EXPERIMENTAL DESIGN ANALYSIS OF U.S. ARMY COMMAND AND CONTROL SYSTEMS WITH THE CADRE TOOL

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ABSTRACT

Previous work has involved experimental design interrogation of a series of computer models of human task and workload performance in military command and control (C2) systems. These models, called Computer modeling Of Human Operator System Tasks (CoHOST) (Middlebrooks et al., 1999), have shown a dramatic need for some tool to assist experimental designers in efforts to establish effective experiments. Specific needs include the collection of data in a manner that minimizes the amount of data required while maximizing the effectiveness and power of the data. A desktop tool called Computer-Aided Design Reference for Experiments (CADRE) was developed for this purpose. The CADRE tool includes over 850 pages of reference material covering 25 topics that are divided into five major sections including an introduction to experimental design, supplemental data collection design and analysis, basic analysis of variance (ANOVA) designs, advanced ANOVA designs, and empirical model building. In addition, the CADRE tool contains over 200 pages explaining 39 examples of statistical analyses covered in the reference material and is hyperlinked to Version 9.1.3 of the SAS statistical analysis package. The CADRE tool can be used for choosing experimental design procedures to interrogate and build empirical models in support of complex studies such as future C2 systems computer simulations.

1. INTRODUCTION

While there are several published statistical and experimental design and analysis textbooks that cover basic and advanced experimental design techniques (Keppel and Wickens, 2004; Montgomery, 2005; Myers and Montgomery, 2002; Shadish, Cook, and Campbell, 2002; Winer, Brown, and Michels, 1991), and attempts at automated experimental design references (Mills, Meyer, Rickels, and Hoyland, 1982), there is a current need for a computer-based reference that utilizes modern hardware and software technologies. Such a tool should incorporate an integrated subset of currently accepted basic and advanced experimental design approaches that are useful in complex system research environments investigated by human factors and ergonomics researchers.

Previously, procedural guidance and reference for experimental design and statistical analysis was often summarized in hard copy tables in the covers of textbooks (Siegel and Castellan, 1988). With the advent of hyperlink technology that can be embedded into machine-independent Postscript Definition File (PDF) documents, modern computer technology provides the technical basis for the development of an interactive desktop tool to access a large reference resource to assist researchers in their quest for efficient and effective designs. An example of just how complicated these experimental designs can become in military capability studies is briefly described in the context of using experimental design to interrogate computer simulations.

2. THE CoHOST EXAMPLE

Following the 1991 Persian Gulf War, the U.S. Army determined that its M577 armored command and control (C2) vehicle was obsolete. Responding to this requirement, the Army Research Laboratory (ARL) developed a series of computer simulation models to examine human mental and physical performance capabilities in U.S. Army Battalion and Brigade level tactical operations centers (TOC) resulting from the introduction of a new vehicle with modernized digital communications systems. A computer simulation design was implemented with taxonomic based descriptors of human performance in the military C2 domain using discrete event programming. Using these models a series of computer runs was established to assess the efficiency of information flow and task loading in the TOC.

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2.1. CoHOST Models

A series of computer models called Computer modeling Of Human Operator System Tasks (CoHOST) (Middlebrooks et al., 1999) were developed to address cognitive workload performance in the new work domain fostered by this new C2 systems environment.

This effort resulted in the development of the CoHOST series of models. CoHOST was developed to answer questions about whether human operators could operate effectively in a specified work domain. An experimental design was developed that allowed evaluative conditions to be placed on the simulated human operators in the computer model. Following these conditions a series of computer runs were made to establish test points for identified dependent variables against specified independent variables. With these test points a set of polynomial regression equations was derived to describe the performance characteristics according to the dependent variables of the simulated human operator in the work domain. These regression equations were then used to predict optimum values for the independent variables as indicators of maximum human performance that could be achieved in the work domain.

2.2. Experimental Design Interrogation of CoHOST

CoHOST was then selected for further study to allow an investigation of how to optimize the simulated work domain to maximize predicted human performance. This simulation was used as an environment to generate, collect, and analyze empirical data. Experimental designs were used (Middlebrooks and Williges, 2002) to evaluate performance conditions to be placed on the simulated human operators in the computer model by building empirical models to predict human performance.

After exploring and rejecting several approaches to achieve these experimental objectives, an approach was developed that was an extension of a basic 2^{5-2} fractional factorial design that included an additional level to allow an examination of the quadratic components of the main effects. This design was further optimized by unbalancing the treatment orders to allow the computer simulation requirements to stay within acceptable limits (Banks, Carson, and Nelson, 1996) and still provide enough data to support the desired analysis. A set of polynomial regression equations was developed with these data to predict performance characteristics of the human operator in the work domain simulated in the model. The derivative of the regression equations was taken and set equal to zero to provide the optimum values for the independent variables to produce the maximum human performance according to the dependent variables.

By using appropriate experimental designs to investigate what the decision makers in the work team deemed to be important, predictions were made about how the work domain could be optimized for the most efficient human performance. An augmented fractional-factorial design was developed that allowed an analysis of the main effect for each independent variable along with predictions of higher-order components that might exist in each main effect. The development of this experimental design was accomplished only after extensive review of the literature for suitable approaches and is a clear example of the need for some tool to assist researchers in their attempts to develop effective and efficient designs.

3. THE CADRE TOOL

The CoHOST experiment is a real case example of how the availability of an experimental design and analysis tool can significantly assist researchers in experimental design development and analysis of the results. Development of appropriate experimental designs for complex analyses can be overwhelming to complete, demanding to structure, and incomplete in their results if an ineffective experiment is followed. This example of a highly complex study provided the basis for developing procedures and processes that can ease the burden of the experimental design development and ensure that an effective design is selected that can minimize the data collection effort and maximize the validity of the data.

In 2003 the Army Research Laboratory (ARL), in collaboration with the Virginia Polytechnic Institute and State University (Virginia Tech), sponsored the development of just such a tool which has been named Computer-Aided Design Reference for Experiments (CADRE) and prepared on a CD-ROM (Williges, in press). This three year effort is now coming to fruition and the resulting interactive experimental design and statistical analysis reference resource provides a highly effective aid for researchers quickly to establish efficient experimental designs for their work.

3.1. CADRE Structure

The CADRE tool was designed to be used as an interactive desktop computer tool to aid the human factors and ergonomics researcher in experimental design and analysis. It is delivered on a CD-ROM in a PDF format to facilitate cross-platform computer use.

The human factors experimental design and analysis reference material in CADRE is a compilation of two technical reports (Slater and Williges, 2006; Williges, 2006). The Williges 2006 report provides the primary reference material on experimental design in a PowerPoint presentation with accompanying notes. Over

850 pages of experimental design and analysis reference material for human factors researchers is provided in this report. The content of the reference material is presented in a numbered outline format on PowerPoint slides and descriptive text together with appropriate reference citations are provided for the content of each slide. At the end of each topic presentation, references are provided to the current scientific literature for supplemental readings that are pertinent to the topic presented. The companion report by Slater and Williges is an appendix to Williges' report and provides over 200 pages in SAS of program files (SAS, 2004), output files, and explanations for 39 examples of statistical analyses covered by the 2006 Williges report.

The CADRE tool has several features to facilitate interactive desktop computer use for rapid information location of reference material. These features include extensive bookmarks within the PDF file, links between the reference material and the appendix for each example computational problem, and hyperlinks from the CADRE tool to the SAS desktop interactive statistical program for each example problem.

3.2. CADRE Topics

The CADRE reference material covers 25 topics and is divided in to five major sections including introduction to experimental design, supplemental data collection design and analysis, basic analysis of variance (ANOVA) designs, advanced ANOVA designs, and empirical model building as shown in Table 1.

Topic 1 presents the overall research design process. First, the various stages of research are shown in a flow diagram. Next six critical aspects of this process are highlighted beginning with the research problem through research reports. As with all subsequent topics covered in the reference material, this topic concludes with a summary followed by suggestions for supplemental readings for in-depth coverage of the material covered in this topic.

Topic 2 is an introduction to experimental design. It begins with an overview of various conditions that can threaten the validity of the results of experiments and then offers a general notation for designating designs. Two general experimental design alternatives are presented, and the case is developed for always choosing randomized experimental designs, if possible.

Topic 3 summarizes basic statistical concepts that are fundamental to experimental design. This reference material is not a tutorial on basic statistics. Rather, the material highlights and summarizes key statistical concepts. It is assumed that users of this reference material already have a background in introductory descriptive and inferential statistics. Consequently, this topic is designed as a review of basic concepts without providing detailed descriptions or mathematical derivations. Users should refer to a textbook such as Walpole's latest edition (Walpole, Myers, Myers, and Ye, 2002) on introductory statistics for details on the concepts summarized in this topic if they are not familiar with them. The concepts of sampling distributions, the F-distribution, and statistical hypothesis testing are critical to understanding the experimental design topics covered in this reference.

Table 1. Major Topics in CADRE

Overview
Section 1. Introduction to Experimental Design
Topic 1. Research Design Process
Topic 2. Experimental Designs
Topic 3. Basic Statistical Concepts
Section 2. Supplemental Data Collection and Analysis
Topic 4.. Supplemental Data Collection Methods
Topic 5. Analysis of Nominal Scale Data
Topic 6. Analysis of Ordinal Scale Data
Topic 7. Summary of Supplemental Data
Section 3. Basic Analysis of Variance (ANOVA) Design
Topic 8. Introduction to ANOVA
Topic 9. ANOVA Summary Table Components
Topic 10. Between-Subjects ANOVA Designs
Topic 11. Analysis of Comparisons and Interactions
Topic 12. Within-Subjects ANOVA Designs
Topic. 13. Mixed-Factors ANOVA Designs
Topic 14. Summary of Basic ANOVA
Section 4. Advanced ANOVA Designs
Topic 15. Introduction to Advanced ANOVA
Topic 16. Hierarchical ANOVA Designs
Topic 17. Blocking ANOVA Designs
Topic 18. Fractional Factorial ANOVA Designs
Topic 19. Analysis of Covariance (ANCOVA)
Topic 20. Summary of Advanced ANOVA
Section 5. Empirical Model Building
Topic 21. Introduction to Empirical Models
Topic 22. Multiple Regression
Topic 23. Central-Composite Designs (CCD)
Topic 24. Sequential Experimentation
Topic 25. Summary of Empirical Models

Topic 4 deals with supplemental data collection that augments data from experimental designs. Quantitative supplemental data are very important for understanding and interpreting research results. Most supplemental data are analyzed by nonparametric analyses as opposed to parametric analyses used on the major dependent variables manipulated in the experimental design. Several types of supplemental data collection techniques can be used. This reference concentrates on graphical rating scales that are most often used to collect quantitative supplemental data in human factors research.

Topic 5 deals with an overview of major supplemental data analysis alternatives that can be used with nominal scale data. Only a sample of nonparametric analyses covering the most common techniques used in human factors and ergonomics research is presented in this topic. Siegel (Siegel and Castellan, 1988) provides a detailed discussion of all of these techniques, and their formulae and notation are used throughout this topic for easy reference. The nonparametric techniques in this reference are organized around between-subjects and within-subjects techniques to facilitate an easy choice of nonparametric analysis procedures for nominal data.

Topic 6 deals with an overview of four nonparametric analysis alternatives that can be used with ordinal scale supplemental data. The four procedures described in this reference material are often used in human factors and ergonomics research. Once again, the Siegel and Castellan reference provides a detailed discussion of each of these techniques, and their formulae and notation are used throughout this topic for easy reference. Similar to the approach followed in the discussion on nominal data analysis, the presentation of this topic is organized around between-subjects and within-subjects techniques to facilitate choice of nonparametric analysis procedures for ordinal data.

Topic 7 summarizes the major points discussed in Section 2 dealing with supplemental data. First, supplemental data collection procedures dealing with self reports, questionnaires, and rating scales are reviewed. Second, supplemental data analysis techniques using common nominal and ordinal scale nonparametric procedures are reviewed. Third, a three-step process for dealing with supplemental data in experimental design is presented.

Topic 8 introduces ANOVA designs by discussing their advantages, basic terms, and the three major categories of ANOVA designs used in human factors research. Next, procedures for specifying the underlying statistical model that describes the components of any ANOVA design are presented. The introduction ends with a discussion and example for using ANOVA for statistical hypothesis testing of the difference between two treatment means.

Topic 9 provides an overview of the computational aspects of any between-subjects, within-subjects, or mixed-factors ANOVA design used in human factors research. The subsections are organized around the five major components of the ANOVA Summary Table used for listing the results of an ANOVA. Rather than derive formulae for calculating each component, computational procedures and algorithms are provided. First, each component of the summary table is discussed separately. Then conventions for stating the complete ANOVA Summary Table are presented for each of the three major categories of ANOVA experimental designs used in human factors research.

Topic 10 covers the construction and computational details of the first of the three major categories of ANOVA designs used in human factors and ergonomics research. Between-subjects designs are discussed in terms of one-factor, two-factor, and n-factor designs. The procedures for determining the sum of squares computational formulae for any ANOVA are presented in the discussion of one-factor designs. The concept of an interaction is presented in two-factor designs. Generalizations for constructing and analyzing any between-subjects ANOVA design are summarized under n-factor designs. Computational examples are provided for both a one-way and a two-way between-subjects design. A summary listing of all the ANOVA procedural rules and algorithms for conducting any ANOVA analysis in human factors research is provided at the end of this topic.

Topic 11 covers analytical techniques that can be used to isolate the form or nature of the main effects and interactions that are significant in the overall ANOVA. Basically these procedures deal with multiple paired comparisons of various treatment means. First, this topic covers comparisons and provides examples of both planned and unplanned comparison procedures. Second, special analytical procedures in addition to paired comparisons are covered, and example computations are provided for the analysis of interactions. Although these procedures are demonstrated using between-subjects designs, these same techniques are appropriate for within-subjects and mixed-factors designs covered in the next two topics.

Topic 12 covers within-subjects ANOVA designs in which each subject receives every treatment condition in the human factors experiment. Basic configurations of one- and two-factor designs as well as generalizations to n-factor repeated measures designs are covered. The advantages of within-subjects designs are summarized as compared to between-subjects designs. Additional considerations in using repeated measures are discussed including the homogeneity of covariance assumption, balancing techniques for controlling possible confounding effects of treatment orders, and the effect of differential transfer.

Topic 13 covers the basic configuration and analytical procedures used in mixed-factors ANOVA designs which comprise the third major category of

ANOVA designs. Mixed-factors designs are composed of both between-subjects and within-subjects factors. This type of ANOVA design is often referred to as split-plot designs in the scientific literature. These designs are used quite frequently in human factors and ergonomic research due to the nature of the independent variables being investigated in the experiment. Consider a training research study that investigates training methods and practice trials. The researcher must manipulate the training condition variable as a between-subjects variable because subjects cannot return to a beginning level of knowledge when provided with alternative training. On the other hand, practice trials in this training experiment must be manipulated as a within-subjects factor since each subject receives multiple trials. Consequently, a mixed-factors design is needed. This topic also provides a list of considerations that the research should address when using mixed-factors designs.

Topic 14 provides a brief summary review and roadmap of basic ANOVA in terms of fundamental considerations, ANOVA design classification, ANOVA generalizations, steps in the overall ANOVA design and data interpretation process. Details on these issues are provided in specific topics referenced.

Topic 15 introduces topics in advanced ANOVA that expand upon the basic ANOVA procedures, rules, and algorithms already described in Section 3 of the reference material. Two examples of extending basic ANOVA (i.e., Quasi-F ratios and Randomized Blocks Designs) are presented in detail. In addition, this introduction provides an overview of several special purpose ANOVA design and analysis procedures that satisfy various constraints present in human factors and ergonomics research. Detailed discussions of these procedures are presented in subsequent topics.

Topic 16 covers hierarchical ANOVA designs that include nested factors of interest. This topic describes both the basic layout and the ANOVA computations involved in this class of experimental designs. These basic procedures can be generalized to higher-order hierarchical designs, and the use of hierarchical designs in human factors and ergonomics research is discussed. This topic ends with a general summary of the considerations of using hierarchical designs in human factors and ergonomics research.

Topic 17 deals with ANOVA experimental designs that can be used to control nuisance variable that are confounded with the factors of interest in an experiment. These confounding factors may include the effect of repeated testing sessions or experimenter bias resulting from using several experimenters in data collection. Confounding is controlled through blocking designs where blocks represent the nuisance variable. Through the use of modular representation the exact nature of the block confounding with specific treatment effects of interest can be determined by the experimenter in order to choose an experimental design to avoid confounding blocks with effects of major interest in a factorial ANOVA design. The use of blocking is demonstrated through 2^k factorial designs and extended to pseudo-factor blocking.

Topic 18 deals with fractional replicates of full factorial ANOVA designs. When large-scale factorial designs are used in human factors and ergonomics research, constraints such as time, money, and equipment availability may make the complete factorial design unfeasible and data collection must be restricted to a portion of the design. Obviously, some effects in the full factorial design cannot be evaluated and some effects will be confounded with others if data are not collected on the entire design. The experimenter must select a subset of the complete design that yields the most useful data. Fractional-factorial designs are ANOVA designs in which only a fractional portion of the complete factorial designs are observed. Fractional replications of 2^k, 3^k, and 5^k designs can be constructed through modular representation. Most often 2^{k-p} fractional replicates are used in human factors research to avoid subsequent confounding of partial effects that are present in 3^k and 5^k designs. Alternatively, a subset of fractional-factorial designs called Latin Square designs can be used to specify the subset of treatment conditions to observe when the experimenter is only interested in testing the main effects of three factors of interest. Consequently, this topic describes both 2^{k-p} fractional replicates and Latin Square designs.

Topic 19 deals with an analytical technique for reducing the effect of a covariate to increase the sensitivity of the F-test on effects of interest to the experiment. The covariate is correlated with the dependent variable and its effect is removed through simple linear regression. Both calculations of correlation and simple regression are described as the basic components of analysis of covariance (ANCOVA). Basic computations in ANCOVA and subsequent interpretations of results are described in this topic.

Topic 20 summarizes the advanced ANOVA techniques described in the reference material. This topic provides a summary of design constraints and describes a process for addressing them.

Topic 21 provides an overview of quantitative models with an emphasis on empirical model building developed through efficient experimental design. Empirical models are descriptive models of human behavior based on results obtained through one or more controlled experiments that can be used to predict human performance in complex systems. These empirical models can assist the human factors specialist in conducting design tradeoffs of critical interface parameters.

Topic 22 provides an overview of multiple regression procedures used to generate empirical models that involve more than one factor. First, multiple linear regression is described to demonstrate the calculations involved when considering more than one factor in the empirical model. Both classical and modern regression procedures for selecting the best multiple regression equation are described. Next, polynomial regression is discussed as the general form for stating empirical models in human factors research.

Topic 23 describes experimental designs that can be used to collect data for building second-order empirical models. Specifically, this topic focuses on central-composite designs (CCD) that were developed to explore response surfaces using empirical models. The background, specification, analysis, and an example of a CCD along with a comparison to alternative second-order experimental designs are discussed in this topic.

Topic 24 incorporates the previous topics into an overall strategy for conducting research on complex systems often addressed in human factors and ergonomics research. Due to the nature of complex research, the experimenter can conduct a series of small independent, but interrelated, experiments rather than one large complex study. This topic describes general strategies for conducting complex experiments and specifically draws upon considerations made in response surface methodology for conducting a series of small, interrelated studies. A general paradigm for conducting sequential research is presented along with a detailed example of using this paradigm in human factors research that resulted in a set of guidelines for sequential experimentation. The topic concludes with a description of combining sequential experiments into a common database that incorporates the results of several experiments. This database can then be interrogated to generate integrated empirical models across experiments.

Finally, Topic 25 summarizes the empirical model building techniques. The purpose and characteristics of empirical model building experiments are reviewed, the major components of empirical models are listed, and a sequential experimentation process for human factors research is provided.

3.3. CADRE Bookmarks

The PDF file in CADRE is heavily bookmarked around eight expandable major Bookmark tabs shown in Table 2 that include over 500 bookmarks when fully expanded. The bookmarks were designed to provide the CADRE user with alternative paths for rapid location of information within the tool.

Table 2. Major Bookmark Tabs in CADRE

Bookmark Tab 1. Table of Contents
Bookmark Tab 2. Subject Index
Bookmark Tab 3. Experimental Design Procedures
Bookmark Tab 4. Statistical Analysis Procedures
Bookmark Tab 5. Notes on Computational Examples
Bookmark Tab 6. Appendix on SAS Examples
Bookmark Tab 7. References
Bookmark Tab 8. Supplemental Readings

The first two major bookmark tabs shown in Table 2 deal with selecting specific content in the reference material. Bookmark Tab 1 expands to provide immediate access to various subsections of each topic in the Table of Contents listed in Table 1. Bookmark Tab 2 expands to an extensive subject index arranged alphabetically for easy access to various topics in the reference material.

The next two major tab sections shown in Table 2 expand to bookmarks that provide direct access to various experimental design and statistical analysis procedures described in the reference material. Experimental design procedures in Bookmark Tab 3 deal with issues such as research stages, critical research methods, basic and advanced ANOVA design selection, paradigms and guidelines for sequential experimentation, supplemental data collection, and components of research reports. The Tab 4 Bookmark deals with statistical analysis procedures including basic statistics, various basic and advanced ANOVA computations, simple, multiple linear, and polynomial regression analysis, and empirical model building procedures.

Bookmark Tabs 5 and 6 in Table 2 expand to 39 computational examples provided throughout CADRE. A list of these examples is provided in Table 3. Bookmark Tab 5 expands to a discussion of statistical computations for each example in the reference material. Alternatively, Bookmark Tab 6 provides immediate access to the SAS program Appendix (Slater and Williges, 2006) that describes the SAS (SAS, 2004) statistical analysis procedures.

The final two major bookmark tabs shown in Table 2 deal with additional reference material. Bookmark Tab 7 is a single bookmark to the reference section that includes an alphabetical listing of all references used in the CADRE tool. Finally, Bookmark Tab 8 can be expanded to provide bookmarks to supplemental reading for book chapters and articles in the scientific literature to elaborate upon the reference material presented for each topic listed in Table 1.

3.4. CADRE Links and Hyperlinks

The PDF file of CADRE also supports links between the computational descriptions of the examples in the reference material with the 39 examples in the Slater and Williges (2006) Appendix as shown in Table 3. The reference material describes the various steps in the statistical calculation; whereas, the use of the SAS (2004) statistical package for conducting the analysis is described in the Appendix. Each example in the Appendix provides a problem description, a SAS input file, a SAS output file, and output explanation. Notes are provided throughout the Appendix to describe tailored modifications when using various SAS procedures.

Each of the 39 statistical examples in the Slater and Williges (2006) Appendix is also hyperlinked to Version 9.1.3 of the SAS (2004) statistical analysis package. If the SAS interactive statistical package is active on a user's computer, the CADRE tool can be directly linked to the SAS program file for any example covered in the Appendix. These programs also can be used as a guide for analyzing an experimenter's specific data set by simply modifying the names and numbers of independent variables and the specific data set of the dependent variables.

4. DISCUSSION

CADRE represents one example of a computer-based desktop interactive tool that can assist researchers in conducting complex systems research. This tool can be expanded to incorporate additional experimental design procedures and additional statistical analyses packages that can be hyperlinked to the reference material in CADRE. This tool needs to be widely available to the research community so that improvements based on usage can be made to both the content and interactive nature of CADRE.

In addition, the approach used in developing the CADRE tool can be extended to other desktop tools to assist the human factors researcher. CADRE can be considered the first prototype in a series of tools. Other computer-based tools addressing a variety of research methods (e.g., multivariate analysis, survey procedures, and cognitive task analysis), system design methods (e.g., focus groups, design guidelines, specifications, and requirements), and evaluation methods (e.g., usability assessment, operator workload evaluation, situation awareness, and crew resource management) can be added to this family of tools to be used by human factors professionals.

Table 3. Hyperlinked SAS Examples in CADRE

Example 1.	Interval Estimation
Example 2.	Single-Sample t-Test
Example 3.	Between-Subjects t-Test
Example 4.	Within-Subjects t-Test
Example 5.	Chi-Square Goodness of Fit Test
Example 6.	Chi-Square Test of Independence (2x2 Contingency Table)
Example 7.	Chi-Square Test of Independence (RxC Contingency Table)
Example 8.	Chi-Square Test of Independence (Two Additive 2x2 Partitions)
Example 9.	McNemar Change Test
Example 10.	Cochran Q Test
Example 11.	Kolmogorov-Smirnov Tests
Example 12.	Kruskal-Wallis One-Way ANOVA
Example 13.	Wilcoxon Signed Ranks Test
Example 14.	Friedman Two-Way ANOVA
Example 15.	One-Factor, Between-Subjects ANOVA
Example 16.	Two-Factor, Between-Subjects ANOVA
Example 17.	Planned Comparisons
Example 18.	Unplanned Comparisons
Example 19.	Analysis of Interactions
Example 20.	One-Factor, Within-Subjects ANOVA
Example 21.	Two-Factor, Within-Subjects ANOVA
Example 22.	Geisser-Greenhouse and Huynh-Feldt Corrections
Example 23.	Testing Order Effects in Balanced Latin Squares
Example 24.	Within-Subjects and Between-Subjects Design Comparison
Example 25.	Two-Way, Mixed-Factors ANOVA
Example 26.	Complete Hierarchical Between-Subjects Design
Example 27.	Partial Hierarchical Between-Subjects Design
Example 28.	Simple Blocking of 2^k Within-Subjects Design
Example 29.	Complex Blocking of 2^k Within-Subjects Design
Example 30.	One-Half Replicate of 2^4 Between-Subjects Design
Example 31.	Linear Correlation Coefficient
Example 32.	Alternative Linear Correlations
Example 33.	Simple Linear Regression
Example 34.	Analysis of Covariance (ANCOVA) One-Way, Between-Subjects Design
Example 35.	Multiple Linear Regression
Example 36.	Best Regression Equation
Example 37.	Polynomial Regression
Example 38.	Orthogonal, Between-Subjects, Central-Composite Design
Example 39.	Blocked, Within-Subjects. Central-Composite Design

CONCLUSIONS

Research on Army command and control systems requires knowledge and use of complex experimental design and analysis procedures. The CADRE tool can assist in designing effective experiments that allows data collection requiring minimum effort while maximizing the effectiveness of results. Sections 4 and 5 of CADRE dealing specifically with fractional-factorial designs, polynomial regression, empirical model building, and sequential experimentation are particularly appropriate in investigating emerging C2 systems.

The studies that provided impetus to spawn the development of the CADRE tool were part of on-going efforts to develop better understandings of how to structure socio-technical work environments. These conditions are characterized where teams function in a high stress, time dependent, and decision oriented work setting. Here the goal is to optimize human cognitive performance in the work domain found in military C2 systems. This work is especially relevant for studies of systems not yet in existence such as the Future Combat System (FCS) and Objective Force Warrior (OFW).

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