USAARL Report No. 90-7

Reduction of Variance in Expert Panel Estimates of U.S. Army Combat Vehicle Crew Endurance

By

Glenn W. Mitchell
Francis S. Knox, III

Biomedical Applications Research Division

March 1990

United States Army Aeromedical Research Laboratory
Fort Rucker, Alabama 36362-5292

Notice

Qualified requesters

Qualified requesters may obtain copies from the Defense Technical Information Center (DTIC), Cameron Station, Alexandria, Virginia 22314. Orders will be expedited if placed through the librarian or other person designated to request documents from DTIC.

Change of address

Organizations receiving reports from the U.S. Army Aeromedical Research Laboratory on automatic mailing lists should confirm correct address when corresponding about laboratory reports.

Disposition

Destroy this document when it is no longer needed. Do not return it to the originator.

Disclaimer

The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation. Citation of trade names in this report does not constitute an official Department of the Army endorsement or approval of the use of such commercial items.

Reviewed:

Gerald P. Krueger

GERALD P. KRUEGER, Ph.D.,
LTC, MS
Director, Biomedical Application
Research Division

J. D. LaMothe

J. D. LaMOTHE, Ph.D.
COL, MS
Chairman, Scientific
Review Committee

Released for publication:

David H. Karney

DAVID H. KARNEY
Colonel, MC
Commanding

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY 2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution unlimited
4. PERFORMING ORGANIZATION REPORT NUMBER(S) USAARL Report No. 90-7	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION U.S. Army Aeromedical Research Laboratory 6b. OFFICE SYMBOL (If applicable) SGRD-UAB	7a. NAME OF MONITORING ORGANIZATION U.S. Army Medical Research and Development Command
6c. ADDRESS (City, State, and ZIP Code) P.O. Box 577 Fort Rucker, AL 36362-5292	7b. ADDRESS (City, State, and ZIP Code) Fort Detrick Frederick, MD 21701-5012
8a. NAME OF FUNDING / SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 26787A PROJECT NO. 3E162-787A879 TASK NO. BH WORK UNIT ACCESSION NO. 169

11. TITLE (Include Security Classification)
(U) Reduction of Variance in Expert Panel Estimates of U.S. Army Combat Vehicle Crew Endurance

12. PERSONAL AUTHOR(S)
G.W. Mitchell and F.S. Knox, III

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
	FROM ____ TO ____		

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
23	01	
24	07	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Expert panel, endurance, prediction, chemical defense, performance degradation, group process, modeling, combat vehicle crews

19. ABSTRACT (Continue on reverse if necessary and identify by block number)
An expert panel was assembled to explore the effectiveness of a novel method for reducing the variance of face-to-face group estimates. The panel's task was to estimate the effects of selected physiological and psychological variables on Army aviation and armor combat vehicle crews during representative combat missions. These missions were considered separately for two levels of individual protective equipment. The ESTIMATE-TALK-ESTIMATE method with an impartial group facilitator was used to control the process. The results from the panel demonstrated the effectiveness of this face-to-face, consensus-based method for reducing the variance of their combined estimates. The overall mean percentage reduction of the coefficient of variation was 39.8 ± 0.8 percent. The panel compiled an exhaustive list of parameters required for collection during military field tests to facilitate integration and comparison in future databases. The panel also developed a list of specifications of an accurate predictive model of the physiological and psychological limitations on U.S. Army combat vehicle crew endurance.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Chief, Scientific Information Center	22b. TELEPHONE (Include Area Code) (205) 255-6907 22c. OFFICE SYMBOL SGRD-UAX-SI

DD Form 1473, JUN 86 — Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

Table of contents

List of tables

Preface

During 11-15 January 1988, a panel of U.S. Army scientists and soldiers assembled in Atlanta, Georgia, to explore an interactive face-to-face communication process for estimating the effects of several selected physiological and psychological stressors on U.S. Army combat vehicle crew endurance. Army aviation and armor missions were chosen so that results could be compared to prior field tests. The members of this expert panel were recruited from several major U.S. Army commands and represented both scientific and operational experience. The facilitators of the meeting were provided through a Short Term Analysis Service (STAS) program contract by the U.S. Army Research Office, Research Triangle Park, North Carolina.

The panel planned to address a large number of parameters over a wide range of environments and missions at this week-long meeting, and each parameter had several different states. The number of possible cases to consider showed clear optimism; the actual number of missions and variables addressed, however, was more limited. The experts on sleep, leadership, and morale (from Walter Reed Army Institute of Research) were required to return to their home station on the third day of the meeting. Their inputs for limiting variables and scientific research issues (see below) were solicited prior to their departure, but these variables were not adequately covered for portions of the deliberations.

Acknowledgment

The following persons participated in the expert panel meetings. Their assistance and perseverance is gratefully acknowledged. Without their help, the technique demonstrated here could not have been employed. The cooperation of their institutions in allowing their attendance during the week-long study also is acknowledged.

Michael N. Sawka
Andrew J. Young
U.S. Army Research Institute of Environmental Medicine

Daniel P. Redmond
Paul T. Bartone
Walter Reed Army Institute of Research

Donald B. Headley
U.S. Army Research Institute for the
Behavioral and Social Sciences

Charles H. Wick
U.S. Army Ballistics Research Laboratory

Robert R. Pence
James P. Verney
David L. Carter
U.S. Army Chemical School

The panel would like to thank Drs. Liz Freeman, Roland Coates, and David Gustafson for their professionalism in facilitation of the group. In addition, we would like to thank Ms. Kathy Daigle of Battelle Institute and Dr. Kent Kimball of the U.S. Army Aeromedical Research Laboratory for handling the contract details. The excellence of the facilitators and the support of the contract program were critical to the success of this effort.

==

This page intentionally left blank.

==

Introduction

General

Predictive models of combat endurance for Army combat vehicle crews are needed. Although several models predict selected physiological or psychological aspects of military performance, attempts generally have not integrated these two distinct databases. The use of an integrated approach merges physiological and psychological limits of endurance. This concept logically expects to use a sigmoid curve to describe the relationship between endurance and measures of the physical environment (Mitchell, 1986). Additional data beyond those initially assembled by Mitchell are required to develop the concept into a working model which can be validated and refined.

This report documents the effect of a facilitated group process on reducing the variance associated with expert panel estimation of combat vehicle crew endurance. The arithmetic means (with associated standard errors) of these subjective estimates by experts will be combined with published empirical test results to provide the primary source of data during the initial development of the integrated model mentioned above. Justification for the subjective data source requires examination since estimates by purported experts commonly are known to vary widely. Subsections below address issues concerning why current empirical data alone are inadequate and review the literature demonstrating the utility of subjective estimations and associated methods to reduce their variance.

This report also includes two additional products from the panel's efforts. Using brainstorming techniques illustrated below, its members constructed an exhaustive list of parameters suggested for recording in future field studies. Recording of these data will be necessary for all future studies if an empirical database is to be accumulated which will be sufficient by itself for accurate modeling of combat vehicle crew endurance. To supplement this field study data, additional controlled studies in the research laboratory setting will be required to elucidate underlying mechanisms and provide guidance for future field tests of combat endurance. To provide potential guidance for this effort, the panel assembled a comprehensive list of questions to be addressed by military research laboratories.

Empirical data for modeling endurance

Databases used for modeling often suffer from several weaknesses that limit their applicability to developing endurance indices for combat systems:

(1) Data collected on specific populations of interest (i.e., combat arms crews) are insufficient. Physiological and psychological databases have not always been collected on similar populations.

(2) Many field studies (e.g., Mitchell, Knox, and Wehrly, 1987; Knox et al., 1987; Knox et al., 1989) used different scenarios under broad but selected ranges of environmental conditions to measure a restricted set of parameters. While some measures may have desirable validity, they may not be consistent with the goal of developing an endurance estimation model that will be mission oriented and environmentally sensitive. Hence, it is likely existing databases will have dependent and/or independent measures different from the ones to be used in an integrated model; and, although the data may be helpful, they may not be directly applicable to this model.

(3) If an endurance prediction model is to be developed, the underlying databases must be described in a format appropriate to such a model. A model based on data from a study which allows only one independent variable to vary at a time often is scientifically desirable. However, this approach does not reflect the real world of multiple causation unless enough cases are analyzed to allow inferences on interactions of variables. For example, the critical component of a Bayesian model with interactive variables is the likelihood estimate; i.e., the probability that a predicted endurance will be observed with a crew who are in a particular state and on a specific mission. Existing databases rarely can provide sufficient likelihood estimates in the permutations required to construct a general model with several interactive variables.

(4) Even if the measurement problems described above were resolved, we are likely to find different definitions for the same variable names among different databases.

It will be necessary to synthesize, reduce, and adapt data to the specific need and the specific population. Experience shows one way to collect useful information from several databases is to convene expert panels to derive a description of the assumptions, population(s), and data collection strategies to be used. The panelists review this information in light of their own area of expertise and then provide estimates in a structured format. This process for obtaining judgments is based on extensive research on group estimation and prediction of events as summarized in the next subsection.

It should be emphasized the panelists in this study were, for the most part, scientific matter experts. Many of them had no direct knowledge or experience with the activities the group was trying to predict.

Group estimation as a technique

Several authors have reviewed the literature on subjective estimation of the probability a real world result will be a predicted value (Slovic and Lichtenstein, 1971; Hogarth, 1980; Fischhoff, 1982; Von Winterfeldt and Edwards, 1986). The essence of these reviews is that "people can estimate probabilities quite well" (Lichtenstein and Fischhoff, 1977; Lusted et al., 1980). However, systematic biases, seem to be present that make the typical person overconfident, i.e., individual estimators may believe they know more than they actually do (Lichtenstein, Fischhoff, and Phillips, 1977).

Three increasingly effective methods for improving subjective estimates are recognized. The first is to select estimators who have a thorough and detailed knowledge of the subject matter; that is, to use experts. Several studies show the more people know about the subject, the better and more realistic estimates they are likely to make (e.g., Pitz, 1974). This is why future panels should be comprised of experienced subject matter experts, if available, and panels should include several military scenario experts.

The second way to improve subjective estimation is through training of the estimators in group estimation techniques. Lichtenstein and Fischhoff (1977) examined the effect of training on accuracy of estimates. The training consisted of obtaining subjective estimates on 200 items and, afterwards, counseling estimators on their performance in general (not specific) terms. Using a calibration score as their measure of effectiveness, the researchers found 40 percent of their estimators were "perfectly calibrated" with no training at all and that training made no difference to the performance of those subjects. They also found after one training session, the number of "perfectly calibrated" estimators increased to 84 percent. Highly qualified experts on a subject can almost always be easily trained to be good estimators.

The third way to improve subjective estimates is through group estimation. Gustafson et al., (1973) compared the accuracy of 288 untrained estimators using one individual process and three group processes for estimation of independently determined values for a group of parameters.

The three group processes were:

a) TALK-ESTIMATE, approximating an interacting group in which the experts meet and discuss an issue, and then individually make prediction estimate about a future application of major variables concerning the issue;

b) ESTIMATE-FEEDBACK-ESTIMATE, an approximation of a Delphi process with no face-to-face contact; and

c) ESTIMATE-TALK-ESTIMATE, a variant of the nominal group process (Delbecq, Van de Ven, and Gustafson, 1975).

The ESTIMATE-TALK-ESTIMATE process proved consistently superior to the individual and other group processes (30 percent less error than TALK-ESTIMATE, 33 percent less error than individual estimates, and 40 percent less error than ESTIMATE-FEEDBACK-ESTIMATE). For the ESTIMATE-TALK-ESTIMATE process, the average difference between actual and estimated values was 6 percent for the system they studied.

Methods and materials

Panel composition

The expert U.S. Army panel was composed of 11 estimators who have recognized knowledge of the effects of one or more physiological or psychological variables affecting human performance. They were selected to provide a combination of theoretical and applied backgrounds. U.S. Army aviation and armor subject matter experts (one in each area) were present to provide information and guidance on military doctrinal details. The authors of this report were two of the panelists.

The group's facilitators were selected for their skills in group process and group estimation of operational tasks. This technique is used predominantly in industrial and academic settings. By design, the facilitators' knowledge of military subject material was lacking so that their personal experiences would not influence the process taking place among the actual experts in the group.

Additional input during the panel's deliberations was provided by a mathematical model to predict physiological limitation of crew endurance based on a heat stress model (Pandolf et al., 1986). It is implemented in a hand-held calculator developed at the U.S. Army Research Institute of Environmental Medicine. This model predicts soldier tolerance to exercise heat stress conditions, body temperature responses, and water requirements over a wide range of work rates and environmental conditions while the soldiers wear a variety of clothing ensembles. Another critical factor which was subjectively integrated into the heat stress calculator output was the effect of dehydration on human work performance. The precision of estimates of body temperatures and water losses were limited by lack of detailed information concerning metabolic rates of soldiers performing these missions, since this variable is required by the program. Metabolic rates estimated by the panel were used during the meeting.

Training in group process

Nearly a full day was spent creating group cohesion and practicing rules for the group process to be used during the estimation and discussion process. The rules used for interactive discourse (brainstorming ideas and obtaining consensus) are shown in Table 1. These rules were strictly adhered to during the meeting. As an important initial step, a warmup exercise in using the process, the group developed a complete set of general assumptions for the estimates to be made during the meeting (Appendix A). This is part of the general preparation of any estimation group prior to addressing its assigned tasks.

Table 1.
Rules for group process

Brainstorming

- -One person speaks at a time in turn
- -One idea per person per turn
- -OK to pass on your turn
- -No judgement during generation of ideas
- -No discussion during generation of ideas
- -All ideas will be written down by the facilitator
- -Idea generation completed only when everyone passes
- -Facilitator can call short break in process if members seem temporarily blocked for ideas

Clarification process

After brainstorming, there may be some items that need further explanation so that all group members can understand what was meant. The facilitator-leader goes down the brainstormed list one item at a time and asks the person who gave that item to say a little more about it. The person should be <u>very brief</u> unless asked a question by another group member.

Group members should ask clarifying questions if there is an item they don't understand. They can ask such questions as:

"What do you mean by....?"
"Say something more about...."
"Could you be more specific about....?"
"Do you mean....?"

Consensus

- -Get a quick check on where everyone stands
- -One group member speaks at a time in turn
- -Present your opinions (pro and con) on the item to be addressed and explain your opinions if asked when it's your turn
- -Listen to opinions of others when it's their turn
- -It's OK to ask for clarification when it's their turn but save your rebuttal for your own turn
- -Be willing to modify your position
- -Complete one cycle
- -Check for consensus and repeat process if necessary
- -No voting; the format asks for consensus; i.e., can everyone agree or can everyone live with the present choice?

Independent variables and fixed parameters

Dry bulb temperatures of 70 to 100° F (in 10° increments) with a relative humidity of 40 percent were chosen as the fixed values of the independent variable, because physiological and psychological limitations have been reported in these environments experimentally and operationally (Knox et al., 1987; Wing, 1965). The independent parameters considered, for several distinct values or ranges, were: Individual protective equipment (IPE), or chemical protective clothing, at various mission-oriented protective posture (MOPP) levels; amount of sleep permitted prior to mission start; and availability of drinking water. Further information concerning the parameters in this study are in the glossary.

Large military units have not been studied under sufficiently controlled conditions to allow valid endurance estimates or to provide a method for integration of individual and small unit data into larger operational unit outcomes. Thus, the size of the military units considered in this study was restricted to a combat vehicle crew. This small unit size allowed extrapolation of individual data from previous compatible field and laboratory studies.

Dependent variables

Combat vehicle crew endurance was defined by the panel. The group required a full understanding of the details of the missions to define a functional endpoint satisfactorily. The limit of endurance was determined to be identical with the onset of combat ineffectiveness. The criteria for combat ineffectiveness were somewhat different for each mission considered. The focus of this report is on the estimation process rather than on the actual estimates, so the details of mission-specific failure criteria are omitted here. A brief summary of relevant definitions appears in the glossary.

The ESTIMATE-TALK-ESTIMATE method

The ESTIMATE-TALK-ESTIMATE group process method for eliciting subjective judgments was emphasized during the panel sessions. In this process, panelists began by individually making estimates of a specific mission endurance under one set of environmental conditions.

See glossary for definitions of terms and abbreviations.

These estimates were shared by writing them on a large tablet at the front of the room, and the reasons for differences discussed. The experts then re-estimated (individually), and the second-round individual estimates were shared. If significant variance still existed, further rounds of talk and estimation were used to obtain further consensus. Lack of significant revision of individual estimates during a round indicated the end of the process. The final estimates then provided the best mean and variance possible from the assembled group without forcing an artificial consensus.

Results

Changes in variances are influenced by concomitant changes in the means so the percentage reductions in variance do not reflect accurately the change in variability of the estimates. When the means of the group's estimates became smaller (either from the influence of moderate members or from consideration of increasingly severe conditions), the variances were likely to decrease mathematically also. The artificially amplified decrease in the variance can be misleading when comparing reductions in the variance from different means. The coefficient of variation (CV) corrects this problem by normalizing the results to the individual means (Cochran, 1977). Thus the percent change in the coefficient of variation of each estimate for the missions and parameters addressed is presented in Tables 2 and 3 to allow more straightforward assessment of the effect of the process on estimates' variability.

Detailed tables of individual estimates are included in Appendix B. The tables include descriptive statistical analyses of the data for the first and last estimates made during the ESTIMATE-TALK-ESTIMATE cycles. The mean number of hours (with associated variance) that the vehicle crews were estimated to effectively perform the combat mission is displayed for both rounds of estimates, as are the minimum and maximum estimates, the variances, and the coefficients of variation. These results must be interpreted as unvalidated estimates.

During the discussions, the panelists agreed to use their experience with the estimation process to compile an exhaustive list of variables which affect crew endurance in combat. This list is included as Table 4. Repetition of some variables in more than one category was allowed to emphasize the overlap of those variables among traditional analysis categories. The outcome often is an incomplete consideration of the variable in any single study. When these variables are completely specified, they allow estimation of combat vehicle crew endurance and could form a database to be used for reporting the results of future studies in this area. The variable list also was used as a basis for generating a list of the significant research issues (Table 5) which must be addressed to satisfactorily construct a complete predictive model for combat endurance.

A number of research and test organizations studied subsets of the physiological and psychological variables that affect combat endurance of vehicle crews; however, many issues remain to be investigated. Determining details of the interactions of variables were beyond the scope of prior investigations. Moreover, scenarios are not sufficiently detailed to allow reliable comparison or consolidation of results. Table 5 lists the questions determined by the panel to be the most important for subsequent investigation in field and/or laboratory studies.

Discussion

Mean reduction of the coefficients of variation between the first and last estimates was 39.8 ± 0.8 (SE) percent (49.0 percent for aviation; 35.4 percent for armor). The final coefficients of variation were in a range which may be useful in predictive models. Final aviation estimates had significantly less variability than those for armor. A few scenarios had higher variances, perhaps due to the long endurance times predicted with relatively nonrestrictive clothing and low average activity levels during these scenarios. Until validation of these predictions, however, we do not know how much of the variance is accounted for by this model.

Actual mean predicted endurance times presented for any scenarios should not be interpreted as the best possible estimates. The means clustered around the estimate of the most experienced member of the panel in the particular area being discussed (e.g., water consumption or sleep obtained). This convergence on a particular value was apparent especially when there was only one expert present for the parameter being considered. The actual means obtained by the panel will not be discussed in this report since the focus of this effort was on the estimation process itself.

A major factor which may account for much of the large variance of first estimates was a lack of full and common understanding of the mission scenarios. Panelists focussed initially on those aspects of the scenario which related to their own areas of expertise and made assumptions about the remainder of the mission. The TALK which followed the first ESTIMATE revealed the incompleteness of the mission scenario descriptions originally presented. The full discussion of each mission scenario established a pattern of required information that the panelists recognized as essential limiting parameters for all mission-oriented combat scenarios for which endurance is to be estimated.

The generation of an exhaustive list of limiting variables then became a high priority. This list represents a comprehensive summary of the data which should be recorded during a field or laboratory study to best compare and contrast results among different studies. Most of the parameters simply require measurement (and control) during an experiment or exercise, but some require measurement and further development of coded scales and precise definitions. An informal discussion of published studies revealed that many essential data items were known by the participants or the investigators, but simply were not recorded and/or published. These data become increasingly difficult to find or accurately reconstruct. This list should be used to construct standardized techniques and units of measurement as well as data collection forms for future studies. Computerized databases also should be constructed using these data items to assemble and analyze the results of these studies. This will effectively standardize relevant portions of research protocols.

Gaps in the data needed to estimate physiological and psychological factors limiting endurance were identified during the panel's deliberations. Some of the data required can be obtained in controlled laboratory settings, although many field-obtainable results are needed as well. The panel's list of unresolved research questions is a compilation of those issues in the area of combat endurance modeling that require further study on a priority basis.

The mean endurance times for various missions produced by this panel were based on variation of a single parameter at a time over several discrete environmental conditions. The remaining limiting variables were assumed to be fixed. Of course, this is a very artificial situation. In the real combat scenario to be modelled, several variables will be changing at the same time. Consideration of this covariance was not within the scope of this panel's tasks.

The mathematical form of the final predictive model to be constructed may be Bayesian (multiplicative) rather than multiattribute (additive), so the parallel pursuit of a Bayes' Theorem approach is desirable. This will require only a minor modification of this estimation technique: multiple randomly generated scenarios allowing variation of all the parameters of interest are used for repetitively estimating endurance. The relative impact of summed interactions rather than each variable independently then is considered. Mathematical regression formulas developed from these data directly may predict endurance from the combination of specified conditions. Pursuit of both types of models can provide most efficiently prospective models of the real world to be validated by field studies and experience.

Conclusions

An expert panel, using the ESTIMATE-TALK-ESTIMATE group process method, demonstrated a mean reduction of 39.8 percent in the coefficients of variation of their original estimates of combat vehicle crew mission endurance. These missions required rigorous specification to arrive at meaningful estimates, and the panel members used group process techniques to compile a comprehensive list of variables which must be known to compare and contrast data from field and laboratory tests studying elements of these missions. In addition, the group documented a list of research issues that must be addressed to arrive at a model for these missions which has usable precision. The group process used demonstrated its effectiveness for reducing the variance of expert panel estimates. This technique should be considered for future similar situations when consensus and best estimates are needed.

Table 2.
Percent reduction of coefficient of variation (CV)
of aviation-related estimates for each parameter considered

Aviation scenario	Parameter value	Temperature (DB °F)	Reduction of CV (%)
Screening force	MOPP level 2	70	95.0
		80	87.8
		90	78.7
		100	-5.7
	MOPP level 4	70	83.8
		80	89.4
		90	93.6
JAAT commander	MOPP level 2	80	60.9
		90	42.1
	MOPP level 4	70	8.4
		90	54.6
		100	-51.5

See glossary for definitions of terms and abbreviations.

Table 3.
Percent reduction of coefficient of variation (CV)
of armor-related estimates for each parameter considered

Armor scenario	Parameter value	Temperature (DB °F)	Reduction of CV (%)
Silent watch	MOPP level 2	70	32.7
		80	30.6
		90	32.1
		100	36.3
	MOPP level 4	70	10.8
		80	17.9
		90	28.3
		100	57.0
Passage of lines	MOPP level 2	70	81.4
		80	79.6
		90	76.3
		100	72.9
	MOPP level 4	70	25.7
		80	14.5
		90	14.5
		100	30.2
	Sleep 0-2 hrs	70	32.9
		100	8.4
	Sleep 2-4 hrs	70	39.7
		100	1.7
	Sleep 4-6 hrs	70	54.3
		100	24.4
	Sleep 6-8 hrs	70	51.3
		100	15.8
	Water >1 qt/hr	70	38.3
		80	37.3
		90	22.3
		100	28.8
	Water 1 qt/6 hrs	80	25.9
		90	27.3
		100	42.1
	Water 1 qt/12 hrs	70	19.0
		80	38.1
		90	54.0
		100	72.2

See glossary for definitions of terms and abbreviations.

Table 4.
Limiting variables for predictive models of vehicle crew endurance in combat

Biomedical/physiological
- Sleep during the 72 hours prior to mission
- Sleep during mission (including catnaps)
- Fluid intake
- Crew health
- Physical fitness of crew
- Acclimatization
- Use of medications including chemical warfare pretreatment
- Time spent in prior combat
- Nutritional state
- Auditory acuity

Mission
- Intensity and frequency of skirmishes
- Protective clothing
- Metabolic rate and type of work
- Formal work/rest plan
- Expectation of relief
- Availability of combat support, combat service support, and field artillery support
- Crew understanding of tactical mission
- Timeline of physical and mental tasks
- Night operations
- Familiarity with terrain

Environment
- Weather (temperature, humidity, radiant load)
- Protective clothing
- Visibility (man-made and environmental)
- Presence or absence of chemical agents
- Night operations
- Vehicle microenvironment for each crewmember
- Terrain

Leadership
- Leadership skills of crewmembers
- Leaders' abilities
- Level of responsibility of each crewmember
- Rotation of jobs among crew
- Use of communication skills among crew
- Crew understanding of tactical mission
- Uncertainty factor (know where and who friends and enemies are)
- Tank commander's position in total unit
- Maintenance status of vehicle

Table 4. (Continued)

Training
-Individual skills of crew
-Physical fitness of crew
-Acclimatization status
-Prior experience in protective clothing
-Confidence in equipment
-Rotation of jobs among crew
-Use of communication skills among crew
-Amount of time crew has worked together
-Familiarity with terrain
-Previous combat experience
-Maintenance status of vehicle
-Crewmembers' confidence in each other
Threat
-Intensity and frequency of skirmishes
-Protective clothing
-Availability of combat support, combat service support, and field artillery support
-Visibility (man-made and environmental)
-Enemy psychological operations
-Perceived fighting capability of enemy
-Presence or absence of chemical agents
-Uncertainty factor/fear
Morale
-Availability of combat support, combat service support, and field artillery support
-Unit and individual morale levels
-Visibility (man-made and environmental)
-Formal work/rest plan
-Expectation of relief
-Confidence in equipment
-Enemy psychological operations
-Perceived fighting capability of enemy
-Crew understanding of tactical mission
-Mental stress (status of dependents)
-Uncertainty factor/fear
-Familiarity with terrain
-Time in prior combat
-Previous combat experience
-Maintenance status of vehicle
-Crewmembers' confidence in each other

Table 5.
Unresolved research issues
in combat vehicle crew endurance modeling

Biomedical/physiological
- What changes in combat effectiveness occur from medications commonly available to soldiers in combat (antidiarrheal, antitussive, analgesics)?
- What are the effects of sleep loss on psychomotor, cognitive, and coordination tasks and thermoregulation?
- What are the effects of sustained operations on combat effectiveness?
- What are the effects of protective clothing on cognitive, psychomotor, visual, and auditory performance?
- What is the effect of mild thermal strain on cognition?

Mission
- What is the minimum acceptable crew performance standard for each study scenario from Army standards and National Training Center data?
- What are detailed metabolic rates of crewmembers during study scenarios?
- What type of physical work is involved in each study scenario's individual tasks (muscle groups/static or dynamic)?
- What is the task and timeline analysis and drinking water availability for each study scenario?
- What is the effect of night vision equipment on psychomotor performance and cognitive performance?
- What is the psychological effect of night operations on combat effectiveness?
- What is the importance of combat experience to combat effectiveness?

Environment
- What is the microenvironment of each study vehicle for the appropriate range of external environmental and operational factors (e.g., hatches or doors open/closed, weapons firing, engine running)?

Leadership
- What are the quantifiable measures of leadership?
- What is the influence of midrange leadership skills on combat effectiveness?

Table 5. (Continued)

Training
- What is the relationship between physical fitness, cognitive and psychomotor skills?
- What is the minimum training in chemical protective clothing and equipment (especially MOPP 4) for adaptation (habituation)?
- What is minimum training for carrying out individual and collective tasks in all levels of MOPP?
- What is minimum sustainment training in all levels of MOPP to maintain skills?
- What are degradation factors for all levels of MOPP for individual and collective skills including extended operations?

Threat
- What is the measure of psychological preparation for combat stress?
- How valuable are psychological coping skills for increasing soldiers' combat effectiveness?
- What are the degradation factors for actual combat and continuous operations?
- How does perceived force ratio influence combat effectiveness?
- How does the perceived enemy lethality influence combat effectiveness?
- What is the experience of programs using chemical threat stimulant(s) to induce fear?
- How does the first skirmish experience influence subsequent combat effectiveness?

Morale
- What are quantifiable measures of unit and individual morale?
- What is the influence of midrange morale levels on combat effectiveness?

Global
- What are the qualitative and quantitative interactions among the relevant limiting variables in terms of their influence on combat effectiveness?
- What are the synergistic effects of these variables when considered in combination?

Glossary

coefficient of variation (CV) - A normalized measure of variability obtained by dividing the standard deviation (see variance below) by the mean. This measure allows more comparison of variance data from different sets of estimates since the mean and variance often tend to change together; that is, as the mean becomes smaller, the variance also becomes smaller. It is dimensionless.

dry bulb temperature (DB) - This is the ambient air temperature indicated by a common thermometer, usually expressed in degrees Fahrenheit (°F) by United States troops.

endurance - It is essential to know when, after the start of the continuous mission, the vehicle crew becomes combat ineffective. For armor vehicles, this is the loss of two of the four crewmembers since job cross-training has been assumed. For helicopters, this is the point at which the crewmember(s) no longer can control the aircraft, navigate, or acquire and shoot targets. For these estimates, no combat materiel or personnel losses and no maintenance or resupply problems were assumed to exist.

individual protective equipment (IPE) - The clothing and personal equipment worn and carried by soldiers to protect them against chemical, biological, and radiation hazards and contaminants on the battlefield.

joint air attack team (JAAT) - The JAAT is composed of U.S. Air Force close air support aircraft, U.S. Army attack and scout helicopters, acting as a combined arms team. The commander of such a team commonly is in the scout helicopter and coordinates fire support, air defense artillery, and ground maneuver forces against enemy armored formations, command vehicles, and enemy air defense weapon systems.

maximum (MAX) - The largest estimate obtained.

mean - The value obtained by adding the estimates of the group and dividing this sum by the number of persons providing estimates. It is commonly known as the "average" and has dimensions of hours for these estimates.

minimum (MIN) - The smallest estimate obtained.

mission oriented protective posture (MOPP) - The state of military readiness to protect or defend in a chemically, biologically, or radiologically contaminated battlefield. Here, used in conjunction with the individual protective equipment (IPE) levels of use by United States troops. In this study, two levels of MOPP were in use:

Level 2 - Outer garments, not closed, and boots are worn.

Level 4 - Closed outer garments, boots, gloves, hood, and mask are worn. This is maximal chemical protection.

passage of lines - Passage of one unit through the positions of another, as when elements of a covering force withdraw through the forward edge of the main battle area, or when an exploiting force moves through the elements of the force that conducted the initial attack. A passage may be either forward or rearward. In this scenario, a rearward passage with delays in alternate positions was assumed to provide a continuous operations setting.

relative humidity (RH) - The percent saturation of the ambient air. It is related closely to the difference between the dew point temperature and the ambient dry bulb temperature.

screening force - A screening force maintains surveillance, provides early warning to the main body, impedes and harasses the enemy with supporting indirect fire, and within its capability destroys enemy reconnaissance elements.

silent watch - The establishment and maintenance of a concealed position and high level of alertness in order to detect and observe enemy positions or movements and to await the approach of an unsuspecting enemy column into a prepared zone of fire.

sleep - It was defined as the number of hours of sleep obtained by each crewmember during the 24 hours prior to the mission start. Arbitrarily, they each had the same amount of sleep. The highest sleep category is essentially normal sleep for each crewmember while the least is none to only an hour or so. In these scenarios, no additional sleep was assumed to be possible.

variance (VAR; s^2) - A measure of the variability of the estimates. It is obtained by dividing the sum of the differences between each estimate and the mean of the estimates by the number of estimates minus 1. The larger the deviations of the estimates from the mean, the larger the variance will be. The square root of the variance is the standard deviation of the estimate. Variance has dimensions of $hours^2$ for these estimates.

water - It was defined as the amount of portable drinking water available to each crewmember daily and was assumed to be replenished every 24 hours. The most water available was essentially unlimited, while at worst there was only 2 quarts available each day per crewmember.

Bibliography

Cochran, W. G. 1977. Sampling techniques. New York: Wiley.

Delbecq, A., Van de Ven, A., and Gustafson, D. H. 1975. Group techniques for program planning. Glenview, IL: Scott Foresman.

Fischhoff, B. 1982. Debiasing. In: D. Kahneman, P. Slovic, and A. Tversky (eds.), Judgments under certainty: Heuristics and biases. (pp 422-444). London: Cambridge University Press.

Gustafson, D. H., Shukla, R. U., Delbecq, A., and Walster, G. W. 1973. A comparative study of differences in subjective likelihood estimates made by individuals, interacting groups, delphi groups, and nominal Groups. Organizational behavior and human performance. 9:280-291.

Headley, D. B., Brecht-Clark, J. M., Feng, T. D., and Whittenburg, J. A. 1988. The effects of the chemical defense ensemble and extended operations on performance and endurance of combat vehicle crews. Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences Technical Report Number 811.

Headley, D. B., Brecht-Clark, J. M., and Whittenburg, J. A. 1989. Sustained operations of artillery crews in NBC and non-NBC environments. Military medicine. 154:511-515.

Hogarth, R. 1980. Judgment and choice: The psychology of decisions. Chichester, England: Wiley.

Knox, F. S., Simmons, R. R., Christiansen, R., and Siering, G. 1987. Results of physiological monitoring from the 1985 P2NBC2 test at Fort Knox, Kentucky. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory Report Number 87-6.

Knox, F. S., Mitchell, G. W., Edwards, R. R., and Sanders, M. G. 1989. Results of physiological monitoring from the 1985 P2NBC2 tests at Fort Sill, Oklahoma. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory Report Number 89-14.

Lichtenstein, S., and Fischhoff, B. 1977. Do those who know more also know more about how much they know? The calibration of human judgments. Organizational behavior and human performance. 20(2):159-183.

Lichtenstein, S., Fischhoff, B., and Phillips, L. D. 1977. Calibration of probabilities: The state of the art. In: Jungerman, H. and De Zeeuw, G. (eds.), Decision making and change in human affairs, (pp 275-324). Dordrecht, Holland: Reidel.

Lusted, L. B., Roberts, H. V., Edwards, W., Wallace, P. L., Lahiff, M., Loop, J. W., Bell, R. S., Thornbury, J. R., Seale D. L., Steele, J. P., and Fryback, D. G. 1980. Efficacy of diagnostic X-ray procedures. Chicago: American College of Radiology.

Mitchell, G. W. 1986. Integrated concept for physiology, psychology and performance. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory Letter Report Number 86-3-3-2.

Mitchell, G. W., Knox III, F. S., and Wehrly, D. J. 1987. Results of physiological monitoring from the 1985 P2NBC2 tests at Fort Benning, Georgia. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory Report Number 87-5.

Pandolf, K. B., Stroschein, L. A., Drolet, L. L., Gonzalez, R. R., and Sawka, M. N. 1986. Prediction modeling of physiological responses and human performance in heat. Computers in biology and medicine. 16:319-329.

Pitz, G. F. 1974. Subjective probability estimates for imperfectly known quantities. In: Gregg, L.W. (ed.), Knowledge and cognition. New York: Wiley.

Slovic, P., and Lichtenstein, S. 1971. Comparison of Bayesian and regression approaches to the study of information processing in judgment. Organizational behavior and human performance. 6:649-744.

Von Winterfeldt, D., and Edwards, W. 1986. Decision analysis and behavioral research. London: Cambridge University Press.

Wing, J. F. 1965. Upper thermal tolerance limits for unimpaired mental performance. Aerospace medicine. 36:960-964.

Appendix A

General Assumptions

-There are readers, including field commanders, who will understand and use the output of this project.

-The primary purpose of this project is to provide estimates for training purposes.

-Useful conclusions can be made from information available to the experts even though there are gaps in the database.

-The focus of the estimates is on task taxonomies rather than on ability taxonomies.

-Data from laboratory studies can be applied to field scenarios.

-This panel will deal with moderate levels of strain only; not severe levels.

-There are unit and individual differences in response to both the variables and the environment.

-Bounds can be estimated effectively for the effects of the variables and the environment.

-Each scenario addressed must have an 'expert' on content present at sessions dealing with that scenario.

-The type of conflict is high intensity battle in the European theater with no relief available and continuous enemy action.

-Scenarios have definable end points; limits of combat endurance.

-Common effects of variables and environment on multiple systems can be identified.

-Ambiguity in estimates is inherent and can be tolerated.

-The size of the error in estimation can be estimated.

-The scenarios for this panel are useful militarily.

-Individual, mission, and environmental factors will be included in all estimates.

-Although there are interactive terms among variables, they can be separated for the purpose of this project and the individual stress-strain relationships can be understood.

-There are effects of the environment on the variables of interest.

-Leadership has an effect on all other variables.

-'Morale' and 'leadership' can be understood in quantifiable terms.

-Any 'weak links' in the combat systems can be identified.

-Effectiveness equates to Army Readiness Training and Evaluation Program type scores and is an end point measure.

-Effectiveness can be lost for either physiological or psychological reasons, but operationally the mechanism does not matter for time estimates.

-Clothing of crewmembers is constant.

-Consensus of the panel implies either 100 percent agreement that the answer is best or 100 percent agreement to support the current answer.

-Field and laboratory validation will be necessary for all quantitative estimates prior to final acceptance.

-Because of risks, there will not be peacetime field tests at the limits of strain.

-The goals of the research and testing communities can be matched.

-The output of this project is not the 'final answer' and the process needs to be validated.

Appendix B

Endurance estimates from expert panel
using ESTIMATE-TALK-ESTIMATE process

Estimates of vehicle crew endurance by limiting variable
for a range of dry bulb temperatures
with relative humidity (40 percent)

Assumptions:
Once begun, each mission is performed continuously
No maintenance or resupply problems exist
No reinforcements, replacements, or reserves exist

Combat scenarios used:
Aviation - JAAT commander - OH-58C scout helicopter
Screening force - AH-1S attack helicopter
Armor - All missions - M1A1 main battle tank

Estimates for which there was no second round
(i.e.; insufficient time for completion)
are indicated by dashes in appropriate columns

Table B-1.
Aviation - screening force (MOPP)

Variable	DB/RH		First estimates	Last (hours)
MOPP level 2	70°F/40%			
		MEAN	34.1	16.5
		VAR	1069	0.6
		MIN	16	16
		MAX	99	18
		CV	95.9	4.8
	80°F/40%			
		MEAN	31.8	15.7
		VAR	1096	4.0
		MIN	16	12
		MAX	99	18
		CV	104	12.7
	90°F/40%			
		MEAN	30.7	14.5
		VAR	1136	11.6
		MIN	14	8
		MAX	99	18
		CV	109	23.4
	100°F/40%			
		MEAN	12.4	12.0
		VAR	16.8	17.6
		MIN	6	6
		MAX	16	16
		CV	33.1	35
MOPP level 4	70°F/40%			
		MEAN	30.7	9.8
		VAR	1218	3.2
		MIN	8	8
		MAX	99	12
		CV	113	18.4
	80°F/40%			
		MEAN	25.0	7.8
		VAR	1325	1.4
		MIN	7	7
		MAX	99	10
		CV	146	15.4
	90°F/40%			
		MEAN	13.2	4.8
		VAR	2958	0.2
		MIN	5	4
		MAX	48	5
		CV	130	8.3
	100°F/40%			
		MEAN	3.2	---
		VAR	1.2	---
		MIN	2	---
		MAX	4	---
		CV	34.4	

See glossary for definitions of terms and abbreviations.

Table B-2.
Aviation - JAAT commander (MOPP)

Variable	DB/RH		First estimates	Last (hours)
MOPP level 2	70°F/40%			
		MEAN	17.5	---
		VAR	5.8	---
		MIN	16	---
		MAX	22	---
		CV	13.7	---
	80°F/40%			
		MEAN	16.8	15.8
		VAR	7.3	1.0
		MIN	14	14
		MAX	22	17
		CV	16.1	6.3
	90°F/40%			
		MEAN	15.3	14.3
		VAR	13.7	4.0
		MIN	12	12
		MAX	22	16
		CV	24.2	14.0
	100°F/40%			
		MEAN	13.0	---
		VAR	14.4	---
		MIN	8	---
		MAX	16	---
		CV	29.2	---
MOPP level 4	70°F/40%			
		MEAN	11.7	9.7
		VAR	15.2	12.2
		MIN	8	5
		MAX	18	14
		CV	33.3	36.1
	80°F/40%			
		MEAN	8.3	---
		STDEV	1.4	---
		MIN	7	---
		MAX	10	---
		CV	16.9	---
	90°F/40%			
		MEAN	5.8	5.3
		VAR	1.4	0.2
		MIN	5	5
		MAX	8	6
		CV	20.7	9.4
	100°F/40%			
		MEAN	3.8	4.0
		VAR	0.2	0.6
		MIN	3	3
		MAX	4	5
		CV	13.2	20.0

See glossary for definitions of terms and abbreviations.

Table B-5.
Armor - Passage of lines (water)

Variable	DB/RH		First estimates	Last (hours)
Water >1 per hr	70°F/40%			
		MEAN	29.8	32.0
		VAR	31.7	13.7
		MIN	24	27
		MAX	36	36
		CV	18.8	11.6
	80°F/40%			
		MEAN	28.9	31.5
		VAR	43.6	20.2
		MIN	20	24
		MAX	36	36
		CV	22.8	14.3
	90°F/40%			
		MEAN	25.3	27.5
		VAR	33.6	24.0
		MIN	20	20
		MAX	36	36
		CV	22.9	17.8
	100°F/40%			
		MEAN	21.8	21.5
		VAR	50.4	25.0
		MIN	12	14
		MAX	36	30
		CV	32.6	23.2
Water 1 per 2 hrs	70°F/40%			
		MEAN	30.3	---
		VAR	34.8	---
		MIN	20	---
		MAX	36	---
		CV	19.5	---
	80°F/40%			
		MEAN	30.3	---
		VAR	34.8	---
		MIN	20	---
		MAX	36	---
		CV	19.5	---
	90°F/40%			
		MEAN	22.4	---
		VAR	24.0	---
		MIN	14	---
		MAX	30	---
		CV	21.9	---
	100°F/40%			
		MEAN	17.3	---
		VAR	24.0	---
		MIN	10	---
		MAX	24	---
		CV	28.3	---

See glossary for definitions of terms and abbreviations.

Table B-5. (Continued)

Variable	DB/RH		First estimates	Last (hours)
Water 1 per 6 hrs	70°F/40%			
		MEAN	27.6	---
		VAR	51.8	---
		MIN	14	---
		MAX	36	---
		CV	26.1	---
	80°F/40%			
		MEAN	23.3	21.5
		VAR	53.3	25.0
		MIN	12	12
		MAX	36	26
		CV	31.3	23.2
	90°F/40%			
		MEAN	14.4	12.4
		VAR	34.8	13.7
		MIN	8	8
		MAX	24	18
		CV	41.0	29.8
	100°F/40%			
		MEAN	10.1	7.1
		VAR	29.2	4.8
		MIN	5	5
		MAX	18	12
		CV	53.5	31.0
Water 1 per 12 hrs	70°F/40%			
		MEAN	21.9	22.4
		VAR	57.8	39.7
		MIN	10	10
		MAX	30	30
		CV	34.7	28.1
	80°F/40%			
		MEAN	18.5	16.8
		VAR	53.3	16.8
		MIN	8	8
		MAX	30	22
		CV	39.4	24.4
	90°F/40%			
		MEAN	11.6	9.4
		VAR	44.9	6.3
		MIN	4	6
		MAX	24	12
		CV	57.8	26.6
	100°F/40%			
		MEAN	8.1	5.9
		VAR	30.2	1.2
		MIN	2	4
		MAX	18	8
		CV	67.9	18.6

See glossary for definitions of terms and abbreviations.

Table B-6.
Armor - Silent watch (MOPP)

Variable	DB/RH		First estimates	Last (hours)
MOPP level 2	70°F/40%			
		MEAN	59.3	52.5
		VAR	713	253
		MIN	30	30
		MAX	99	72
		CV	45.0	30.3
	80°F/40%			
		MEAN	58.5	51.8
		VAR	756	285
		MIN	30	30
		MAX	99	72
		CV	47.0	32.6
	90°F/40%			
		MEAN	49.4	44.3
		VAR	682	256
		MIN	22	24
		MAX	99	72
		CV	53.2	36.1
	100°F/40%			
		MEAN	39.9	38.3
		VAR	702	262
		MIN	14	22
		MAX	99	72
		CV	66.4	42.3
MOPP level 4	70°F/40%			
		MEAN	31.0	28.0
		VAR	68.9	44.9
		MIN	18	22
		MAX	40	40
		CV	26.8	23.9
	80°F/40%			
		MEAN	26.5	24.6
		VAR	46.2	27.0
		MIN	16	18
		MAX	35	35
		CV	25.7	21.1
	90°F/40%			
		MEAN	16.9	14.6
		VAR	50.4	19.4
		MIN	10	8
		MAX	30	20
		CV	42.0	30.1
	100°F/40%			
		MEAN	11.8	9.3
		VAR	38.4	4.4
		MIN	6	6
		MAX	24	12
		CV	52.5	22.6

See glossary for definitions of terms and abbreviations.