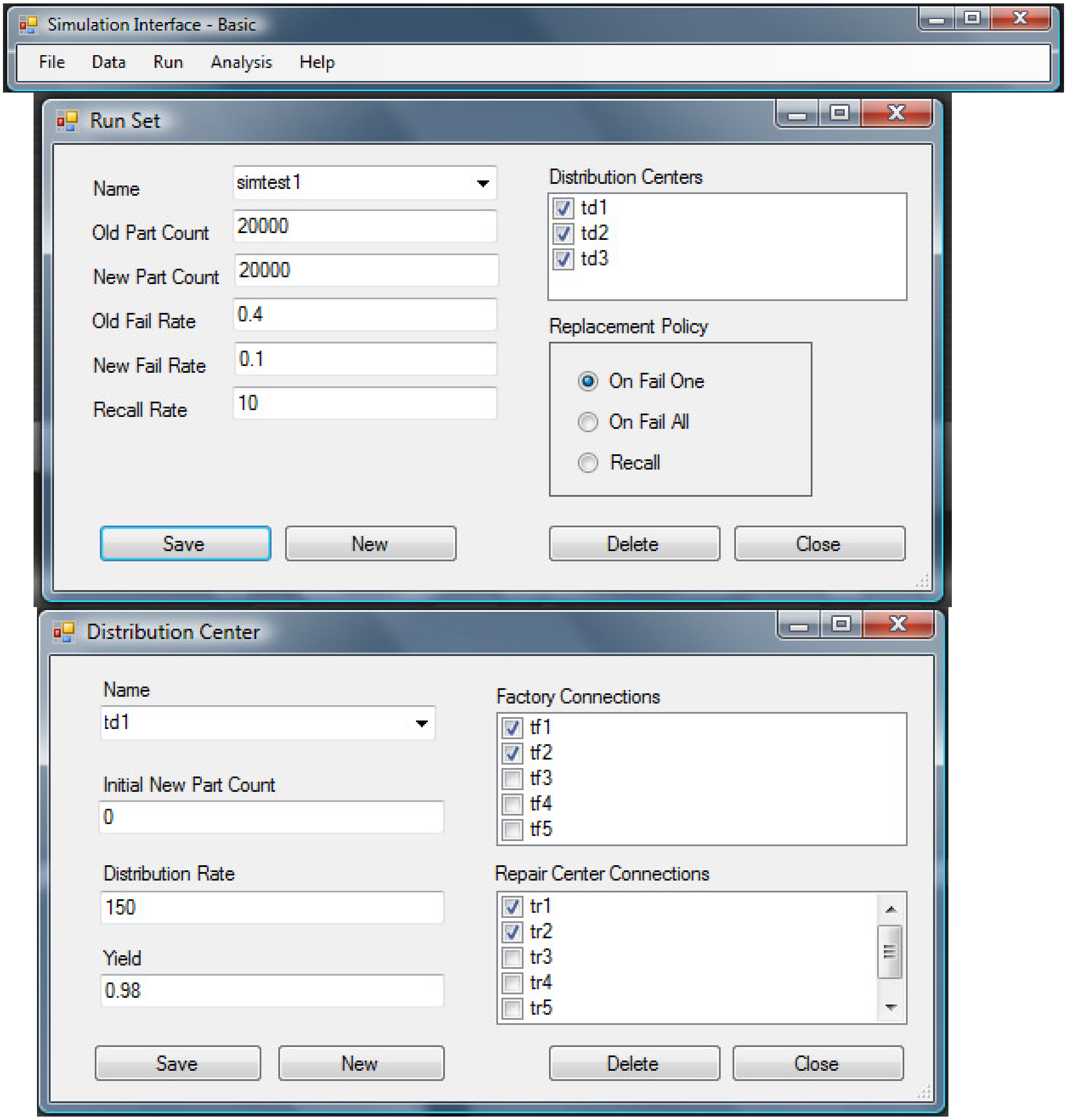
Improved execute run set form.



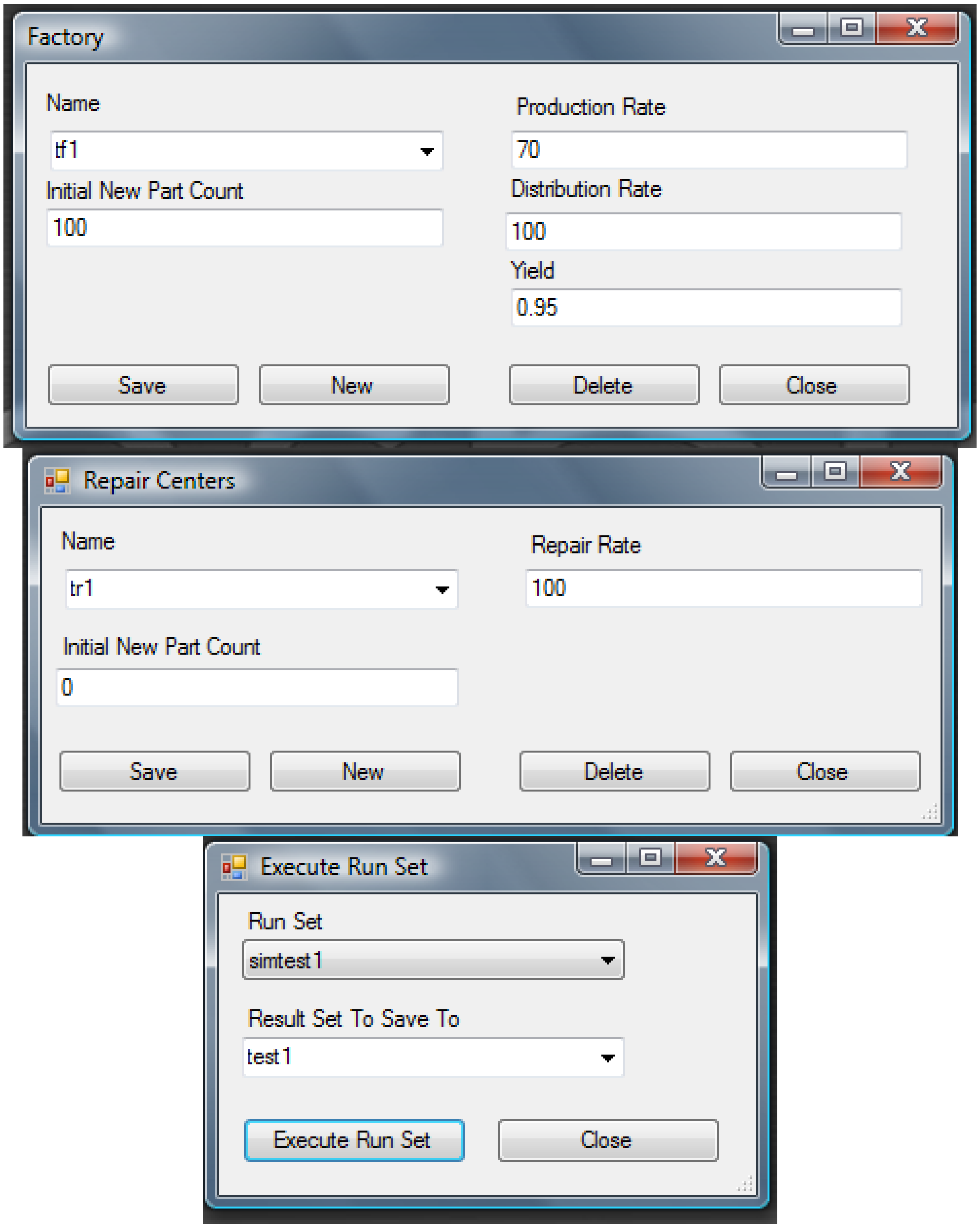
Improved tabular data analysis form.



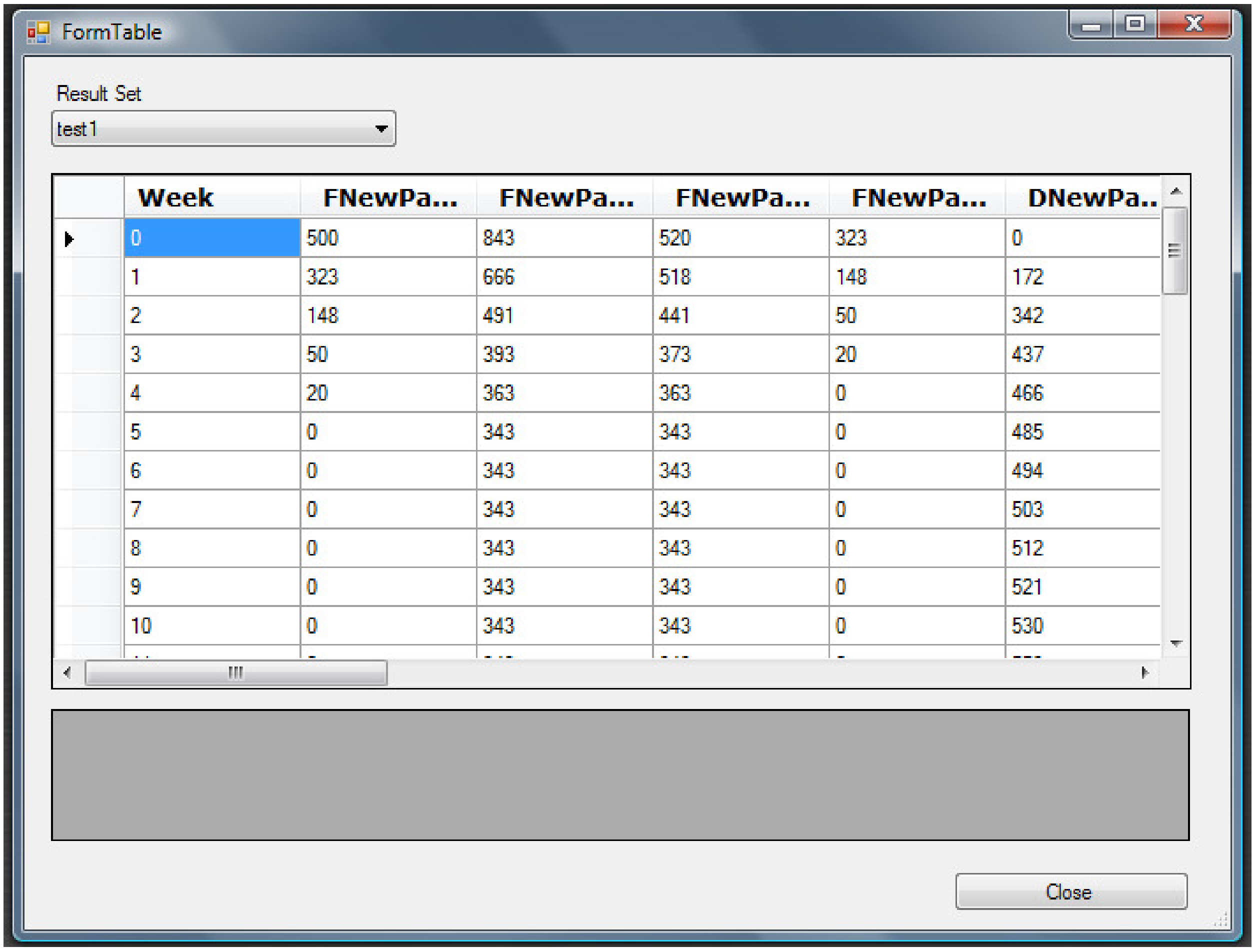
Improved graphical analysis data form.



Basic main, run set and distributor data forms.

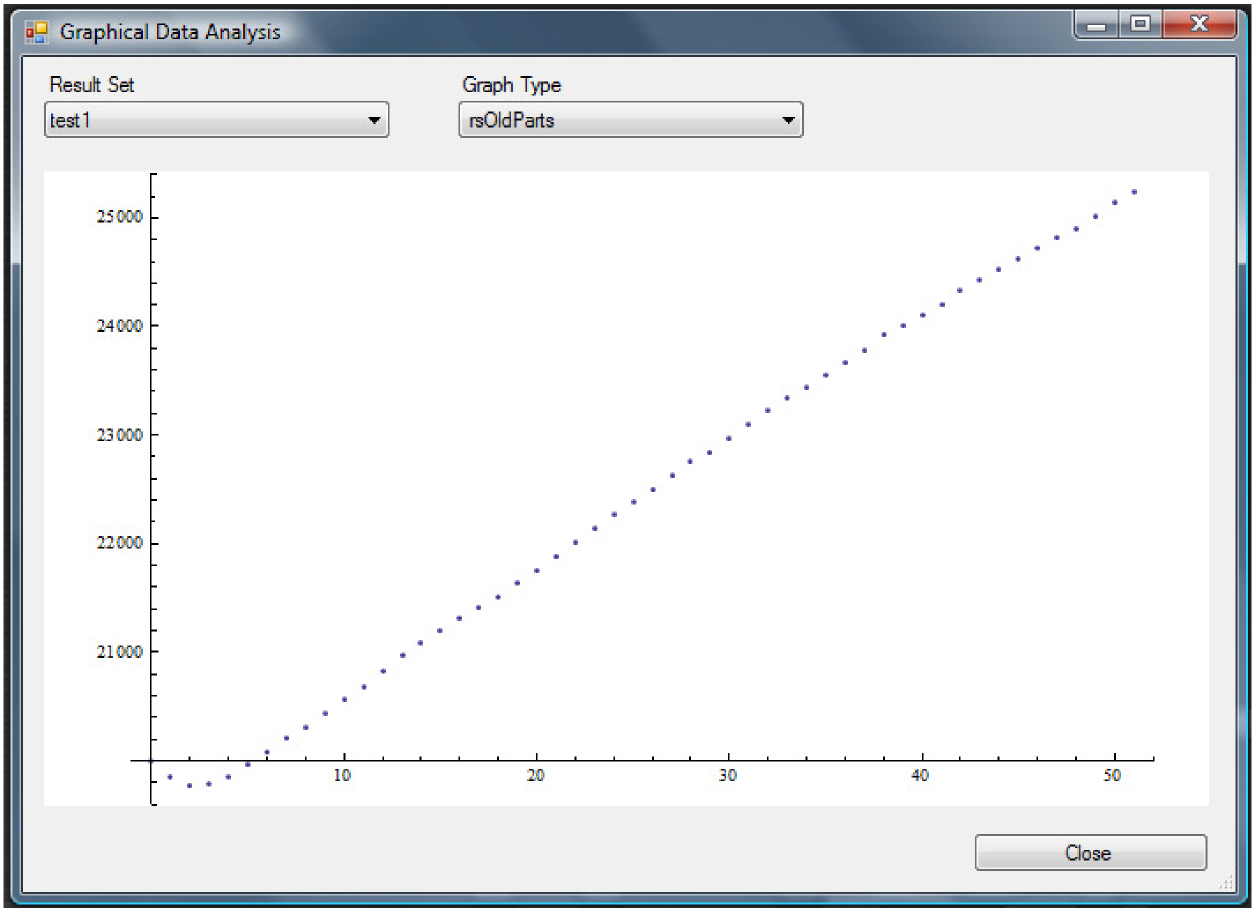


Basic factory, repairer data forms and execute run set form.



Week	FNewPa...	FNewPa...	FNewPa...	FNewPa...	DNewPa..
0	500	843	520	323	0
1	323	666	518	148	172
2	148	491	441	50	342
3	50	393	373	20	437
4	20	363	363	0	466
5	0	343	343	0	485
6	0	343	343	0	494
7	0	343	343	0	503
8	0	343	343	0	512
9	0	343	343	0	521
10	0	343	343	0	530

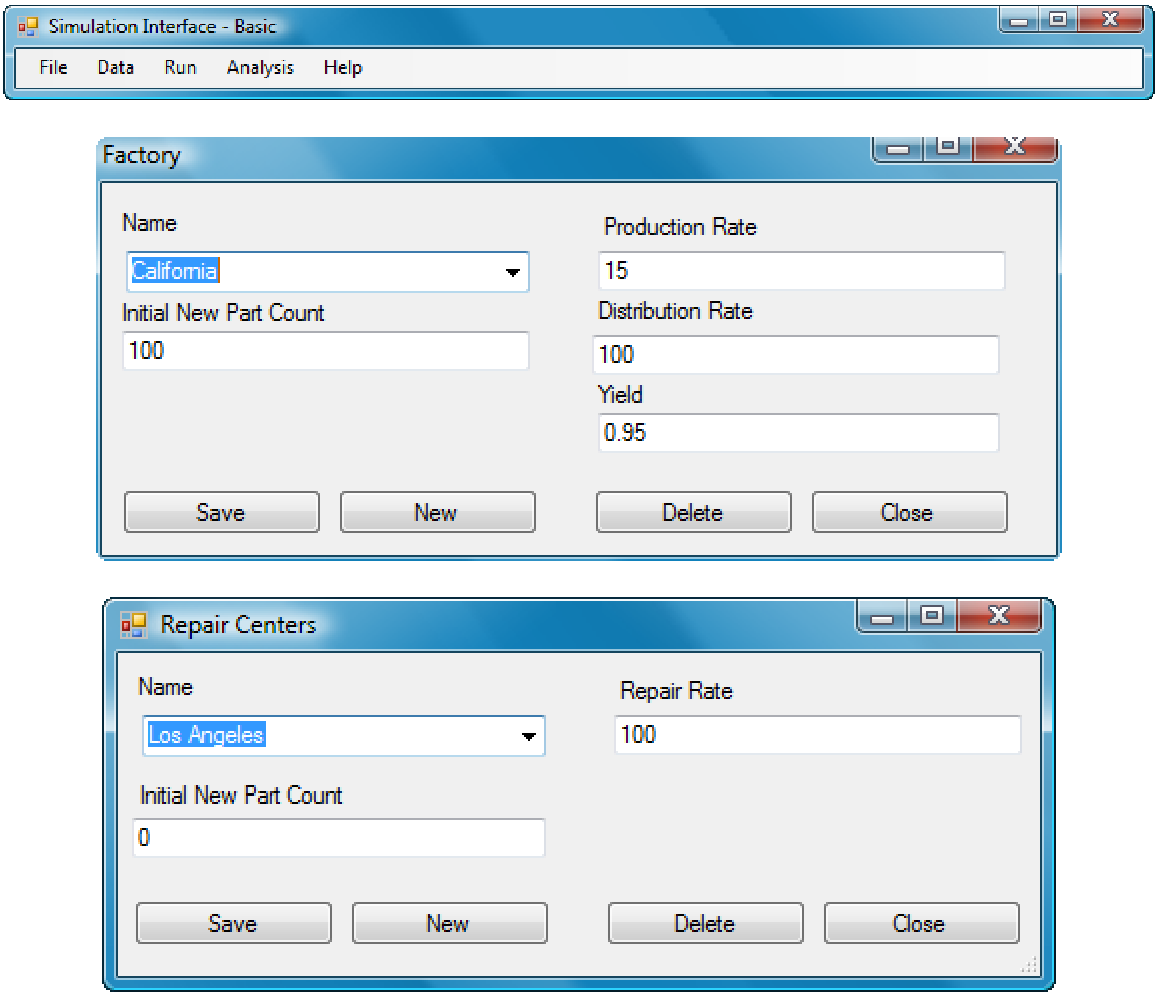
Basic tabular data analysis form.



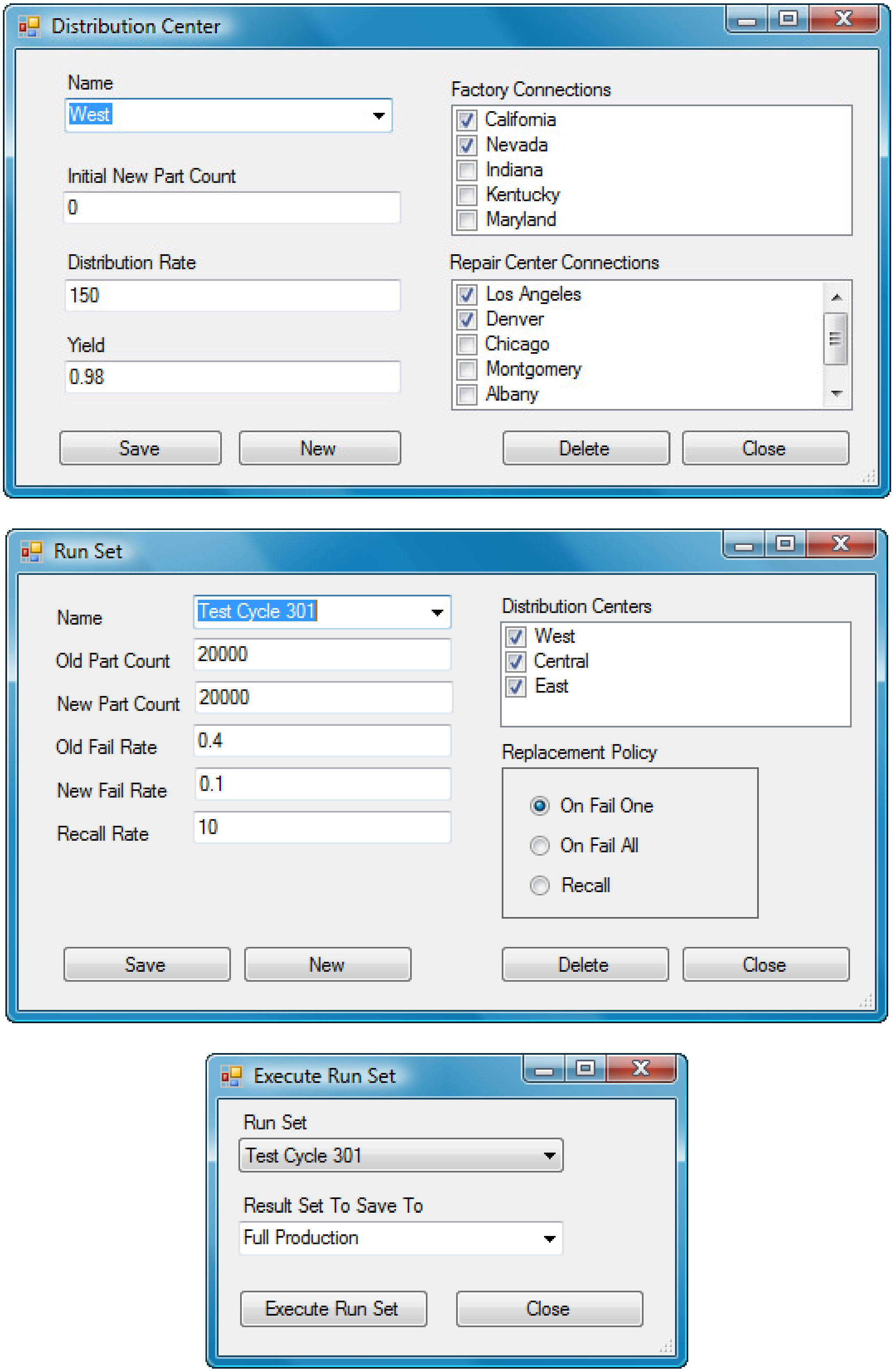
Basic graphical analysis form.

Appendix Z

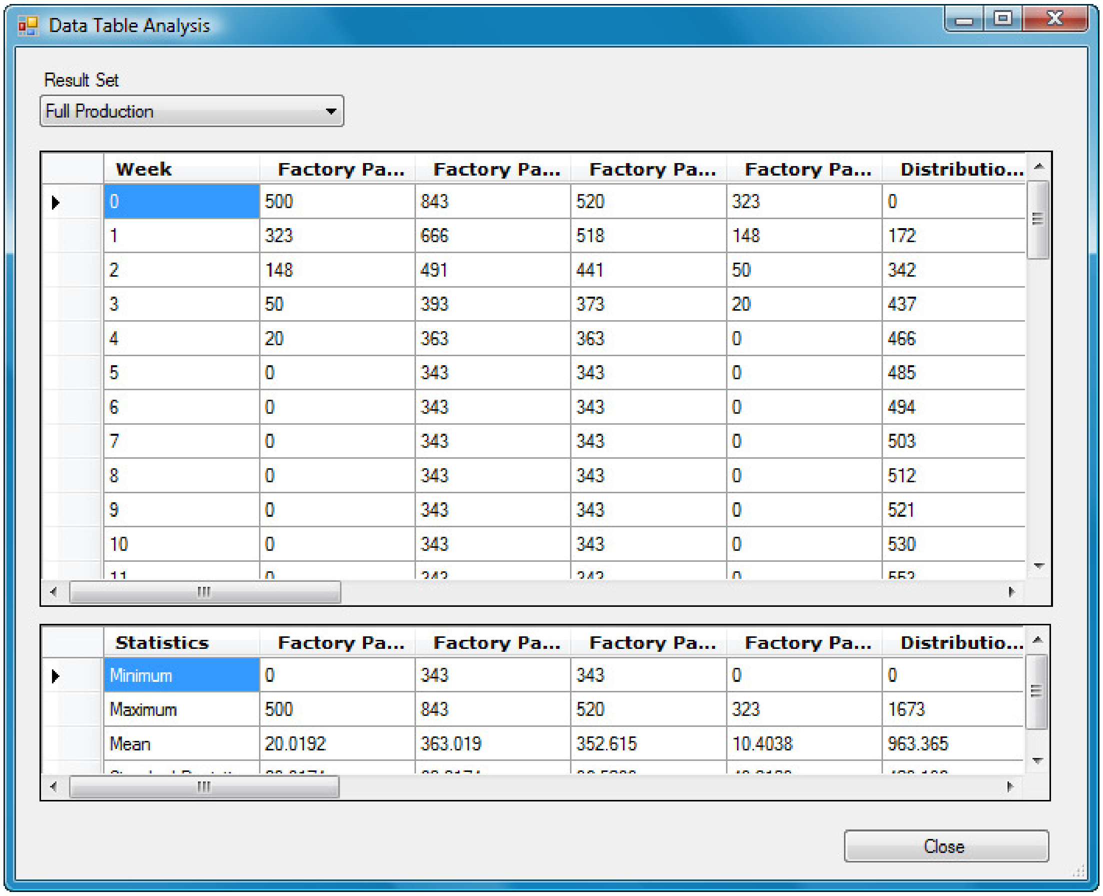
Final Application Interface



Basic main menu form, factory data, and repair center forms.

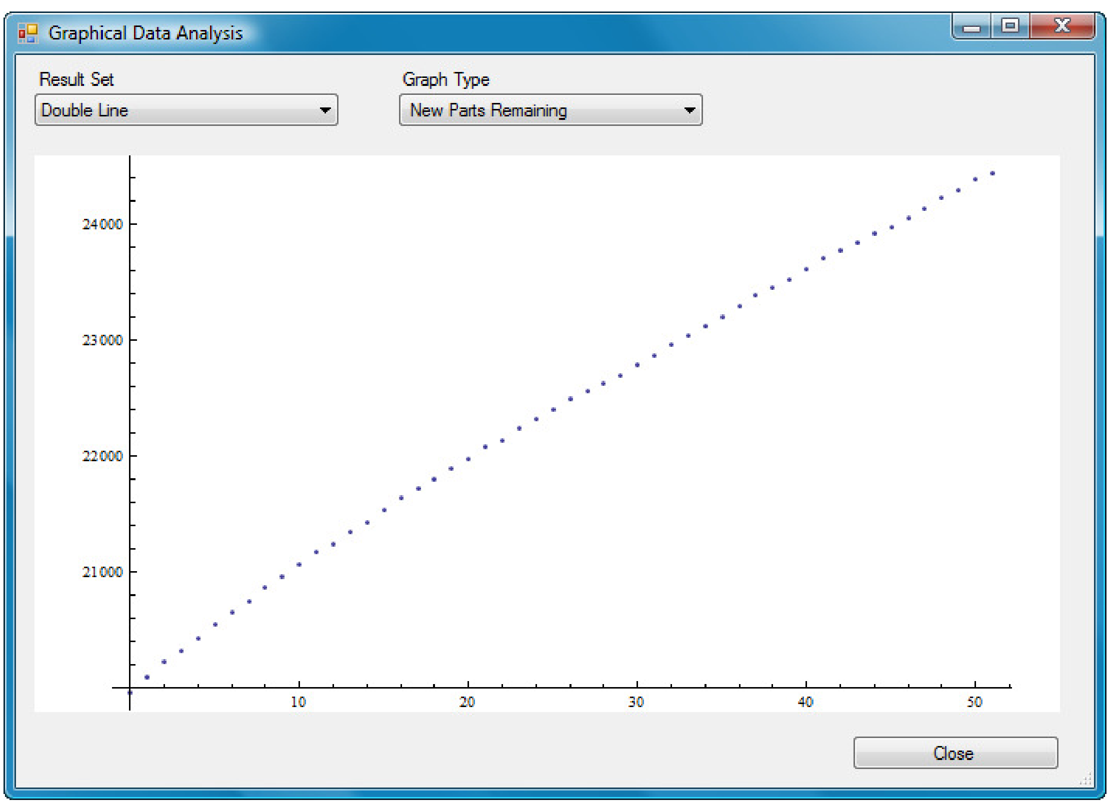


Basic distributor, run set, and execute run set forms.

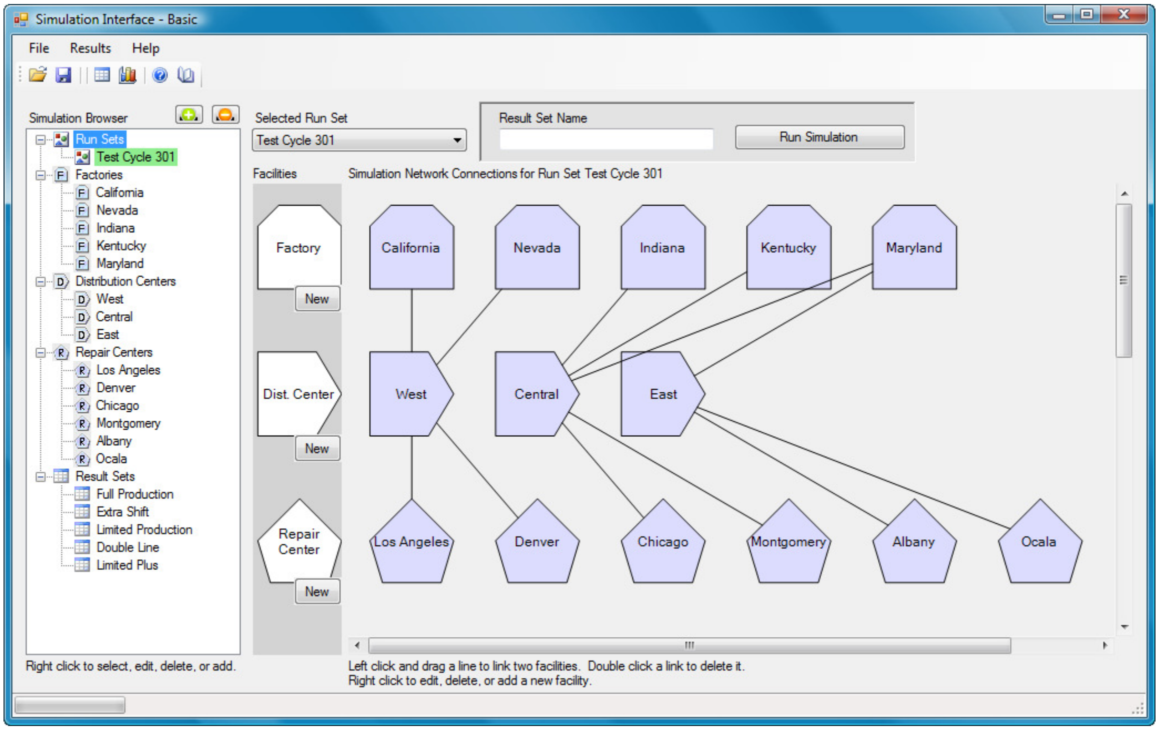


Week	Factory Pa...	Factory Pa...	Factory Pa...	Factory Pa...	Distributio...
0	500	843	520	323	0
1	323	666	518	148	172
2	148	491	441	50	342
3	50	393	373	20	437
4	20	363	363	0	466
5	0	343	343	0	485
6	0	343	343	0	494
7	0	343	343	0	503
8	0	343	343	0	512
9	0	343	343	0	521
10	0	343	343	0	530

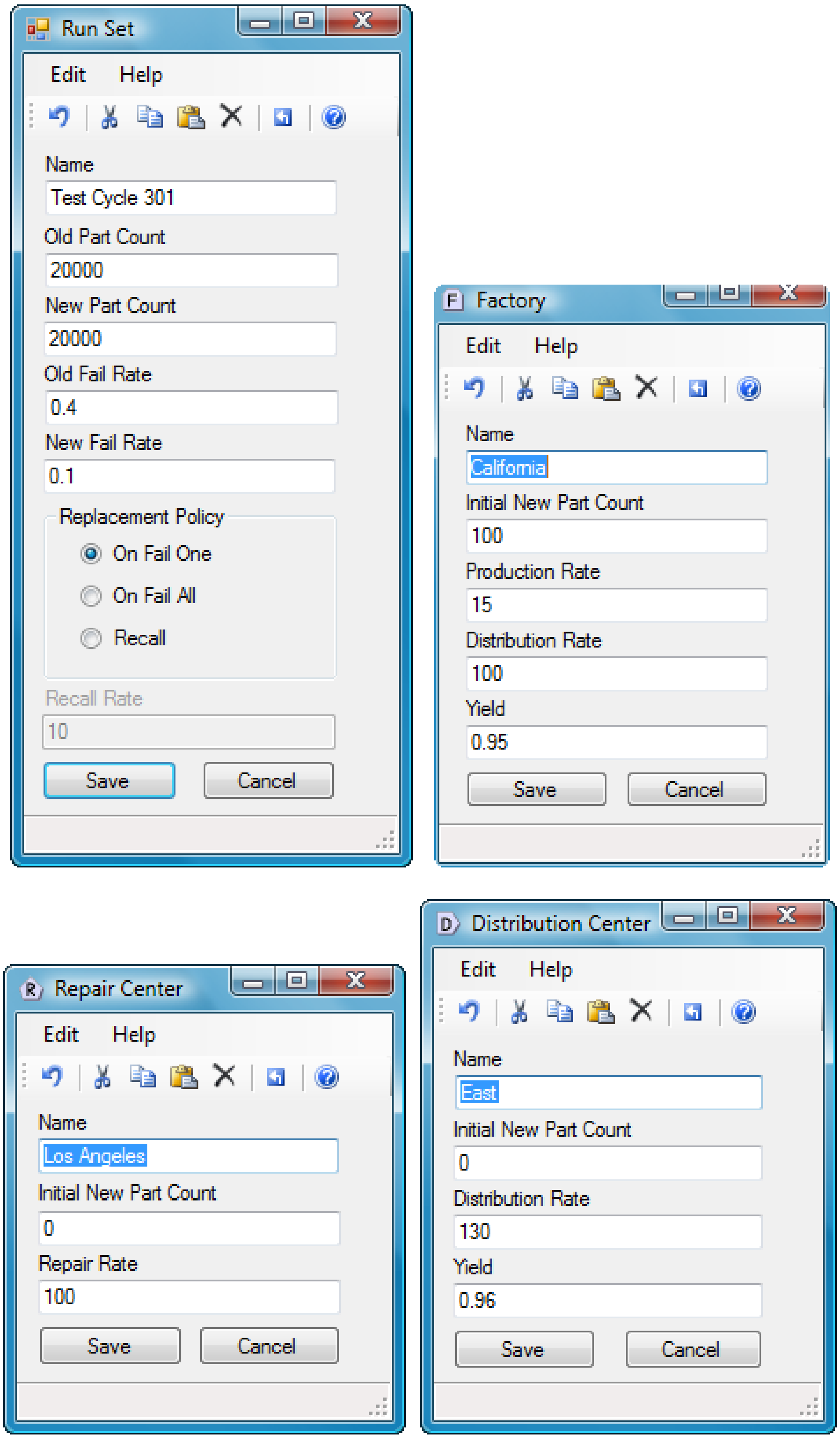
Statistics	Factory Pa...	Factory Pa...	Factory Pa...	Factory Pa...	Distributio...
Minimum	0	343	343	0	0
Maximum	500	843	520	323	1673
Mean	20.0192	363.019	352.615	10.4038	963.365



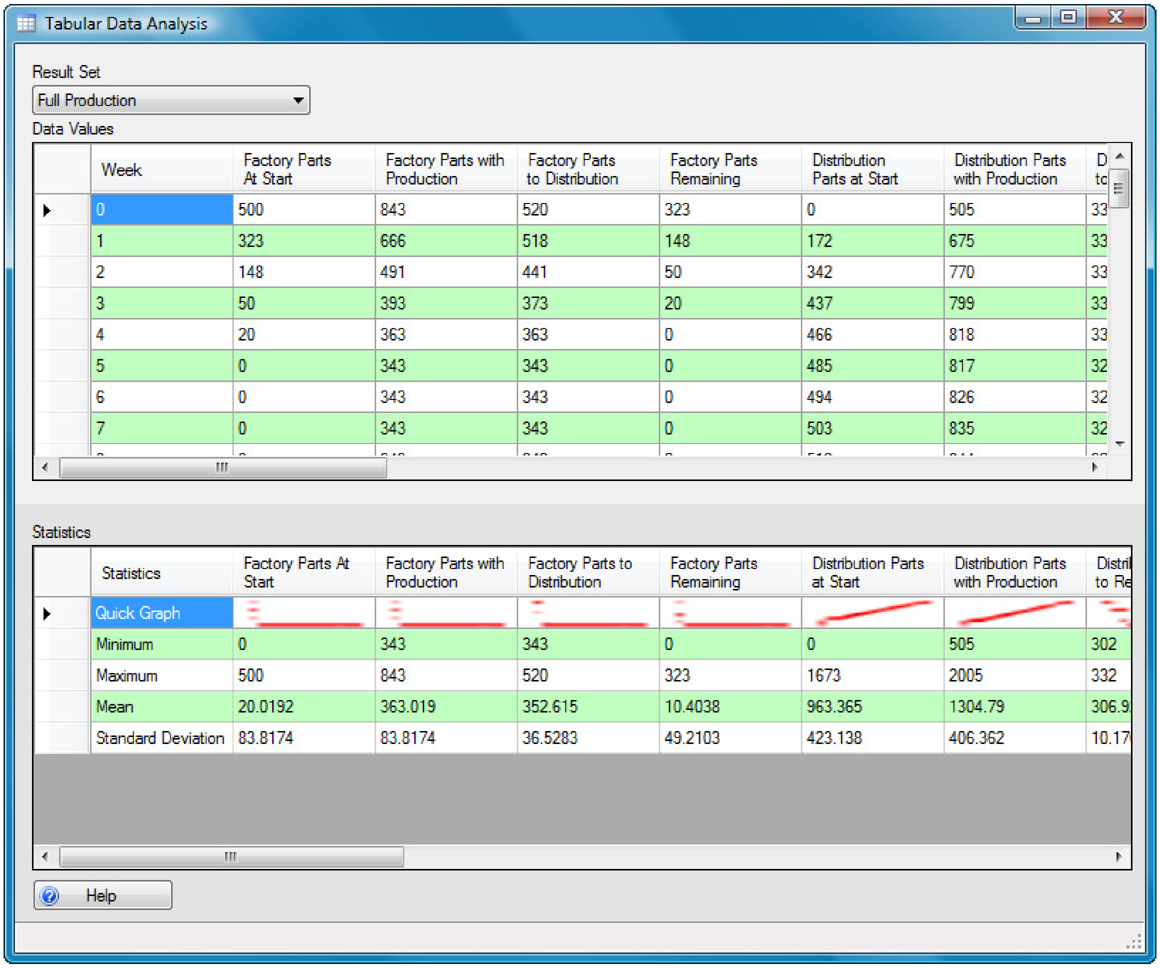
Basic tabular data and graphical analysis forms.



Improved main form.

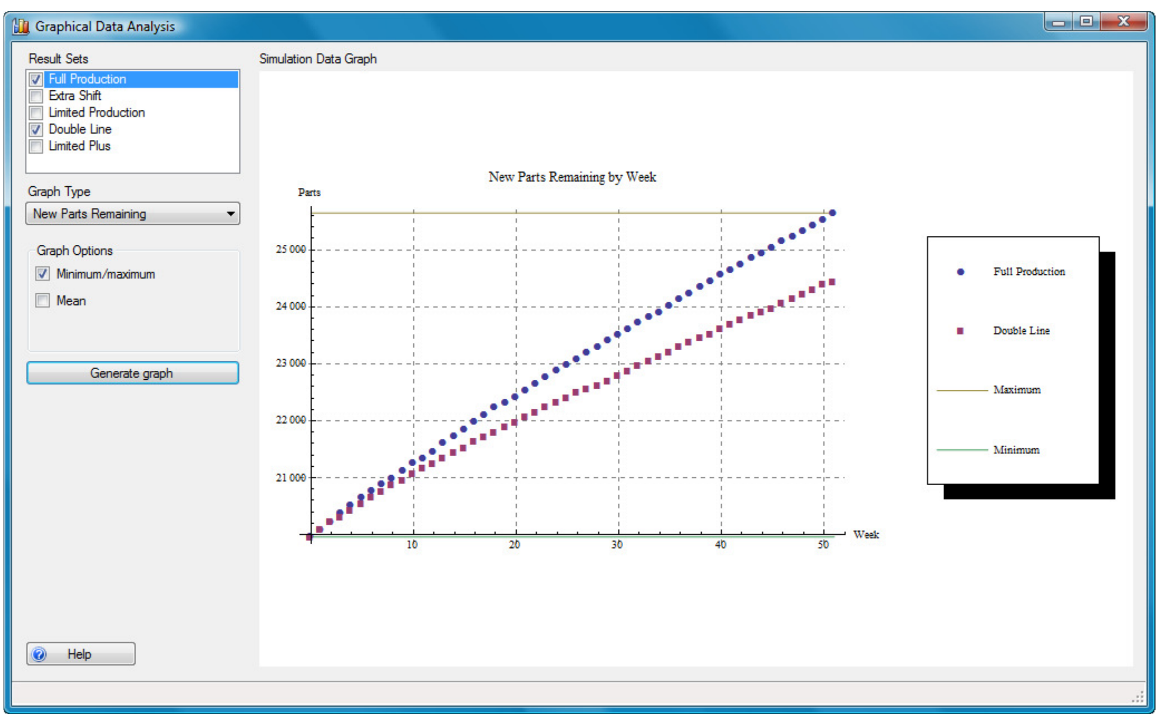


Improved data entry forms – run set, factory, repairer, and distributor.



Week	Factory Parts At Start	Factory Parts with Production	Factory Parts to Distribution	Factory Parts Remaining	Distribution Parts at Start	Distribution Parts with Production	D tc
0	500	843	520	323	0	505	33
1	323	666	518	148	172	675	33
2	148	491	441	50	342	770	33
3	50	393	373	20	437	799	33
4	20	363	363	0	466	818	33
5	0	343	343	0	485	817	32
6	0	343	343	0	494	826	32
7	0	343	343	0	503	835	32

Statistics	Factory Parts At Start	Factory Parts with Production	Factory Parts to Distribution	Factory Parts Remaining	Distribution Parts at Start	Distribution Parts with Production	Distri to Re
Quick Graph							
Minimum	0	343	343	0	0	505	302
Maximum	500	843	520	323	1673	2005	332
Mean	20.0192	363.019	352.615	10.4038	963.365	1304.79	306.9
Standard Deviation	83.8174	83.8174	36.5283	49.2103	423.138	406.362	10.17



Improved tabular and graphical analysis forms.

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