DESMATICS, INC.

P. O. Box 618
State College, PA. 16801
Phone: (814) 238-9621

Applied Research in Statistics - Mathematics - Operations Research

FINAL REPORT: STATISTICAL RESEARCH APPLICABLE TO THE NAVY'S BIODYNAMICS PROGRAM

by

Kevin C. Burns
and
Dennis E. Smith

TECHNICAL REPORT NO. 112-17

May 1984

This study was supported by the Office of Naval Research
under Contract No. N00014-79-C-0128, Task No. NR 207-037

TABLE OF CONTENTS

I. INTRODUCTION

This final technical report prepared under Contract No. N00014-79-C-0128 summarizes a research investigation conducted by Desmatics, Inc. under sponsorship of the Office of Naval Research. This research has focused on problems of biodynamics applicable to the Navy's program at the Naval Biodynamics Laboratory (NBDL). The following sections briefly summarize the research accomplished under this contract and provide a reference list of all technical reports (with abstracts), journal articles, and presentations resulting from this research effort.

II. RESEARCH SUMMARY

The statistical research conducted by Desmatics, Inc. under this contract focused on two major problem areas within the Navy's biodynamics program at NBDL. Those were: (1) impact acceleration injury and (2) ship motion sickness. Additional research was conducted in the area of performance testing, which is relevant to both of the primary research topics. The following three sections provide a brief summary of Desmatics' work in each area.

A. IMPACT ACCELERATION INJURY

Desmatics research in this area was directed toward the establishment of tolerance limits to $-G_x$ acceleration. This required the development of probabilistic models for impact acceleration injury and Desmatics chose the logistic response model as the generic form most appropriate for that purpose. A major portion of the Desmatics research effort was devoted to the development of optimal procedures for these models. A parallel line of research involved fitting specific response functions to empirical data gathered from $-G_x$ acceleration experiments carried out at NBDL using rhesus monkeys as subjects.

One of the Desmatics technical reports in this area discussed optimal designs for estimation of the parameters of a logistic function. Further research considered the problem of augmenting an existing experimental design. In addition, Desmatics studied procedures for incor-

porating various sources of auxiliary information into the modeling process and thereby improving the parameter estimates. Computational aspects of these procedures were discussed and simulation used to evaluate their efficacy.

Using the NBDL data base consisting of 93 $-G_x$ acceleration runs on rhesus monkeys, several different logistic models were constructed and evaluated. Those models were based on different sets of predictor variables, including the forces and torques in the region of injury, sled profile variables, head dynamic response variables, and the initial position of the head. These models were thoroughly documented and evaluations were made of each variable's ability to predict injury. Additional research involved the extraction of optimal predictor variables from the head dynamic response time traces. Finally, the NBDL rhesus experiments were compared to earlier research on baboons.

B. SHIP MOTION SICKNESS

A major component of the Navy's ship motion research program has been the study of single and mixed frequency vertical whole-body sinusoidal motion. Desmatics considered several alternative characterizations of sinusoidal motion and attempted to extend those characterizations to dual-frequency motion. No characterization consistently provided accurate predictions of motion sickness incidence.

Desmatics examined the distributional properties of some existing time to first emesis data. Based on its analysis, Desmatics postulated a mixture of two statistical populations as an overall model of time to

first emesis. Empirical evidence suggested that the subpopulation of susceptible volunteers was well-modeled by a Weibull distribution. Further research involved comparing the results of experiments using dual-frequency sinusoidal motion.

C. PERFORMANCE TESTING

Part of the research work at NBDL involves the administration of performance tests in order to evaluate the effects of various factors on performance. Often, each individual is required to take multiple administrations of each of several tests. Desmatics developed a computer program designed to produce a feasible schedule for test administration.

When an individual is tested repeatedly over time, correlations between the scores make statistical analysis difficult. Desmatics chose a model which adequately describes many situations of this type and studied inference procedures for that model. Several candidate test statistics were evaluated with simulated data. Charts and tables were prepared from the simulation results to give bounds for the significance levels of each test statistic.

III. DESMATICS TECHNICAL REPORTS

Desmatics Report Number: 112-1 Date: July 1979

DTIC Number: AD-A071625

Title: AN EXAMINATION OF STATISTICAL IMPACT ACCELERATION INJURY PREDICTION MODELS BASED ON TORQUE AND FORCE VARIABLES

Authors: Dennis E. Smith and John J. Peterson

Abstract: This technical report describes the construction of impact acceleration injury prediction models from a set of twenty-eight $-G_X$ accelerator runs involving Rhesus monkeys with securely restrained torso and unrestrained head. Peak torque and force variables measured during these runs were used to predict injury likelihood. The relative contribution of these variables was examined with respect to the original and a modified version of the data set. Two possible prediction models were used to construct two critical envelopes, i.e., those values of the variables for which the predicted probability of injury (or fatality) is less than or equal to some specified probability. The preferred model was identified and discussed.

Desmatics Report Number: 112-2 Date: August 1979

DTIC Number: AD-A072682

Title: STATISTICAL PROCEDURES FOR EXTRACTING OPTIMAL PREDICTOR VARIABLES FOR USE IN AN IMPACT ACCELERATION INJURY PREDICTION MODEL

Authors: Dennis E. Smith and John J. Peterson

Abstract: An empirical impact acceleration injury prediction model can be based on an underlying logistic function using information extracted from dynamic response data to define independent (predictor) variables. This report describes statistical procedures for the extraction of optimal predictor variables. The application of the statistical techniques of principal components analysis and canonical correlation analysis is described. An outline of how the data analysis may be conducted with the BMDP statistical computer package is discussed.

Desmatics Report Number: 112-3 Date: November 1979

DTIC Number: AD-A077279

Title: SCHEDULER: A COMPUTER PROGRAM FOR SCHEDULING ADMINISTRATION OF PERFORMANCE TESTS

Authors: Robert L. Gardner and Dennis E. Smith

Abstract: This report describes SCHEDULER, a computer program which implements a heuristic scheduling algorithm. This algorithm is designed to produce a feasible schedule for administration of performance tests to a group of subjects who are required to take multiple adminstrations of each of several tests. Provision is made for scheduling up to ten tests in parallel during each of several periods per day. Availability of subjects and tests may be specified in terms of an internal calendar which may be linked to the real-world calendar, so that a completion date for the schedule may be determined. The SCHEDULER program may be used experimentally in evolving scheduling strategies or may be used to produce a working schedule for a real set of circumstances. The results of a series of experimental runs are presented, as well as some conclusions regarding strategies for a specific application. The program input and output formats are described in detail and a system flow chart is provided.

Desmatics Report Number: 112-4 Date: January 1980

DTIC Number: AD-A080572

Title: OPTIMAL DESIGNS FOR ESTIMATION OF THE TWO-PARAMETER LOGISTIC FUNCTION

Authors: Leslie A. Kalish and Dennis E. Smith

Abstract: In this report, optimal designs for weighted least squares and maximum likelihood estimation of the two-parameter logistic function are constructed. In particular, four criteria for optimality are considered: D, A, E and G-optimality. The D and G-optimality criteria are found to be invariant to changes in scale while the A and E-optimality criteria are not. Practical problems which arise in the implementation of the optimal designs are discussed.

Desmatics Report Number: 112-5 Date: May 1980

DTIC Number: AD-A085004

Title: OPTIMAL AUGMENTATION OF EXPERIMENTAL DESIGNS FOR ESTIMATION OF THE LOGISTIC FUNCTION

Authors: Leslie A. Kalish and Dennis E. Smith

Abstract: A criterion for optimal augmentation of an experimental design is applied to the problem of estimating the logistic function. A simulation study is conducted to evaluate the procedure in the two-parameter case. Examples in the development of impact acceleration injury prediction models are given.

Desmatics Report Number: 112-6 Date: August 1980

DTIC Number: AD-A087810

Title: A GENERAL STATISTICAL APPROACH FOR USING AUXILIARY INFORMATION IN THE DEVELOPMENT OF AN IMPACT ACCELERATION INJURY PREDICTION MODEL

Authors: John J. Peterson and Dennis E. Smith

Abstract: This report discusses general procedures for simultaneously incorporating various sources of auxiliary information into an impact acceleration injury prediction model. The sources of auxiliary information considered are supplemental continuous empirical data and a priori knowledge in the form of model parameter estimates and constraints.

Desmatics Report Number: 112-7 Date: February 1981

DTIC Number: AD-A095299

Title: COMPUTATIONAL ASPECTS OF INCORPORATING AUXILIARY INFORMATION INTO AN IMPACT ACCELERATION INJURY PREDICTION MODEL

Authors: John J. Peterson and Dennis E. Smith

Abstract: Auxiliary information may sometimes be used in development of a mathematical model in order to improve the estimated values of unknown parameters. This report discusses computational procedures which allow the application of commonly used nonlinear estimation programs to incorporate various sources of auxiliary information into an impact acceleration injury prediction model.

Desmatics Report Number: 112-8 Date: February 1981

DTIC Number: AD-A096750

Title: PRELIMINARY ANALYSIS OF MOTION SICKNESS INCIDENCE DATA

Authors: Carl A. Mauro and Dennis E. Smith

Abstract: This report analyzes motion sickness data obtained from experiments involving the Office of Naval Research motion generator. Based on the analysis, a mixture of two statistical populations has been postulated as an overall model of time to first emesis.

Desmatics Report Number: 112-9 Date: September 1981

DTIC Number: AD-A105463

Title: A MONTE CARLO STUDY OF THE USE OF AUXILIARY INFORMATION IN THE DEVELOPMENT OF AN IMPACT ACCELERATION INJURY PREDICTION MODEL

Authors: Dennis E. Smith and John J. Peterson

Abstract: This report describes a small-scale Monte Carlo investigation of procedures for incorporating various sources of auxiliary information into an impact acceleration injury prediction model. Parameter estimates are tabulated and compared for standard and modified models. Based on the results of the investigation, the procedures appear to be helpful in reducing the mean square error of predictions.

Desmatics Report Number: 112-10 Date: November 1981

DTIC Number: AD-A107996

Title: ACCELERATION MEASURES AND MOTION SICKNESS INCIDENCE

Authors: Carl A. Mauro and Dennis E. Smith

Abstract: An important aspect of motion sickness research is to establish quantitative relationships between sickness incidence and various parameters of the motions that induce sickness. At present, however, only whole-body vertical sinusoidal motion has been studied to any reasonable degree. The purpose of this report is to examine the predictive utility of six different characterizations of sinusoidal motion and to investigate their possible extension to dual frequency motion.

Desmatics Report Number: 112-11 Date: June 1982

DTIC Number: AD-A116440

Title: RESEARCH ON THE DEVELOPMENT OF A STATISTICAL IMPACT ACCELERATION INJURY PREDICTION MODEL FROM $-G_x$ ACCELERATOR RUNS

Authors: Dennis E. Smith and David Aarons

Abstract: Statistical impact acceleration injury prediction models are developed for the head/neck segment from data obtained during 68 $-G_x$ accelerator runs. These runs involved sub-human primates (Rhesus monkeys) with securely restrained torso and unrestrained head. The data was collected by the Naval Biodynamics Laboratory (NBDL) as part of its research effort on acceleration impact injury prevention. Three classes of prediction models are constructed, one based on sled profile variables, another based on head dynamic response variables only, and the third comprised of the combined set of independent variables. The model predictions are compared with the observed results to evaluate performance.

Desmatics Report Number: 112-12 Date: February 1983

DTIC Number: AD-A125779

Title: THE EFFECT OF ENVIRONMENTAL CHANGE IN SINGLE-SUBJECT EXPERIMENTS

Authors: Kevin C. Burns and Dennis E. Smith

Abstract: Statistical procedures for testing the mean of a first-order autoregressive model are evaluated. Two types of test statistic are considered. One involves estimating the autocorrelation and using that estimate to transform the data. The second type of test statistic is of the form T/w, where w is a function of the estimated autocorrelation and $T = \sqrt{n}\bar{Y}/s$. The usual estimation of the autocorrelation is used initially and compared to a revised estimator which provides less biased estimates. Each procedure is evaluated according to its performance on a set of simulated data.

Desmatics Report Number: 112-13 Date: May 1983

DTIC Number: AD-A129353

Title: STATISTICAL IMPACT ACCELERATION INJURY PREDICTION MODELS BASED ON $-G_x$ ACCELERATOR DATA AND INITIAL HEAD CONDITIONS

Authors: Kevin C. Burns and Dennis E. Smith

Abstract: Statistical impact acceleration injury prediction models are developed using data from 23 high-level $-G_x$ acceleration runs. These runs involve Rhesus monkeys with securely restrained torsos and unrestrained heads. The models are based on peak sled acceleration and initial head conditions. The model predictions are compared with those given in an earlier report based on different data and an estimate of Fisher's information matrix is used to evaluate the relative worth of the two data bases.

Desmatics Report Number: 112-14 Date: May 1983

DTIC Number: AD-A129082

Title: AN EMPIRICAL INVESTIGATION OF SEVERAL TESTS FOR THE MEAN OF A FIRST-ORDER AUTOREGRESSIVE PROCESS

Authors: Kevin C. Burns and Dennis E. Smith

Abstract: Four test statistics are considered for testing hypotheses about the mean of an AR(1) process. Simulated data are used to estimate the actual significance levels obtained when using $t_\alpha(n-1)$ as the critical value. Smoothing functions are fit to the empirical significance levels as functions of sample sizes. These functions are presented graphically and an example given as to how they might be used.

Desmatics Report Number: 112-15 Date: August 1983

DTIC Number: AD-A131930

Title: MOTION SICKNESS INCIDENCE: DISTRIBUTION OF TIME TO FIRST EMESIS AND COMPARISON OF SOME COMPLEX MOTION CONDITIONS

Author: Kevin C. Burns

Abstract: A statistical mixture model is used to fit time-to-emesis data. The Weibull probability distribution is shown to provide a good fit for those subjects who either become sick or withdraw from the experiment within two hours. The second part of the mixture accounts for those subjects who neither quit nor vomit within two hours. The lognormal probability model is shown to give a poorer fit to the data and figures showing the relative fits of the estimated Weibull and lognormal distributions are provided. A nonparametric test is used to compare the five motion conditions of the Correlation Study. That test shows that there are significance differences in severity among the conditions.

Desmatics Report Number: 112-16 Date: May 1984

Title: COMPARISON OF RHESUS MONKEY AND BABOON $-G_x$ EXPERIMENTS

Author: Kevin C. Burns

Abstract: NBDL $-G_x$ acceleration rhesus experiments are compared to the results of Clarke et al. with baboons using the Air Force shoulder harness-lap belt restraint. Baboons are shown to have significantly less tolerance to $-G_x$ acceleration. The differential effect of peak sled acceleration is shown to be the same for each species. The statistical models used are logistic response functions of peak sled acceleration and the initial yaw angle of the head.

IV. JOURNAL ARTICLES AND PRESENTATIONS

In addition to the technical reports listed in Section III, significant research findings have been documented in four journal articles. Research accomplishments have also been presented at two scientific and technical meetings. A complete listing of journal publications and technical presentations prepared under this contract is given below:

A. JOURNAL PUBLICATIONS

PREDICTIVE MODEL OF DYNAMIC RESPONSE OF THE HUMAN HEAD/NECK SYSTEM TO $-G_x$ IMPACT ACCELERATION by Dennis E. Smith and W. R. Anderson, Aviation, Space and Environmental Medicine, Vol. 49, pp. 224-233, Jan. 1978.

A STATISTICAL EXAMINATION OF THREE APPROACHES FOR PREDICTING MOTION SICKNESS INCIDENCE by Dennis E. Smith, Aviation, Space and Environmental Medicine, Vol. 53, pp. 162-165, Feb. 1982.

A STATISTICAL ANALYSIS OF MOTION SICKNESS INCIDENCE DATA by Carl A. Mauro and Dennis E. Smith, Aviation, Space and Environmental Medicine, Vol. 54, pp. 253-257, May 1983.

MOTION SICKNESS INCIDENCE: DISTRIBUTION OF TIME TO FIRST EMESIS AND COMPARISON OF SOME COMPLEX MOTION CONDITIONS by Kevin C. Burns, Aviation, Space and Environmental Medicine, 1984 (to appear).

B. TECHNICAL PRESENTATIONS

THE STRUCTURE OF A STATISTICAL MODEL FOR PREDICTING IMPACT ACCELERATION INJURY, The Neuroelectric Society 1977 Annual Meeting, Marco Beach, FL, Dec. 1977.

ACCELERATION MEASURES AND MOTION SICKNESS INCIDENCE, International Workshop on Research Methods in Human Motion and Vibration Studies, New Orleans, Sept. 1981.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1 REPORT NUMBER 112-17	2. GOVT ACCESSION NO.	3 RECIPIENT'S CATALOG NUMBER
4 TITLE (and Subtitle) FINAL REPORT: STATISTICAL RESEARCH APPLICABLE TO THE NAVY'S BIODYNAMICS PROGRAM		5 TYPE OF REPORT & PERIOD COVERED Final Report 6. PERFORMING ORG. REPORT NUMBER
7 AUTHOR(s) Kevin C. Burns and Dennis E. Smith		8. CONTRACT OR GRANT NUMBER(s) N00014-79-C-0128
9 PERFORMING ORGANIZATION NAME AND ADDRESS Desmatics, Inc. P.O. Box 618 State College, PA 16804		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR 207-037
11 CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research Arlington, VA 22217		12. REPORT DATE May 1984 13. NUMBER OF PAGES 13
14 MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Distribution of this report is unlimited.		DISTRIBUTION STATEMENT A Approved for public release Distribution Unlimited
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Impact Acceleration Injury Ship Motion Sickness Performance Testing Logistic Response Models Mixture Distributions Autoregressive Process		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This final technical report prepared under Contract No. N00014-79-C-0128 summarizes a research investigation conducted by Desmatics, Inc. under sponsorship of the Office of Naval Research. This research has focused on problems of biodynamics applicable to the Navy's program at NBDL. The major problem areas studied were impact acceleration injury and ship motion sickness.		

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)