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THESIS

SIMPLIFIED RESILIENCY ANALYSIS OF
U.S. ARMY TOE UNITS

by

James R. Thomas

March 1988

Thesis Advisor: Thomas P. Moore

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The objective of this research is to develop and demonstrate the use of an alternative methodology for the Army force structure community to determine the resiliency of U.S. Army Table of Organization and Equipment (TOE) units. A survey was developed to gain an understanding of the TOE design environment, TOE procedures, and those design characteristics which have an impact on the resiliency of a unit. The survey was distributed by mail to various Army organizations involved with the TOE design process and 59 of 150 surveys were returned. The research led to the conclusion that a simplified resiliency methodology could be used to estimate a unit's resiliency. This methodology is demonstrated.

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Simplified Resiliency Analysis of U.S. Army TOE Units

by

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

The objective of this research is to develop and demonstrate the use of an alternative methodology for the Army force structure community to determine the resiliency of U.S. Army Table of Organization and Equipment (TOE) units. A survey was developed to gain an understanding of the TOE design environment, TOE procedures, and those design characteristics which have an impact on the resiliency of a unit. The survey was distributed by mail to various Army organizations involved with the TOE design process and 59 of 150 surveys were returned. The research led to the conclusion that a simplified resiliency methodology could be used to estimate a unit's resiliency. This methodology is demonstrated.

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I. INTRODUCTION

A. PROBLEM OVERVIEW

The success of the United States Army in a major conflict in the 1980's relies greatly on the premise that superior technology can overcome the Eastern Block's tremendous numerical advantages in both personnel and equipment. However, as the American political system moves toward a solution to the immense U.S. deficit, the defense budget is coming under increased fiscal scrutiny. This fact became quite evident in fiscal year 1988 when 35 billion dollars was cut from the defense budget.

The Defense Department's strategy to implement fiscal year 1988 budget reductions is to protect the pay of military personnel by delaying the procurement of major weapons systems. Presumably, the justification for these new weapon systems was the fact that the United States and its allies are vastly outnumbered. Purchase of these state-of-the-art weapon systems would provide our military the hardware to adequately meet the threat. If the budgetary strategy of delaying new weapon systems continues, our nation's ability to deter Soviet Pact aggression may be dangerously diminished.

Faced with the realities of the U.S. socio-economic dilemma of the 1980's, optimal resource allocation within the Defense Department is essential. While scientists must continue to pursue technological advances which will hopefully result in the development and timely funding of superior weapons systems, all branches of the military must constantly strive for self- improvement in every conceivable manner.

In addition to the strategic problems caused from the numerical advantages enjoyed by our adversaries, the nature of modern warfare mandates that changes be made in our conventional approach to military tactics. For example, in a conflict on the AirLand battlefield of Western Europe in the 1980's, contemporary weaponry will cause great chaos, thus requiring rapid change and movement of military units. These factors will greatly affect the classical approach of forward units engaging the enemy, and then returning to the rear area for periods during which logistical support units will provide for reconstitution in the form of "fresh" troops and new equipment. Current Army doctrine predicts that this battlefield will require units to operate 24 hours a day and to anticipate attacks from all directions. Additionally, the chaos of this battlefield will isolate many units by disrupting logistical operations and communications systems. [Ref. 1]

These realities have created the need for military units to recover quickly from combat losses. This ability is referred to as resiliency. Resiliency is defined by Golub as ". . . the ability of a unit to continue initial operations after having sustained varying levels of damage." [Ref. 2: p. 35] The concept of resiliency can be further delineated as inherent and circumstantial resiliency. Inherent resiliency refers to the resiliency which a unit possesses due to its organizational design. Circumstantial resiliency refers to the total resiliency which is possessed by a table of organization and equipment (TOE) design as a result of its circumstances, i.e., due to both the inherent resiliency of the design and the combat service support and personnel replacements which are available as a result of the doctrinal location of the unit [Ref. 3: pp. 7-9]. Unless otherwise stated the term resiliency in this thesis refers to inherent resliency.

The resiliency of combat units will be an extremely important factor in the next war. For example, [Ref. 4: p. II-1] points out that

> Given the likely replacement resource and time constraints in a short-warning Central European conflict, the reorganization of attrited units to form combat capable formations offers an obviously useful alternative approach to the large-scale replacement of assets.

Therefore, by designing inherently resilient Army units, the combat effectiveness of the U.S. Army during war may be significantly increased.

B. RESEARCH OBJECTIVES

The objectives of this research are to survey the Army TOE design community to determine the factors that influence the structural design of Army TOE combat units with a specific focus on how the concept of resiliency fits into the overall design process. Procedures used in the TOE design process will be described in terms of univariate statistics. Multivariate methods will be used to determine the relative importance of resiliency in the overall design process, and to quantitatively determine the relative weights of the characteristics which produce resilient Army units. After these weights are computed, an indexing procedure will be developed and validated. It is hoped that this procedure will assist TOE designers in measuring the resiliency of existing and proposed Army TOE units.

C. THESIS ORGANIZATION

Chapter I presents the purpose of the thesis, the basic themes it will emphasize, and the research methodology. Chapter II discusses the results of the literature investigation and reviews the methodologies used to perform resiliency analysis in the U. S. Army.

Chapter III documents the development of the resiliency survey and includes data analysis of the survey results. Chapter IV presents the methodologies used to derive several resiliency indices, describes an application of the indices to an actual Army TOE unit, and performs sensitivity analysis on the results. Chapter V summarizes the results of the research and describes areas for further research and study.

II. BACKGROUND.

A. LITERATURE INVESTIGATION

An extensive literature search was initiated to obtain the published literature regarding the resiliency of military organizations. Searches were conducted through both the Defense Logistics Studies Information Exchange (DLSIE) and Defense Technical Information Center (DTIC) data bases. Additionally, a thorough search was conducted at the Combat Developments and Experimentation Center (CDEC) library at Ford Ord, California. It became quite apparent in the early stages of the literature search that research involving resiliency concepts as related to military organizational structures is very limited. In fact, the term resiliency is not listed as a key word in any of the aforementioned data bases. The focus of the search was then directed to the related areas of combat effectiveness, unit cohesion, reorganization, combat casualties, combat stress, degradation of combat units, readiness, and reconstitution. A brief discussion of the salient literature relating to the concept of resiliency is contained in the following paragraphs.

It has been argued that the combat effectiveness of military units is a function of the casualty percentage experienced by the unit. In her book, *Casualties as a Measure of the Loss of Combat Effectiveness of an Infantry Battalion*, Dorothy K. Clark analyzed WW II combat data and concluded that the data did not support measuring the combat effectiveness of a unit by a casualty percentage. While the casualty percentage can provide information on the combat effectiveness of a unit, the degradation of a unit's leadership, fire support, and communications assets are all key factors in determining a military unit's ability to continue its mission. [Ref. 5]

A further refinement in the evaluation of the factors that cumulatively degrade a military unit's combat effectiveness over time can be found in *Criteria for Reconstitution of Forces*, by Elizabeth W. Etheridge and Michael R. Anderson. This study was accomplished to assist commanders of combat units to relate their specific combat effectiveness level to the requirement for reconstitution. The study hypothesized that combat effectiveness and the reconstitution decision are judgmental determinations made by the commander based on his perceptions and weightings of the many factors present on the modern battlefield. However, the research showed that the surveyed officers made the reconstitution decision almost exclusively on the status of personnel and equipment strength levels. [Ref. 6]

In both of the aforementioned studies of combat effectiveness, human factors issues surfaced as a significant variable to be considered when determining a unit's level of combat effectiveness. *A Study of Human Factors that Affect Combat Effectiveness on the Battlefield,* by Charles D. Marashian, attempted to determine to what degree various human factors affected combat effectiveness and the soldiers will to fight. The survey data collected from commanders in the Viet Nam war supported the premise that certain human factors were significantly related to combat effectiveness. The perception of the soldier's possibility of survival, competent leadership, and the soldier's belief that what he is doing is right were shown to be directly related to combat effectiveness. A surprising finding of the study was that the survey respondents did not consider combat experience or unit cohesion as key factors that influenced combat effectiveness. [Ref. 7]

By far the most complete document concerning the concept of reconstitution is *New Approaches to Reconstitution in High Intensity Conflict in the Modern Battlefield,* by the BDM Corporation. The study addresses the many facets of the complex problem of restoring combat effectiveness of degraded military units. There were two key observations made regarding combat effectiveness. The first is that combat effectiveness indicators are interactive.

> The combat effectiveness of two identical battalion task forces that suffered identical attrition may vary widely. One battalion task force may be combat effective due to exceptionally good leadership, high morale and esprit de corps. The second may be ineffective due to the lack of one or all of these same qualities.

The second major observation was that indicators can be identified and used to determine combat effectiveness, but the ultimate assessment of the unit's effectiveness regarding its ability to perform its prescribed mission is left to the unit commander. [Ref. 4: p. 63]

In summary, the literature investigation revealed that the study of those factors which allow an army unit to maintain its combat effectiveness over time (resiliency) has been very limited. Although the literature investigation did highlight various techniques used in attempting to quantify the importance of certain factors in the restoration and maintenance of a unit's combat effectiveness, no clear consensus emerged as to what makes effective or resilient combat units. Additionally, the focus of the literature is on the influence that certain factors have on the combat effectiveness of a specified unit under various scenario dependent conditions. The focus of this research, on the other hand, is to determine which properties present in a TOE design can be used to estimate its inherent resiliency. In light of these observations, this research is a venture into a relatively new area.

B. CURRENT RESILIENCY ANALYSIS METHODOLOGIES

There are two methodologies available to measure the resiliency of army units; Analysis of Military Organizational Effectiveness (AMORE) and Army Unit Resiliency Analysis (AURA).

1. AMORE

The AMORE algorithm divides the personnel and equipment assets into the smallest structures of the unit that will equally contribute to the accomplishment of the unit mission. These units are called mission essential teams. Transferability matrices for both equipment and personnel are developed which depict the combinations of feasible asset substitutions and the amount of time that these substitutions require under battlefield conditions. After probabilities of degradation for personnel and materiel are determined, the AMORE model simulates unit degradation using a Monte Carlo technique. Following the degradation, the unit is reconstituted using a transportation/assignment algorithm using the transferability matrices. The model then computes the expected value over time of the best reconstituted unit capability for the specified mission and the simulated degradation. [Ref. 8]

2. AURA

The AURA methodology consists of a series of complex computer programs which extensively cover the multifaceted aspects of the modern battlefield. These programs provide the ability to model nuclear vulnerability, conventional lethality, toxic dissemination, MOPP degradation, toxic nuclear dose/time responses, reliability failures, repair requirements performance, threat weapon delivery, deployment postures and criteria, and conventional lethality. To model these affects, AURA contains more than 24,000 lines of FORTRAN code [Ref. 3: p. 13] and [Ref. 3 refid=mcmast].

A key aspect of the AURA methodology is that it employs the unique feature of connectivity. Connectivity is the concept that an incoming round destroys personnel and equipment in the area of impact. This nonlinear feature of the model is a significant departure from the linear methodology used in AMORE to model degradation [Ref. 2: p. 37].

A more detailed description of AMORE and AURA is given by Moore in [Ref. 3: p. 38].

C. NEED FOR NEW RESILIENCY ANALYSIS METHODOLOGIES

On 20 June 1983 the commander of TRADOC, General William R. Richardson rescinded the mandatory use of AMORE to support new organizational designs. [Ref. 9]. This action occurred primarily for three reasons. First, the input data requirements to run AMORE were substantial. This fact made the policy of mandatory use of the model infeasible. Secondly, since much of the input data was subjective, sensitivity analysis revealed that two analysts independently studying the same unit could come up with totally different, but reasonable, results. The third reason was that AURA had just been developed and was thought to be particularly suitable for modeling heterogeneous units.

While both models had their own proponents and critics, in 1984 the question of which methodology was superior had not been analytically addressed. Therefore, a pilot study was conducted to determine which methodology was more efficient in terms of level of effort required, and which methodology resulted in the most productive results. The study concluded that AURA is clearly superior in measuring a unit's resiliency. However, perhaps the most relevant conclusion was that both methodologies require a tremendous amount of data input and are considered equally efficient, or inefficient, depending on terms of reference.

Resiliency analysis in the Army is now accomplished by the use of AURA. However, since the AURA methodology requires vast amounts of input data, considerable computer expertise, and the availability of large scale computers, its use is not widespread. If the designers of TOE units are to incorporate resiliency into their TOE designs, alternate methodologies must be developed which require less effort to use. [Ref. 9]

D. BACKGROUND INTERVIEWS

During the period April and May 1986, Dr. Thomas P. Moore of the Department of Administrative Sciences at the Naval Postgraduate School visited ten Army installations to obtain an understanding of how the concept of resiliency is actually perceived and implemented by the designers and documentors of TOEs in the Training and Doctrine Command (TRADOC). Interviews were conducted with key individuals involved in the design process. Most of the interviews were conducted with personnel in the Directorate of Combat Development (DCD) at each of the eight TRADOC schools. These DCDs are responsible for designing new TOEs as well as modifying existing TOEs. Interviews at the DCDs spanned all functional levels of the TOE design process;

designer, reviewer, and approver. However, the interviews concentrated on the TOE designer. Interviews were also conducted with key personnel at two of the Army's three Coordinating Centers, where TOE design work done by the TRADOC schools is reviewed [Ref. 3: p. 2].

It quickly became apparent in the course of the interview process that the importance of resiliency to the TOE design community was extremely varied. The importance of the various characteristics thought to be key elements in making a design resilient were equally varied. Characteristics such as Military Occupational Specialty (MOS) substitutability, commonality of equipment, degree of cross-training, and other characteristics, all received varying degrees of importance from one interview to another.

From the in-depth review of existing literature, as well as throughout the interview process, it was apparent that a study had never been conducted to gain some underlying consensus from the TOE design community regarding the relative importance of the various characteristics thought to be key to the resiliency of TOE units.

III. THE RESULTS OF THE RESILIENCY SURVEY

A. THE SURVEY - AN OVERVIEW

The resiliency survey contained a total of 47 questions which covered five primary areas of interest: demographics of the survey population; the TOE work environment; current overall TOE design process; resiliency and TOE design; the respondent's use of resiliency concepts; and computer usage of TOE designers. A copy of the complete survey is included in appendix A.

The survey was designed to obtain the necessary information while seeking to minimize time requirements placed on survey respondents. Consistent with these goals, three slightly different surveys were developed to enable the research team to cover all the relevant areas of interest.

1. Administration

The resiliency survey was mailed on July 29, 1987. Individuals who were personally interviewed the previous year by Dr. Moore were mailed surveys. Additionally, sets of five surveys each were mailed to the appropriate managers in the Directorate of Combat Developments at each of the TRADOC schools. These managers were requested to disseminate surveys to appropriate individuals involved in the TOE design process. Of the 150 surveys mailed, 64 surveys were returned. This represents a 42% return rate and is lower than was desired. Five surveys were less than 50% complete and were not used. Fifty-nine valid surveys comprised the final data set.

2. Data Preparation

For the data analysis phase of the thesis, the original 47 questions contained in the resiliency survey had to be divided into smaller elements so that each possible response would have a unique variable in the data base. Therefore, the possible responses to each of the questions in the survey were numbered from 1-140. The data was manually entered into a formatted SAS (Statistical Analysis Systems) input file created with four records for each survey respondent. To minimize human error in the data entry phase, templates were used on the surveys. After the data was entered, it was checked for errors using the SAS PRINT PROC UNIFORM procedure.

The data was also entered into an APL data base. To significantly reduce the potential for data input errors, an APL program was written to display both the current number of the survey and question to be entered. Through this process a 140 x 59 array was constructed. Each column represents one survey. Verification and correction of entered data was accomplished using the APL function editor. To establish both the SAS and APL data bases, a total of 16,520 manual entries were required.

B. A SURVEY DEFICIENCY

As stated previously, three slightly different surveys were needed to to cover the selected research areas. Unfortunately two of the three versions of the survey contained repetitive typographical errors when they were mailed out. The errors were located in the possible responses to questions 13 thru 38, primarily involving the pairwise comparisons of possible resiliency related characteristics of TOEs. This caused some confusion among several of the survey respondents who then called to report the problems. Within a week of mailing the original surveys, a letter explaining the problem and corrected copies of the appropriate pages were sent to the survey recipients.

C. DATA ANALYSIS PLAN

The purpose of the data analysis plan is to insure that the objectives of the thesis are met. It was designed concurrently with the survey and provides a systematic method for data analysis. The data analysis plan was applied to the six major areas of investigation as follows.

1. Demographics, TOE Work Environment, and TOE Computer Usage

To obtain an understanding of these variables, both graphical and non-graphical procedures were used to describe means and frequencies.

2. TOE Design Procedures

In this area of the survey, the respondents were provided with the list of design criteria shown in Figure 3 on page 20, and asked to rank order them in importance from 1-12, with 1 representing the most important. The use of the multivariate procedures constructing interval scales from ordinal data (CISFOD), variable clustering (VC), and principle component analysis (PCA) were planned. The CISFOD procedure was used to create an interval scale of the design criterion so that the magnitude of their relative importance to the design process could be compared. PCA and VC were used to see if the set of 12 design criteria could be reduced by eliminating redundancies in the original set of variables and thus more concisely express the design criteria which appeal to TOE designers.

3. Resiliency and TOE Design

In this section, survey respondents were asked to rank characteristics which are possibly related to resiliency, on a scale ranging from strongly negative to strongly positive. The CISFOD procedure was used to obtain numerical estimates of the strength of the relationships between the characteristics and resiliency. Bounds and relative locations were also found for each characteristic.

The analytic hierarchy process (AHP) was used in this section to determine the relative weights of resiliency characteristics through a pairwise comparison process. A decision theory tool of this nature is very useful as it provides a procedure to quantitatively estimate relationships which groups or individuals have trouble expressing. [Ref. 10: p. 42]

4. Use of Resiliency Concepts

To determine the importance of resiliency to the TOE design community, the respondents were asked to indicate the relative importance that they placed on resiliency as a design concept. There were four possible responses ranging from it is an indispensable factor to it is not an important factor. The Fisher Exact Test was used to test the hypothesis that "the importance of resiliency within the TOE community is independent of job position." Six separate tests were required to test all possible pairs of job positions.

D. DATA ANALYSIS

In this section the results of the statistical techniques described in the data analysis plan are discussed. There are primarily two objectives of the analysis. First, through the use of these procedures, it is anticipated that an overall understanding of the methodology used to design TOE units will emerge. Secondly, the multivariate methods will provide a mechanism to estimate the importance of resiliency.

1. Univariate Analysis

a. Demographics

The job positions of the survey recipients are displayed in Figure 1 on page 12. All 13 TRADOC schools, three Coordinating Centers, TRADOC Headquarters, three TRAC (TRADOC Analysis Centers), and several other organizations were represented in the survey population.

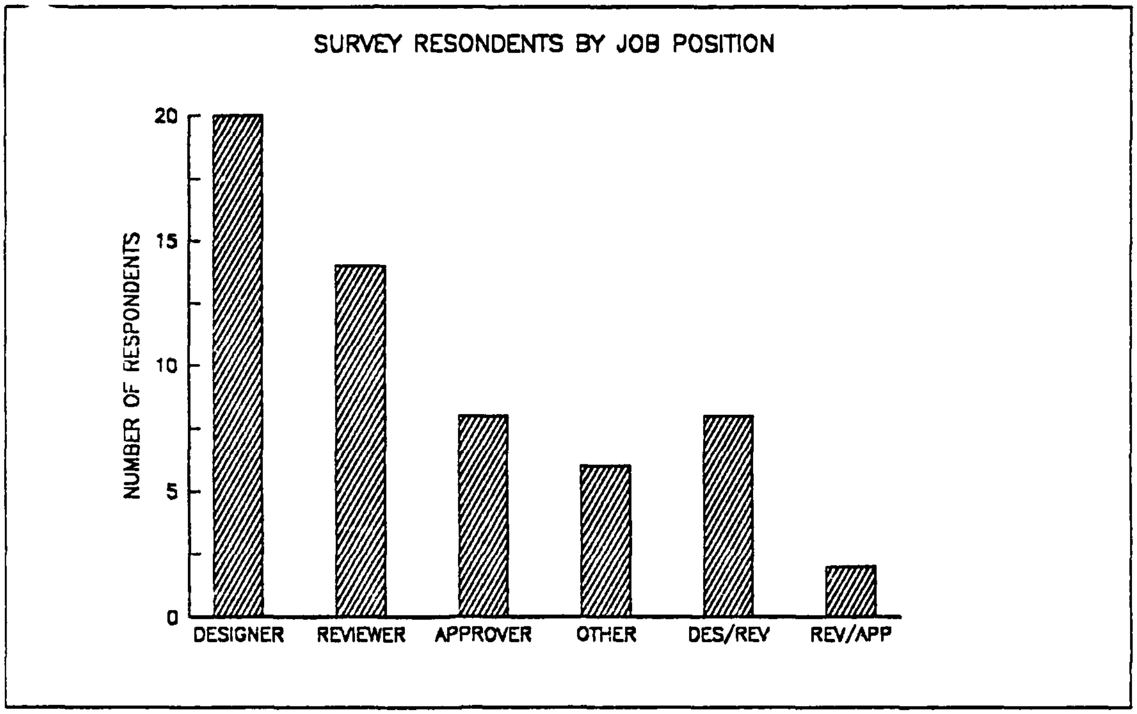

Figure 1. Number of survey respondents per job position: DES/REV represents respondents who indicated that the were both designers and reviewers. Similarly, REV/APP are those who indicated they were reviewers and approvers.

b. TOE Work Environment

A major portion of the survey was designed to obtain an understanding of the respondent's work experience in the TOE design process. As depicted in Table 1 on page 13, the average man-month work experience per military or civilian survey respondent is 76 months (6.33 years) with a standard deviation of 66 months (5.5 years), and a range from 1 month to 20 years.

To gain an understanding of the time required to perform various functions in the design process, the survey asked respondents to indicate workload requirements for both the design and review process. Table 2 on page 13 shows a breakdown, by TOE unit type, of the average number of TOEs which the survey respondent's organization either designs or is responsible to maintain if the design requires modification or routine review. The majority of the TOEs involved is clearly shown to be in the section/squad/team and company sized units.

Table 1. AVERAGE MAN-MONTH WORK EXPERIENCE IN TOE DESIGN PROCESS

	MEAN	STD DEV	MAXIMUM
Present TOE Position	39	38	240
Other TOE Positions	37	54	180
Total Experience	76	66	

Table 2. NUMBER OF TOES YOUR ORGANIZATION DESIGNS OR MAINTAINS

UNIT SIZE	MEAN	STD DEV
Section/Squad/Team	45	52
Platoon	6.5	8.4
Company	33	45.5
Battalion	6.8	9.6
Brigade	1.5	2.3
Division	.89	2.3

The man-hours required to both design and review new TOEs and to modify existing TOE designs are depicted in Table 3 on page 14 and Table 4 on page 14 respectively. In both charts the total sample standard deviation was computed by using the fact that the variance of a sum is the sum of the variances. This computation assumes that the random variables are independent.

c. *Computer Usage*

The last three questions of the survey solicited respondents for their personal computer hardware and software experience. There were two primary goals for including these questions in the survey. First of all, as a result of the personal interviews with individuals involved in the TOE design process, Dr. Moore concluded that

> The observed turmoil and variety in the TOE designer's computer environment poses a significant challenge for resiliency analysis. Great care must be taken to

Table 3. MANHOUR REQUIREMENTS TO PRODUCE NEW TOE

	DESIGN		REVIEW		TOTAL	
UNIT	MEAN	STD DEV	MEAN	STD DEV	MEAN	STD DEV
Platoon	152	201	41	121	193	234
Company	353	294	71	196	424	353
Battalion	554	349	326	94	648	478

Table 4. MANHOUR REQUIREMENTS TO MODIFY EXISTING TOE

	DESIGN		REVIEW		TOTAL	
REQUIREMENT	MEAN	STD DEV	MEAN	STD DEV	MEAN	STD DEV
Major addition or deletion of equipment	48	136	51	188	99	232
Major addition or deletion of personnel	19	43	31	110	50	118

provide resiliency analysis tools which will fit into the TOE designer's computational environment. [Ref. 3: p. 32]

Therefore, a primary goal of these questions was to describe the aggregate software and hardware resources available to the TOE designers. A second goal was to measure the actual use of computers within the TOE design community. This information will help to determine which hardware and software combinations would be most suitable for future implementation of new resiliency analysis methodologies developed for the TOE design community.

The first of these three questions asked the respondent to indicate the type of office and desktop computer systems currently available at the respondent's work place. Table 5 on page 15 indicates that the availability of these systems is limited. The column labeled proportion represents the proportion of N respondents which indicated that the system was available. Multiple answers were appropriate, if more than one system was available to the respondent.

The respondents' actual computer experience[1] is depicted in Table 6 on page 16. These results are particularly interesting when analyzed with regard to Table 5. For example, Table 7 on page 16 displays the conditional use of the computer systems provided they were available to the survey population.

Table 5. SURVEY RESPONDENTS COMPUTER SYSTEM AVAILABILITY

SYSTEM	N	PROPORTION	STD DEV
IBM PC	55	0.1818	0.5474
IBM Compatible Zenith PC	55	0.4000	0.5323
Non-IBM Compat. Zenith PC	55	0.1454	0.7049
Wyse Terminal w/ Intel CPU	55	0.5090	0.5399
WYSE PC	55	0.4363	0.6313
DEC Rainbow 100 PC	54	0.0555	0.4082
Apple MacIntosh PC	54	0.1111	0.4624
IBM-AT PC	53	0.0000	0.0000
Other	53	0.2075	0.4094

The most important observation is that the Wyse terminals with Intel CPUs have both the highest rate of availability (0.5090) and by far the highest probability of conditional (0.9637) use. Wyse also had the highest rate of availability (0.4363) and the highest probability of conditional use (0.6917) among personal computers. The data certainly shows that the use of IBM PCs and compatibles is limited. Furthermore, the IBM-AT PC's availability rate of zero followed by a 0.0377 experience rate must be attributed to experience gained outside the workplace.

The software experience of the survey respondents is also low. Only 43% of the respondents have a minimum of five hours experience using MS or PC DOS.[2] In

1 10 hours was set as the minimum level for a response. In table 5, N indicates the number of responses for the respective question.

2 5 hours was established as a minimum for a response.

Table 6. SURVEY RESPONDENTS COMPUTER EXPERIENCE

SYSTEM	N	PROPORTION	STD DEV
IBM PC	53	0.0943	0.2950
IBM Compatible Zenith PC	53	0.1698	0.3790
Non-IBM Comp. Zenith PC	53	0.0188	0.1373
WYSE Terminal w Intel CPU	53	0.4905	0.5046
Wyse PC	53	0.3018	0.4634
DEC Rainbow 100 PC	53	0.0000	0.0000
Apple MacIntosh PC	53	0.0566	0.2332
IBM-AT PC	53	0.0377	0.1923
Other	53	0.2075	0.4094

Table 7. CONDITIONAL PROBABILITY OF COMPUTER USE

SYSTEM	PROBABILITY
IBM PC	0.5187
IBM Compatible Zenth PC	0.4245
Non-IBM Comp. Zenith PC	0.1293
Wyse Terminals w Intel CPU	0.9637
WYSE PC	0.6917
DEC Rainbow 100 PC	0.0000
Apple MacIntosh PC	0.5094
IBM-AT PC	0.0000
Other	1.0000

the use of quantitative software, one third of the participants indicated that they had experience with LOTUS 1-2-3 and 28% had used dBASE. BASIC was the leading programming language with a usage rate of 20%. Table 8 on page 17 exhibits the entire results of the survey respondents' software experience.

Table 8. SURVEY RESPONDENTS SOFTWARE EXPERIENCE

SOFTWARE	N	PROPORTION	STD DEV
Word Perfect	53	0.1132	0.3198
Wordstar	53	0.1320	0.3418
Display Write	53	0.0754	0.2666
Multimate	53	0.0566	0.2332
Lotus 1-2-3	53	0.3396	0.4781
Visicalc Spreadsheet	53	0.0566	0.2332
Multiplan Spreadsheet	53	0.1320	0.3418
MS DOS or PC DOS	53	0.4339	0.5003
Basic	53	0.2075	0.4094
FORTRAN	53	0.1698	0.3790
COBOL	53	0.0377	0.1923
Pascal	53	0.0188	0.1373
PL1	53	0.0000	0.0000
dBASE	53	0.2830	0.4547

d. Importance of Resiliency

In an attempt to understand TOE designers' individual feelings about resiliency, survey respondents were asked to indicate the relative importance they placed on resiliency. Figure 2 on page 18 displays the possible responses and associated frequencies of the respondents.

To test the hypothesis that the importance which survey respondents placed on resiliency is independent of job position, the responses were paired to produce two categories. The first combines the "indispensable" and "somewhat important" responses and the second category consists of the responses "after everything else" and "not important." These categories were matched with various pairs of job positions and the following hypothesis was tested using the nonparametric Fisher Exact test.

Ho: The importance of resiliency within the TOE design community is independent of survey respondent's job position.

	Response	Frequency
•	It is an indispensable factor	11
•	Somewhat important factor	11
•	Comes into play after all other factors have been addressed	22
•	Resiliency is not a factor in the TOE design process	6
•	No response	9

Figure 2. Responses of Participants to Importance of Resiliency

Ha: The importance of resiliency within the TOE design community is not independent of job position.

While all combinations of job positions were tested, the only comparison with statistical significance at the $\alpha = .05$ level was found between designers and "all others." The "all other" grouping included reviewers, approvers, others, and any respondent which indicated that he belonged to two categories. These results indicate that TOE designers believe significantly less strongly than "all others" that resiliency is important.

2. Multivariate Analysis

a. Current TOE Design Procedures

To gain insight into the current procedures used by the TOE design community, Section III of the resiliency survey asked survey participants to rank order, from most to least important, the TOE design criteria shown in Figure 3 on page 19. The most important criterion received a rank of one and the least important criterion received a rank of 12. Those criteria which the survey respondent felt were not used, were not ranked. The number following each criterion listed in Figure 3 on page 19 refers to the variable number associated with that criterion in the data base. For example, Q49 refers to the variable "combat effectiveness of the TOE" and it is used in both tables and figures.

The CISFOD procedure was used to obtain a scaled ranking of the design criteria. Criterion 12, the write-in response, was most frequently listed as the most important criterion. Upon examining the surveys, we found each such response to be

CRITERIA	VARIABLE NAME
• Combat effectiveness of the TOE	Q49
• Total cost of the equipment and personnel in the TOE	Q50
• Resiliency of the TOE	Q51
• Annual personnel costs for the TOE	Q52
• Annual support (logistics, etc.) costs of the TOE	Q53
• Total of all annual operating costs for the TOE	Q54
• Cost of procuring the equipment for the TOE	Q55
• Whether or not the TOE is below its manpower ceiling	Q56
• Combat survivability of the TOE	Q57
• Combat supportability of the TOE	Q58
• How well the TOE conforms to applicable regulations	Q59
• Other	Q60

Figure 3. TOE Design Criteria

unique. Since the CISFOD procedure assumes that all of the responses to criterion 12 are identical, we were forced to eliminate this criterion from the data set. Only the remaining 11 criterion were used in the CISFOD procedure.

Shown in Table 20 on page 64 is the P_{ij} array for the current design criterion. The P_{ij} array represents the proportion of responses that ranked criteria i over criteria j [Ref. 11: p. 12]. For example, reading across the first row to the Q50 column, the 0.611 represents the proportion of respondents who ranked Q49 higher than they ranked Q50. The proportion of respondents who ranked Q50 higher than Q49 is 0.389.

The next step in the CISFOD procedure requires that the P_{ij} array be converted to z scores of the standard normal distribution Consequently, Table 21 on page 65 gives the z value which corresponds to each P_{ij} entry. The column averages of the Z array are the scale values of the design criteria. [Ref. 11: p. 7]. These scale values were transformed linearly onto a 1-10 scale for presentation.

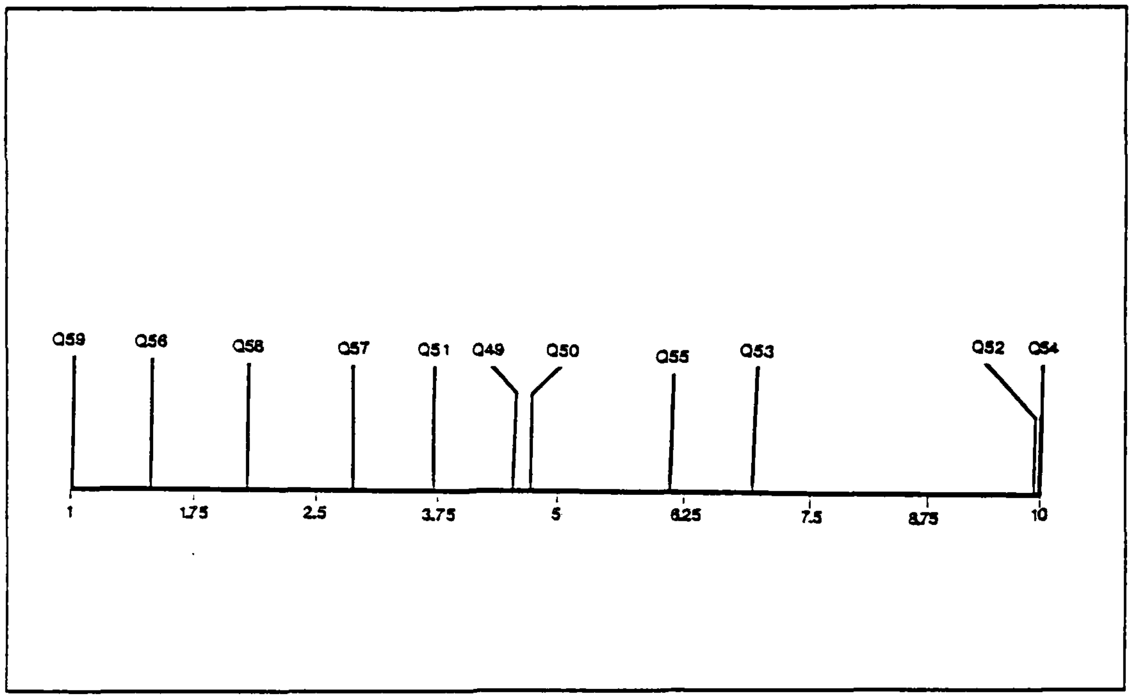

Figure 4. Interval Scale Estimation of TOE Design Criteria

As depicted in Figure 5 on page 21, the cost related criteria were considered by the survey respondents to be the most important criteria. The CISFOD procedure was repeated without the cost criteria and the results are shown in Figure 5 on page 22. When comparing the two scales, it is interesting to note that when cost is excluded from the comparison, the remaining criteria keep their relative order and approximate magnitudes with the exception of combat effectiveness. When the cost criteria are included, resiliency and combat effectiveness are relatively close in position. However, when costs are excluded combat effectiveness is shown to be nearly twice as important as resiliency.

Variable clustering (VC) was next performed on the eleven TOE design criteria. The goal of this procedure is to see if the design criteria could be grouped into clusters which exhibit understandable aggregate characteristics. This was accomplished using the SAS VARCLUS procedure and the results are shown in Table 9 on page 22. The column labeled OWN CLUSTER gives the squared correlation of the variable with its own cluster component. The larger the R^2 value in the OWN CLUSTER column the better. All four of the clusters seem to have adequately high OWN CLUSTER values

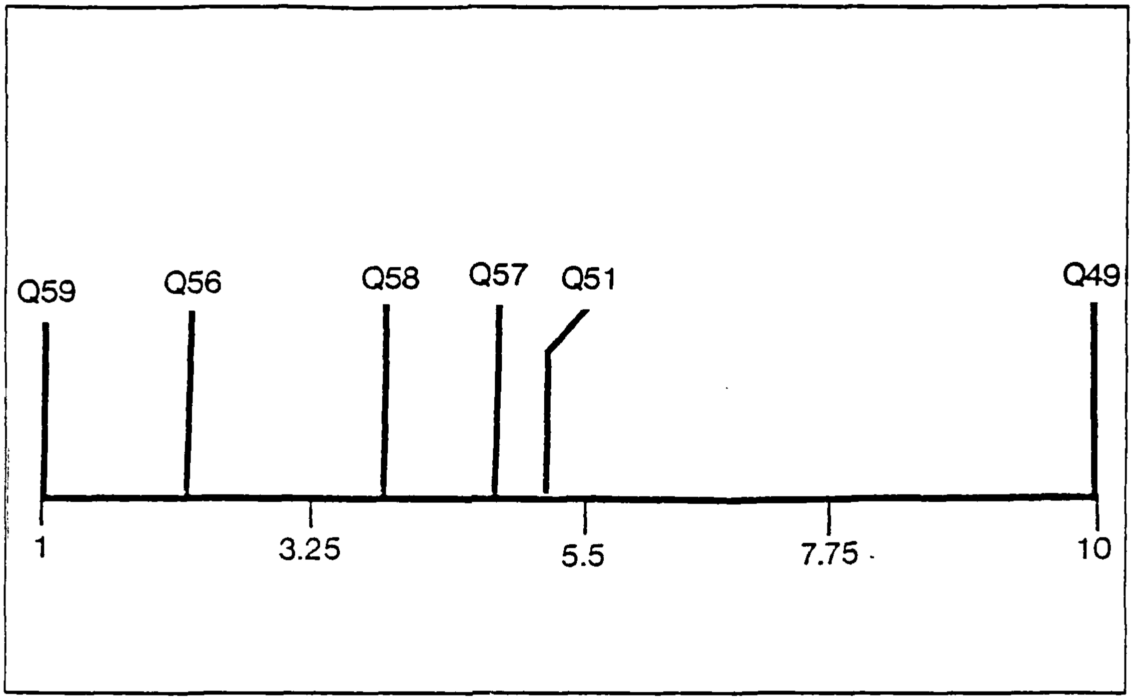

Figure 5. Interval Scale Estimation Excluding TOE Design Cost Criteria: Produced by the Constructing Interval Scales from Ordinal Data Procedure using all current TOE design criteria, except cost criteria.

indicating that the clusters are well defined. The NEXT HIGHEST contains the next closest R^2 of the variable with a cluster component other than its own. The smaller the value the better in this case. With the exception of cluster 3, all clusters have at least one NEXT CLOSEST value which is not small and would imply that the variable with the high value is close to becoming a member of another group. This fact makes for less defined clustering. The 1 - R^2 RATIO is the ratio of one minus the OWN CLUSTER R^2 and 1 - NEXT HIGHEST R^2 . A small ratio indicates that there are well defined disjoint clusters. Cluster 2's 1 - R^2 values indicate that it is not well defined. The other clusters have at least one variable with a 1 - R^2 value higher than desired. This again indicates that the clusters are not totally disjoint. [Ref. 12: p. 125]

Although the results of the variable clustering technique must be interpreted with reservations, the clusters formed do offer an interesting opportunity for interpretation. Cluster 1 is composed entirely of TOE cost criteria which represent direct costs

Table 9. VARIABLE CLUSTERS

TOTAL VARIATION EXPLAINED = 7.989881

PROPORTION = 0.7264

	VARIABLE	R-SQUARED WITH OWN CLUSTER	R-SQUARED WITH NEXT HIGHEST	1-R**2 RATIO
CLUSTER 1				
	Q51	0.8202	0.1247	0.2054
	Q52	0.8174	0.1705	0.2201
	Q54	0.6938	0.4840	0.5934
	Q55	0.7704	0.3514	0.3540
CLUSTER 2				
	Q49	0.6081	0.4740	0.7451
	Q57	0.5204	0.2846	0.6704
	Q58	0.7855	0.0467	0.2250
CLUSTER 3				
	Q51	0.7209	0.2065	0.3518
	Q59	0.7209	0.0864	0.3055
CLUSTER 4				
	Q53	0.7662	0.4713	0.4422
	Q56	0.7662	0.1250	0.2672

of establishing and operating the TOE. Consequently, this cluster could be called DCOST. Cluster 2 is composed entirely of combat criteria and therefore could be called CBT. Cluster 3 contains both resiliency and regulatory conformance. From several comments written on surveys a case can be made that resiliency is more of a "regulated" design criteria than those which can historically be attributed to effective combat units[3]. This group could be referred to as REG. Cluster 4 is composed of the support costs and manpower ceiling criteria. Since manpower ceiling constraints are imposed

[3] Written survey comments are included in appendix B.

as cost constraints, and support costs are those to support continued unit operations, this category could be labeled as indirect costs and called ICOST.

The last statistical procedure used in this part of the research was principle component analysis (PCA). PCA finds an orthogonal transformation of the original variables to a new set of uncorrelated variables, called principle components. Each principle component is a linear combination of the original variables, representing some aggregate characteristic of those variables. The objective of PCA was to reduce the dimensionality of the set of variables to eliminate possible redundancies and thereby, more concisely express the current TOE design criteria which appeal to the TOE design community.

Table 10. PRINCIPAL COMPONENT ANALYSIS LOADING COEFFICIENTS

	EIGENVECTORS			
	PRIN1	PRIN2	PRIN3	PRIN4
Q49	0.371502	0.236887	-.040908	0.391135
Q50	0.337296	0.230244	0.288659	-.146832
Q51	0.277370	-.293442	0.421316	0.300746
Q52	0.336727	0.320141	-.040551	-.363004
Q53	0.396899	-.156822	-.155953	0.310585
Q54	0.407318	0.021830	-.056744	-.206104
Q55	0.373415	0.210357	0.256765	0.275860
Q56	0.206479	0.168484	-.457519	0.239153
Q57	-.198219	0.320544	0.357054	-.394247
Q58	-.090991	0.511468	0.345528	0.418169
Q59	0.069419	0.490121	-.431487	0.026510

Each principal component is a linear combination of the original variables, with coefficients equal to the eigenvectors of the correlation or covariance matrix. PCA procedures state that principal components are interpreted on the basis of those variables with the same sign and large magnitude [Ref. 12: p. 621]. Using the PRIN COMP feature of SAS, Table 10 was generated. The first four principle components accounted for 62% of the total variation within the variable set. However, upon examination of the first four principal components, there appears to be no obvious interpretation, and therefore, these principal components did not prove useful.

b. Resiliency and TOE Design

The questions in this portion of the survey asked respondents for their opinions about relationships between resiliency and certain characteristics of a TOE design. The characteristics are listed in Figure 6 on page 25. A positive characteristic is one which, when increased, leads to an increase in the resiliency of the TOE design. Conversely, a characteristic which is a negative influence decreases resiliency when the characteristic increases.

Using the "interval scale from categorical judgments" method, the raw frequency array, F_{ij}, was constructed and is shown in Table 22 on page 66. The F_{ij} array is used to produce a cumulative frequency array, P_{ij}, and is displayed in Table 23 on page 67. These cumulative frequencies are then converted into a Z_{ij} (the z score corresponding to the P_{ij} value) array of normal probabilities in Table 24 on page 68. Figure 7 on page 27 shows the relative relationship of the fifteen characteristics with resiliency [Ref. 13: p. 7].

The generic size of the unit (Q86) was the dominant positive influence on resiliency as depicted in Figure 7 on page 26. Based on the overall importance that DCOST (direct cost) demonstrated in the analysis of current design criterion, the inference here is that if cost constraints are relaxed (more dollars) and larger units are designed, the inherent resiliency of the unit will be greatly increased.

The next three most important characteristics are all related to human factor issues. The first, morale of the unit's personnel (Q85) was the only other characteristic to be scaled in the very positive category (Q85). According to [Ref. 6: p. 7.1] unit morale was listed by Vietnam Commanders as a most important factor in the ability of a unit to reconstitute. The next two most important characteristics, which top the positive category, are the degree of reconstitution training (Q84) and unit leadership abilities (Q83). All three of these characteristics are directly related to the overall condition of the human factors status of the unit.

Characteristic	VAR
• Number of different MOSs	Q71
• Number of people divided by number of MOSs	Q72
• Degree of task similarity between MOSs	Q73
• Degree of vulnerability to personnel	Q74
• Degree of vulnerability to equipment	Q75
• Numbers of different kinds of major equipment	Q76
• Degree of equipment substitutability	Q77
• Technical complexity of repairing equipment	Q78
• Technical complexity of equipment operation	Q79
• Time required to repair battlefield damage	Q80
• Mean number of units of equipment per type	Q81
• Degree of personnel crosstraining	Q82
• Managerial skills of leaders	Q83
• Degree of reconstitution training	Q84
• Unit morale	Q85
• Generic size of unit	Q86

Figure 6. Resiliency Characteristics

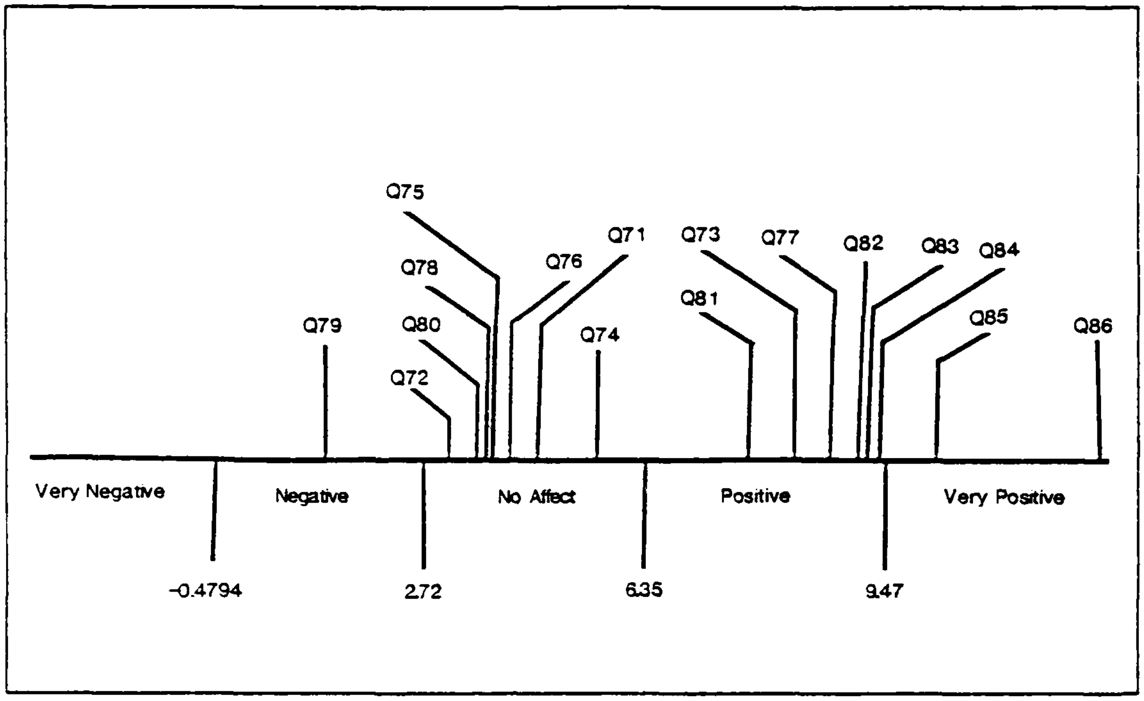

Figure 7. Interval Scale of Resiliency Characteristics: Produced by the Constructing Interval Scales from Categorical Judgments Procedure of Resiliency Characteristics.

The fifth highest ranking characteristic with a positive influence on resiliency is the degree of crosstraining of unit personnel (Q82). This is the first characteristic considered so far which the TOE designer can influence. Certainly crosstraining is greatly affected by the training program established by the unit's leadership, but the TOE designer can affect this by requiring that manpower spaces be filled with individuals who possess specified primary military occupational specialties (MOS) and secondary military occupational specialties (SMOS). By providing the unit commander with qualified personnel assets that can secondarily perform other individual's functions, the training effort required to achieve a certain degree of crosstraining will be lessened and personnel "redundancy" increased.

The next positive influence on resiliency is the degree of substitutability between the various types of equipment (Q77). This implies that the survey respondents believe that if a certain piece of equipment is destroyed or malfunctions the probability that the unit loses the ability to perform a particular function is reduced if substitute equipment is available. For example, if a TOE designer was confronted with the problem of which type of vehicle to add to a transportation unit, vehicle A may be chosen over vehicle B due to the commonality of engines of vehicle A and the existing vehicles already contained in the TOE. Equipment cannibalization was noted as an important factor in [Ref. 4: p. 67].

The last two characteristics in the positive category are the the degree of similarity between the tasks involved in the MOSs in the TOE (Q73), and the mean number of units of equipment per equipment type (Q81). The key to both of these characteristics in relation to the concept of resiliency is that overall internal redundancy of the unit is increased. Substitutability is enhanced by both characteristics.

Seven of the fifteen characteristics were included in the no effect category. The degree of vulnerability to combat damage to personnel (Q74) and equipment (Q75) were both considered as not affecting resiliency. There are possibly two reasons why vulnerability was not considered. First of all, vulnerability is largely scenario dependent. Secondly, resiliency refers to the ability of a unit to continue initial operations after having sustained varying levels of damage. So to a certain extent, resiliency analysis is interested in what happens to the combat effectiveness of the unit after damage has been done.

The only characteristic listed in the negative category was the technical complexity of operating the equipment in the TOE (Q78). While one would expect to find this in the negative category, it is surprising that the time to repair battle damage (Q80) was not included for the same reason. It seems logical that the greater the complexity of equipment the longer it would take to repair it. BDM Corporation [Ref. 4: p. 88] stated that repair capability enhances a combat unit's ability to internally reorganize and continue combat operations. Consequently it seems logical to conclude that increasing times to repair the equipment in the unit lead to decreasing resiliency.

Both the variable clustering and principle component analysis techniques were applied to these 15 characteristics. Unfortunately, neither method produced interpretable results and therefore no conclusions could be drawn from the analyses.

c. Pairwise Comparisons of Characteristics.

In this portion of the survey respondents were asked to compare selected pairs of characteristics and indicate their relative influence upon resiliency. The possible responses were that the pair of characteristics had equal influence, or one was slightly more influential, quite a bit more influential, immensely more influential, or absolutely more influential than the other.

The overall objective of this portion of the survey was to generate sufficient pairwise comparisons to fill an 8 x 8 matrix involving 8 of the 16 potential resiliency characteristics. This matrix contained all questions asked on the three surveys. Depicted in Figure 8 on page 69 is the aggregated matrix and the sources for each pairwise comparison.

Since survey 3 did not contain sufficient questions to comprise a complete matrix of pairwise comparisons, inferences about the consistency of this matrix would have to be made from the consistency of surveys 1 and 2. The mean consistency ratio of survey 1 was 0.24734 with a standard deviation of 0.163505. These same statistics for survey 2 are 0.271298 and 0.2444 respectively, and are higher than the Saaty targeted consistency ratio of 0.1.[4] However, consistency is improved by active interaction of the participants in the problem solving process. By using the AHP in the form of a survey, this interaction is very limited. Consequently, the consistency ratios obtained using this method were expected to be higher than the 0.1 level. Furthermore, Saaty doesn't say that data sets with consistency ratios greater than 0.1 shouldn't be used. In fact in several places in his books on AHP, Saaty uses sets of pairwise comparisons which have consistency ratios greater than 0.1 [Ref. 10: p. 88].

We assume that if the consistency ratio for survey 3 responses could be measured, it would be approximately equivalent to the consistency ratios obtained in Surveys 1 and 2. Furthermore, the aggregated 8 x 8 matrix consistency ratio is 0.0068 and is well under the 0.1 level. This indicates that the AHP weights are derived from a group of people whose order relations on the characteristics are primarily transitive and that the weights are an accurate estimate of the underlying ratio scale of the compared resiliency characteristics. [Ref. 10: p. 54]

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[4] The consistency ratios for surveys 1 and 2 were computed using the APL program in appendix F.

IV. THE RESILIENCY INDEX

In this chapter we will discuss the development of several different estimates of the inherent resiliency of a TOE unit. These estimates will be referred to as unit (as in TOE unit) resiliency indices. The first section of this chapter describes the process in which characteristics from the TOE were selected as terms for the unit resiliency index. The second and third sections describe how these characteristics were quantified and scaled. The fourth section illustrates the use of a specific unit resiliency index on a mechanized infantry rifle company. The final section of this chapter discusses the changes which lead to the various versions of the unit resiliency index.

A. SELECTION OF CHARACTERISTICS.

As depicted in Figure 8 on page 69, the 8 x 8 aggregated resiliency matrix was generated from the pairwise comparisons of resiliency characteristics in all three surveys. The weights obtained for each characteristic using the AHP could now be used as the coefficients in an index used to estimate the resiliency of a TOE unit [5]. The form of the index is as follows:

$$R = \sum_{i=1}^{n} W_i X_i \tag{4.1}$$

where R is the unit's resiliency index value, X_i is the quantifiable measure of characteristic i in the unit, and W_i is the coefficient of X_i, as determined using the AHP.

The pairwise comparisons yielded information about the following characteristics:

- **MOS Depth** - The number of soldiers in the TOE divided by number of MOSs in the TOE.
- **Task Similarity** - The degree of task similarity between the MOSs in the TOE.
- **Equipment Depth** - The number of units of equipment in the TOE divided by the number of distinct types of equipment.
- **Equipment Substitutability** - The degree of substitutability between the equipment in the TOE.
- **Crosstraining** - The degree of crosstraining of personnel in the TOE.

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[5] The APL program in appendix G was used to compute the AHP coefficients for the resiliency index.

- **Equipment Vulnerability** - The degree of equipment vulnerability in the TOE.
- **Mean MTTR** - The average mean time to repair the equipment in the TOE.
- **Reconstitution Preparation** - The degree the unit has practiced and prepared for reconstitution in a combat environment.

In order to apply this indexing procedure to an actual TOE unit, specific quantitative measures of each of the characteristics must be defined. Unfortunately, several of these characteristics are very difficult to quantify. Equipment substitutability, equipment vulnerabilty, and mean MTTR fall into this category. As a consequence, these characteristics ultimately weren't used in the resiliency index.

The crosstraining characteristic also wasn't used directly in the resiliency index. Respondents to the survey indicated clearly that the crosstraining of personnel within a TOE unit can substantially improve the resiliency of that unit. Unfortunately previous interviews with TOE designers indicate that they believe crosstraining is strictly a training issue, one over which the TOE designer has no control. [Ref. 3: p 26]

While the unit commander is the person ultimately responsible for crosstraining within a unit, the commander isn't in the best position to determine who should be crosstrained, and what MOSs to crosstrain. On the other hand, the TOE designer is in a very good position to suggest which positions should be crosstrained, and the MOS to be the subject of this crosstraining. He has the most up-to-date knowledge of doctrine, tactics, equipment and organization. The TOE designer also has the time and resources needed to do careful thinking about the combinations of knowledge achieved thru crosstraining which will best help the unit sustain its combat effectiveness.

The TOE document is the obvious way for the TOE designer to communicate to the unit commander this careful thinking about who should be crosstrained, and what MOS they should receive the crosstraining in. Operating on the assumption that TOE designers can do this if they so choose, we developed a way to represent crosstraining in the resiliency index. This representation occurs through the use of two other characteristics: task similarity and MOS Depth.

The last characteristic in the list above was also excluded from the resiliency index. This characteristic, reconstitution training, was considered by survey respondents to have a positive effect on resiliency. A quantifiable definition of the characteristic, such as the number of field exercises per year in which reconstitution training took place, could be used to measure this characteristic for an existing unit. However, this characteristic isn't influenced directly by the TOE designer. Since our approach has been to design the resiliency index from the perspective of the TOE designer, the crosstraining characteristic wasn't included in the resiliency index.

Since the number of pairwise comparisons that could be included in the survey was limited, Figure 7 on page 26 was examined to determine if there were additional quantifiable characteristics that should be included in the index. The characteristic which was described in the survey as the "degree of technical complexity to operate the equipment in the TOE" (Q79) was considered by the survey respondents as having a strong negative impact on resiliency. This unique feature seemed to warrant its inclusion in the index. However, to include the "complexity of operating the equipment" required some modification to our weighting methodology.

Examination of Figure 7 on page 27 shows that this characteristic is symmetric about zero (no influence on resiliency) with respect to the positive characteristic equipment depth (Q81). Therefore, we estimated the index weight for the "complexity of operating the equipment" to be equal to the AHP weight for equipment depth. All the coefficients were then normalized to obtain the final weights for the resiliency index. Since the complexity of operating the equipment represents a negative influence on resiliency, the quantitative measure of the characteristic was structured to reflect this property in the structure of an additive index.

While this approach is certainly not as accurate as having this characteristic included in the original pairwise comparison matrix, the normalization procedure did preserve the relative weights between the original characteristics. We believe that the completeness gained in the resiliency index from the inclusion of this characteristic outweighs the loss of exact AHP weights. Therefore, the final characteristics and AHP weights used in the resiliency index are:

- X_1 = **MOS Depth** - the number of people in the TOE divided by number of MOSs in the TOE. The corresponding AHP weight is $W_1 = 0.2147995$.
- X_2 = **Task Similarity** - the degree of task similarity in the MOSs in the TOE. The corresponding AHP weight is $W_2 = 0.317297$.
- X_3 = **Equipment Depth** - the mean number of units of equipment per equipment type in the TOE. The corresponding AHP weight is $W_3 = 0.2531023$.
- X_4 = **Operating Complexity** - the degree of technical complexity involved in operating the equipment in the TOE. The corresponding AHP weight is $W_4 = 0.2147995$.

B. QUANTIFICATION OF CHARACTERISTICS

Estimation of each characteristic of the index required the development of a procedure to quantify the amount of a specific characteristic in an actual TOE. These procedures are described in the following sections.

1. MOS Depth

This characteristic was computed by dividing the total number of soldiers in the TOE by the number of distinct MOSs in the TOE. This provides a measure of the average soldier depth per MOS. A larger value is indicative of a more resilient unit structure. The form of the computation is:

$$X_1 = \frac{n}{m} \tag{4.2}$$

where:

n = number of people in the TOE

m = number of MOSs in the TOE

2. Task Similarity

The approach used to quantify this characteristic is to estimate the mean proportional similarity of tasks for the possible pairings of soldiers in the TOE. For a particular pairing of soldiers, A and B, with different MOSs, the proportion is the fraction of soldier B's job which soldier A can perform if soldier A must substitute for soldier B. Note that a different value may be obtained for this proportion when examining the pairing B and A, i.e., the relationship isn't commutative.

The approach used to quantify this characteristic is to estimate the mean proportional similarity of tasks for the possible pairings in the TOE. By examining the Soldiers Manuals for each of the MOSs in the unit, both the number of total tasks performed by each MOS and the number of common tasks between each pair of MOSs was determined. We define an S_{ij} matrix as follows:

1. m = the number of unique MOSs in the unit.
2. the rows are the MOSs in the unit.
3. the columns are the MOSs in the unit.
4. an entry in the S_{ij} matrix (m by m) is the number of common tasks of the row and column divided by the total tasks in the MOS corresponding to the column.

For example, assume that there are three MOSs in the unit, A, B, and C which perform 10, 15, and 20 total tasks respectively. A matrix of common tasks for the possible pairings of these MOSs is shown in Table 11. Then the corresponding S_{ij} matrix, is depicted in Table 12.

Table 11. COMMON TASK MATRIX

	A	B	C
A	10	5	3
B	5	15	10
C	3	10	20

Table 12. SIJ MATRIX

	A	B	C
A	$\frac{10}{10}$	$\frac{5}{15}$	$\frac{3}{20}$
B	$\frac{5}{10}$	$\frac{15}{15}$	$\frac{10}{20}$
C	$\frac{3}{10}$	$\frac{10}{15}$	$\frac{20}{20}$

Therefore, the quantitative measure of this characteristic, X_2, is given by:

$$X_2 = \frac{\left(\sum_{i=1}^{m} \sum_{j=1}^{m} P_i P_j S_{ij} \right) - n}{n(n-1)} \qquad (4.5)$$

where:

m = number of distinct MOSs in the TOE

n = number of people in the TOE

P_i = number of people with i^{th} MOS

To provide the TOE designer with a method for estimating the change in task similarity by specifying secondary MOSs for crosstraining, the S_{ij} matrix was modified. Assume that MOS A and MOS B are combined to form a primary/secondary MOS and that A ⋃ B represents the total number of distinct tasks performed by this combination. Let C equal the set of tasks performed by MOS C. Then the S_{ij} matrix used in the computation of X_2 above must be expanded as in Table 13.[6] This expanded S_{ij} matrix, now m+1 by m+1, is used to compute X_2 as shown in equation 4.5.

Table 13. EXPANDED SIJ MATRIX

Tasks	A	B	C	A ⋃ B
A	1	S_{ab}	S_{ac}	$\frac{\lvert A\rvert}{\lvert A \cup B\rvert}$
B	S_{ba}	1	S_{bc}	$\frac{\lvert B\rvert}{\lvert A \cup B\rvert}$
C	S_{ca}	S_{cb}	1	$\frac{(A \cup B)\cap C}{\lvert A \cup B\rvert}$
A ⋃ B	1	1	$\frac{(A \cup B)\cap C}{\lvert A \cup B\rvert}$	1

As previously mentioned, examination of the soldiers manuals provided data on both the total number of tasks performed by each MOS and the number of common tasks between every pair of MOSs in the TOE. During this process, data was not collected on the common tasks shared by more than two people. To represent crosstraining, the form of the expanded Sij matrix requires that the common tasks of the

[6] All entries in the expanded S_{ij} matrix are less than or equal to one.

primary/secondary combination and all other MOSs in the unit be estimated. The following estimate was adopted for the number of tasks common to MOS C and the combination of MOS A and B. This estimate derives from the fact that equation 4.6 holds for $|(A \cup B) \cap C|$:

$$\max \{ |A \cap C|, |B \cap C| \} \leq |(A \cup B) \cap C| \leq |A \cap C| + |B \cap C| \tag{4.6}$$

Therefore, we estimate $|(A \cup B) \cap C|$ with:

$$|(A \cup B) \cap C| \simeq \frac{\max \{ |A \cap C|, |B \cap C| \} + |A \cap C| + |B \cap C|}{2} \tag{4.7}$$

The designation of secondary MOSs can also be viewed as contributing to the characteristic of MOS depth. The designated secondary specialty essentially adds a proportion of another soldier to the TOE unit. Therefore, the resiliency index treats the designation of a specialty as the equivalent of adding 1/2 of a soldier with this secondary MOS to the unit, and as a result, this will affect the characteristic MOS Depth.

3. Equipment Depth

A simple way to compute this characteristic would be to divide the total quantity of equipment in the TOE by the total number of distinct equipment types. However, this approach would treat a .45 caliber pistol as equivalent to a Cobra attack helicopter. As this is likely to be unacceptable to TOE designers, we used firepower scores to provide a measure of the relative worth of each particular type of equipment in the unit. Each item of equipment receives a firepower score between 1 and 10 with 10 representing the most important equipment.

Although the firepower scoring procedure has the shortcoming of not reflecting the nonlinear relationships which exist in weapon system mixes, it provides a simple way to establish the relative worth of various weapon systems. For this reason, firepower scores have been used in various military models, including the Army's high resolution Atlas model.

This characteristic takes the following form:

$$X_3 = \frac{\sum_{i=1}^{m} (n_i FP_i)}{\sum_{i=1}^{m} FP_i} \tag{4.8}$$

where:

FP_i = firepower score for the i^{th} equipment type

n_i = total number of units of equipment type i

m = number of distinct types of equipment

4. Operating Complexity

To estimate the effect that the technical complexity of equipment has on the resiliency of a TOE, each item of equipment receives a complexity factor. Since this characteristic has a negative impact on resiliency, the complexity factor scale was designed to run from 0 to 10 with 10 representing the equipment which is simplest to operate. This characteristic is expressed as:

$$X_4 = \frac{\sum_{i=1}^{m}(n_i CF_i)}{\sum_{i=1}^{m} n_i} \tag{4.9}$$

where:

CF_i = complexity factor for the i^{th} equipment type

n_i = total units of equipment type i

m = number of distinct types of equipment

C. SCALING THE CHARACTERISTIC VALUES

The previously described procedures for computing the X_i will produce raw values that vary significantly in magnitude. For example, the degree of task similarity (cross-training) will always be between zero and one. MOS depth, equipment depth, and equipment complexity will vary in size and are primarily a function of the numbers of personnel and equipment in the unit. A scaling transformation was sought that would place all characteristic values, X_i, between 0-1.

The scaling transformation used on the raw characteristic values X_i is the range method. Its general form is:

$$Y = \frac{X - \min X}{\max X - \min X} \tag{4.10}$$

This transformation was used on characteristics X_1, X_3, and X_4, but not on X_2 since it is naturally scaled between 0 and 1.

After the transformation of X_1, X_3, and X_4 , to the 0-1 scale the form of the resiliency index is as follows:[7]

$$R = \left(\sum_{i=1}^{n} W_i \, Y_i \right) \times 100 \qquad (4.11)$$

For display purposes, the resiliency index R was linearly transformed by multiplying by 100.

Various TOEs were examined to provide estimates for the minimum and maximum values for this scaling procedure. While we believe the numbers used to scale these values are representative of the range found in company sized TOE units, we did not have the manpower to assess all existing TOEs to verify that the scale end points we chose were the absolute maximum and minimum values across all TOEs. The values used in the index should be updated as more information becomes available.

1. MOS Depth

The TOEs examined indicated that 190 was a reasonable maximum for the personnel strength of a company sized TOE. The smallest number of MOSs for a TOE unit was estimated to be 8. Therefore, the maximum value initially chosen for this characteristic was 23.75. However, since we wished to investigate the affects of recommending secondary MOSs in the TOE, the maximum value of X_1 was set at 35.625. This larger value results from the fact that secondary MOSs are expected to have an affect on inherent resiliency which is similar to , but not as influential as adding soldiers to the unit. The minimum value was set at 1. The scaling transformation is for X_1 is:

$$Y_1 = \frac{X_1 - 1}{35.625} \qquad (4.12)$$

2. Equipment Depth

The TOEs we examined indicated that a reasonable value for the maximum value of X_3 was 30 and that the minimum was 1. Therefore, the scaling transformation for X_3 is given by:

---

[7] Although X_2 required no transformation, for simplicity of notation in will be referred to as Y_2.

$$Y_3 = \frac{X_3 - 1}{29} \tag{4.13}$$

3. Technical Complexity of Equipment

By inspection of equation 4.9, the largest and smallest possible values of this characteristic are 10 and 0 respectively. The resulting transformation is given by:

$$Y_4 = \frac{X_4}{10} \tag{4.14}$$

D. TEST CASE FOR THE RESILIENCY INDEX

The Mechanized Infantry Company TOE was selected as a test TOE for application of the resiliency index. A company sized unit was chosen, rather than a battalion, because the company is more manageable with respect to the index computations. The Mechanized Infantry Company was chosen because it represents a military unit that has a mix of personnel and equipment.

Displayed in Table 14 on page 39 are the personnel levels as prescribed by this TOE. Although officers are listed in the table they were not used in the index. Specific task lists exist only for enlisted soldiers. Consequently, we couldn't quantify task similarity, X_2, for the officers.

Not all the equipment listed in this TOE was included in the computation of the resiliency index. Only the company's direct fire weapons, vehicles, and major communication devices shown in Table 15 on page 40 were included.

Table 19 on page 42 shows the firepower scores and complexity factors used in the index. Since these values were selected in accordance with [Ref. 14], they are held constant through the analysis of the unit. Furthermore, once an Army wide firepower score table and complexity factor table are developed, these values can be fixed for Army TOE resiliency analysis.

The interactive APL program in appendix G was used to compute the resiliency index as shown in equation 4.11. The program user has the option of designating secondary specialities. The default condition doesn't specify secondary specialties.

E. SENSITIVITY ANALYSIS.

For this analysis, all tables depict selected cases where parameters were modified and the results compared with the results obtained for the baseline case. Each case shown is independent of the other cases and the description in the case column in each table

Table 14. TOTAL PERSONNEL IN THE MECHANIZED INFANTRY (M113) RIFLE COMPANY TOE

GRADE	MOS	QUANTITY
CPT	11000	1
LT	11000	4
E-8	11B5M	1
E-7	11B40	3
E-6	11B30	9
E-6	11H30	1
E-6	31V30	1
E-6	76Y30	1
E-5	11B20	19
E-5	11H20	1
E-5	54E20	1
E-5	76Y20	1
E-4	11B10	41
E-4	11H10	4
E-3	11B10	13
E-3	11H10	2
E-3	11M10	9
TOTAL		112

indicates the only modification made to the baseline case for each modified case. The baseline case refers to the Mechanized Infantry Company (M113) TOE.

1. MOS Depth.

In Table 16 on page 40, the column labeled Y_1 depicts the values of the MOS depth characteristic for the various cases considered in the sensitivity analysis. In all cases, the denominator (total number of MOSs in the unit) is held constant. It can be seen that an increase or decrease of 15 soldiers will cause Y_1 to vary 27% and (16.3%) respectively from the baseline. This indicates that modifications of Y_1 of equal magnitude and in the opposite directions will have asymmetric results. This is due to the mathematical properties of ratios.

Table 15. **MAJOR EQUIPMENT OF THE MECHANIZED INFANTRY (M113) RIFLE COMPANY TOE**

MAJOR EQUIPMENT	QUANTITY
Dragon Anti-Armor Weapons	9
M113 Personnel Carrier w/50 Cal	14
TOW Anti-Tank Weapon/Vehicle	2
Grenade Launchers	22
Grenade Launchers Smode M259	14
M60 Machine Gun	5
Rifle M16A1	107
45 Caliber Pistol	20
Radio Set AN/GRC-150	14
Radio Set AN/PRC-77	17
Radio Set AN/VRC-45	13
Truck Cargo 2-1/2 Ton	2
Truck Utility 1/4 Ton	2
TOTAL	243

Table 16. **SENSITIVITY ANALYSIS OF MOS DEPTH AND TASK SIMILARITY**

CASE	Y_1	Y_2	RI	RI % CHANGE
BASELINE	.20439	.74675	57.09	-
ADD 5 11B20	.2155	.75589	57.499	.7164
DELETE 5 11B20	.19328	.74523	56.684	(.7116)
ADD 5 31V30	.2155	.68605	55.283	(3.165)
ADD 15 11B10	.25993	.77488	59.056	3.443
DELETE 15 11B10	.17106	.72105	55.439	(2.891)

Table 17. MOS DEPTH AND TASK SIMILARITY-MODIFIED COMMON TASK MATRIX

CASE	Y_1	Y_2	RI	% CHANGE
BASELINE (modified)	.20439	.7777	57.95	-
ADD 5 11B20	.2155	.78188	58.324	.645
DELETE 5 11B20	.19328	.77375	57.589	(.6229)
ADD 5 31V30	.2155	.71209	56.109	(3.176)
ADD 15 11B10	.25993	.79928	59.83	3.24
DELETE 15 11B10	.17106	.75171	.56.412	(2.654)

2. Task Similarity

Here we were primarily interested in measuring the effects of changes in the common task matrix on the value of the task similarity characteristic. By increasing the number of common tasks between pairs of MOSs by 20% and holding the total number of tasks performed by each MOS constant, a modified S_{ij} matrix was computed. Table 16 and Table 17 on page 41 show the results obtained with the baseline common task matrix and the modified common task matrix respectively. The average values of Y_2 for the modified S_{ij} matrix were 3.75% higher than corresponding values in the baseline. Since values of Y_1 were held constant, changes in the resiliency index can be attributed to the modifications to the common task matrix. The average resiliency index increased 1.513% and indicates that the TOE designer can increase resiliency by structuring units with a greater proportion of common tasks between MOSs.

Table 18 on page 42 shows 7 cases of primary and secondary MOS designations and the baseline case where no secondary specialties are designated. The cases all depict situations in which secondary specialties were assigned to one or to all of the 11B20 positions in the unit.

The sensitivity analysis reveals that Y_2 is very sensitive with respect to the number of common tasks shared between the designated secondary and the other MOSs in the unit. For example, the designation of 31V30 as a secondary specialty for the 11B20's results in a 7% decrease in Y_2 from the baseline. The 31V30 has 113 total tasks and very few of which are common to the other MOSs in the unit. This results in low values being placed in the expanded Sij matrix.

The greatest increase in Y_2 is seen in the case of designating 11M10 as the secondary specialty for the 19 11B20's. This increase occurs for two reasons. First, the 11M10 performs a total of 82 tasks. Of these 82 tasks, many are common tasks shared with another MOS. The 11B20 performs a total of 80 tasks and has a very high degree of task similarity with many of the MOSs in the unit. Therefore, when this primary/secondary combination is created, it places large entries in the expanded S_{ij} matrix resulting in an increase in Y_2.

Table 18. SECONDARY MOS DESIGNATIONS

CASE	NUMBER DESIGNATED	Y_1	Y_2	RI	RI % CHANGE
BASELINE	-	.20439	.74675	57.09	-
11B20/11H20	1	.2055	.74675	57.098	.014
11B20/11H20	19	.22549	.74993	57.525	.7619
11B20/31V30	1	.2055	.74657	56.989	(.1769)
11B20/31V30	19	.22549	.69399	55.75	(2.347)
11B20/11M10	1	.2055	.75016	57.103	.02277
11B20/11M10	19	.22549	.75453	57.671	1.017

Table 19. EQUIPMENT DEPTH AND OPERATING COMPLEXITY

CASE	FP	CF	Y_3	Y_4	RI	RI % CHANGE
BASELINE	-	-	.50754	.74675	57.093	0
ADD 5 DRAGONS	6	5	.53987	.75541	58.094	1.753
DEL. 5 DRAGONS	6	5	.47522	.7381	56.085	(1.753)
ADD 5 M16's	2	8	.51832	.76407	57.734	1.122
ADD 5 TRUCKS	1	8	.51293	.76623	57.644	.965
DEL. 9 DRAGONS	6	5	.44935	.73117	55.282	(3.17)

3. Equipment Depth and Operating Complexity

Table 19 depicts the various cases testing the sensitivity of equipment depth and equipment complexity. The resiliency index (RI) is a function of changes to both MOS depth and equipment complexity and independent analysis of the affect of each characteristic by itself is not possible.

When the number items of equipment added to the baseline is held constant, as was done with the cases of adding dragons, M16's, and trucks , the equipment depth, Y_3, value varies directly in proportion to the firepower score of the equipment which was added.

Similarly, it can be seen that the largest increase in the equipment complexity Y_4, is from the less complex systems.[8] Adding five more 2 1/2ton trucks almost doubles the increase of adding the same number of dragons.

F. RESILIENCY INDEX ALTERNATIVES

During the characteristic selection process, the driving force in determining which characteristics would be included in the resiliency index was the ability to quantify the characteristic in an actual TOE. Two of the characteristics which were excluded as a result of problems with quantification were the degree of equipment substitutability and the complexity of repairing equipment. Possible methods for quantifying these characteristics are discussed below.

1. Degree of Equipment Substitutability

TOE designers could be administered a survey regarding the degree of equipment substitutability between various pairs of equipment in the TOE. They would be asked to indicate the degree of equipment substitutability of specific pairings on a scale ranging from completely substitutable to not substitutable.

Another approach is to document the subfunctions of each item of equipment and compare them in a common function matrix. This is similar to the method used in quantifying the degree of task similarity and the degree of crosstraining.

2. Degree of Complexity to Repair Equipment

TOE designers could be surveyed for opinions concerning a second possible indicator of maintenance complexity. It might be obtained by examining the length of the TRADOC programs of instruction for the various types of mechanics.

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[8] Remember that equipment with less complex operating procedures achieves higher values of Y_4, and thus higher values of the resiliency index.

V. CONCLUSIONS AND RECOMMENDATIONS

The purpose of this thesis was to propose a computational procedure for estimating the inherent resiliency of an Army TOE design. The resiliency index which was developed has two important characteristics:

1. It can be computed from data in the TOE and a few other sources which are easy to obtain, so that the computations require relatively few manhours to do.
2. The input data is primarily non-judgemental. This is intended to improve the reproducibility of resiliency index values when the computations are performed by different analysts, and to possibly allow the index to be used to compare the inherent resiliency of various diverse types of TOE units.

To develop this method for measuring TOE resiliency, the following major steps were accomplished.

- A survey was used to gain an understanding of how TOE units are designed and what characteristics in such a design affect the inherent resiliency of the unit.
- Using multivariate statistical methods, estimates of the underlying ratio scale between resiliency characteristics were obtained and used as coefficients in an additive resiliency index.
- Procedures were developed to quantify the resiliency characteristics present in actual TOE units.
- An interactive APL computer program was written to perform the resiliency index computations for a variety of TOE designs and circumstances.
- The resiliency index was applied to the Mechanized Infantry (M113) Rifle Company to demonstrate the validity of the index.

The resiliency index is a relatively simple, "quick and dirty" method for estimating the inherent resiliency of a TOE unit. Comparatively speaking, it requires a minimum of manpower effort and provides a means for TOE designers to obtain feedback during the design process. Using this indexing procedure as a screening technique, TOE designs with inherent resiliency problems can be identified for further analysis with AURA.

There are several areas of further research that can result in improvements in the resiliency index:

- An important validation of this or similar resiliency indices should be done as the next step in this research. One way to do this is to chose 8-12 existing company sized TOEs and obtain pairwise comparisons of them with respect to their inherent resiliency. The analytic hierarchy process could then be applied to these pairwise comparisons to obtain numerical ratings for the perceived inherent resiliency of each of these units. These ratings would be compared with the corresponding resiliency index values. It is hoped that the values would be similar, thus demonstrating the validity of the resiliency index computation.

- The resiliency index did not include the officer positions in the TOE because task lists weren't available for these positions. Thus we were unable to quantify task similarity for officers. Further work should be done to estimate the task similarity between officer positions and other MOSs in a TOE design. Examination of the programs of instruction used in the basic and advanced officer courses at the various TRADOC schools might yield the data necessary to accomplish this task.

- The resiliency index developed in this thesis is independent of scenario and provides a simple measure of the inherent resiliency of the unit. There are several modifications which could be used to include specific scenarios, and thereby estimate the circumstantial resiliency of the unit. For example, if the Mechanized Infantry Company was to be deployed in Western Europe in a defensive posture against a soviet tank regiment, then firepower scores could be replaced by weapon system equivalence scores (WSES), which incorporate scenario dependent probabilities of kill into Lanchester homogeneous and nonhomogeneous equations.

- In a scenario dependent index, the resiliency of the unit subject to logistical constraints could be estimated. For example, an ammunition resupply rate (rounds required per day/days between logistical support), and a petroleum resupply rate (gallons of petroleum required per day/days between logistical support) could be used to obtain a measure of a unit's circumstantial resiliency.

- The S_{ij} matrices used to compute the degree of task similarity and the impact of adding secondary MOSs treat all tasks as the same in terms of their relative importance. Weights could be placed on those tasks which are the most critical. Additionally, an integer optimization could be accomplished by maximizing the task depth, subject to minimum constraint levels on certain critical tasks. Secondary MOSs could be included and an optimal force structure of primary and secondary MOSs determined.

- A cost module can be included in the index to provide estimates of the cost of various alternative TOE designs. This enhancement would provide designers with a means of determining optimal designs with respect to cost constraints.

APPENDIX A. THE RESILIENCY SURVEY

DEPARTMENT OF THE NAVY
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CA 93943-5100

IN REPLY REFER TO:

Department of Administrative Sciences

NC4(54Mr)
29 July 1987

SUBJECT: Survey of TOE Designers

@ADDR1
ATTN: @ADDR2 (@PREFIX @LAST)
@CITY, @STATE @ZIP

Dear @PREFIX @LAST:

As you may know, our Department is doing research for the TRADOC Analysis Command on the use of resiliency in the design process for Tables of Organization and Equipment (TOEs). Resiliency has been defined as the ability of a military unit to perform its mission over time, including times following hostile attack. Although resiliency is difficult to measure, it is an important concept for TOE design. So we must find better ways to use this concept in the TOE design process. We hope the enclosed survey will allow you to help us create better ways to estimate the amount of resiliency in a TOE design.

We have found that resiliency is secondary to combat effectiveness and cost considerations in the TOE design process. This is partly due to the difficulty of measuring and defining resiliency. We are assuming that you use resiliency (in some way) when you design a TOE, even if you don't have a formal policy about it. The survey is designed to discover how you think about and use resiliency when you design, review, or approve a TOE.

This information will be used for research purposes only. Your responses will be held in the strictest confidence. They won't be attributed to you or your organization unless you give us written permission. Our research sponsor will not see your survey. Only the thesis student working on the project and I will. Please give us responses which reflect the way you actually do business.

Your completed survey will definitely have an impact on the analysis and will be greatly appreciated. It should be mailed to us no later than 30 August in the enclosed, pre-addressed envelope. If you would like a copy of the final research results, please enclose a self-addressed, 9x12 envelope with your completed survey. This report should be available sometime next fall.

Sincerely yours,

Thomas P. Moore

THOMAS P. MOORE
Asst. Professor of Mgt. Science,
Principal Investigator

Encl 1

DEPARTMENT OF THE NAVY
NAVAL POSTGRADUATE SCHOOL
Department of Administrative Sciences, Code 54Mr
Monterey, California 93943-5008

July 29, 1987

SURVEY (Group II)

Subject: Resiliency Analysis in the TOE Design Process

Section I: Introduction

The purpose of this survey is to obtain data about the way Army TOEs are actually designed, reviewed and approved, and how the concept of resiliency may affect this process.

The work of a TOE designer may include the design of new TOEs, modification of existing TOEs, or the review or approval of design proposals. The term "TOE design" refers to processes which may include: specifying the MOSs of personnel in the TOE; specifying the number of soldiers with a given MOS to be assigned to the unit; specifying the amount and type (LIN) of equipment, supplies, parts, ammunition, tools, and test equipment in the TOE. The TOE design process also includes the modification of an existing TOE to accommodate the addition of improved equipment or changes in the number and training of personnel specified in the TOE.

For this survey, one "TOE modification" is defined to be the collection of all changes a TOE designer makes to a TOE in a single work effort (such an effort may be as short as a few days or as long as several months) and which is in response to:

a. The availability of a new item of equipment, i.e. a new pistol, a new truck, a new test set, or a new howitzer.

b. The creation, deletion or modification of an MOS.

c. A change in the mission or in the anticipated employment of the unit.

Resiliency is defined by Dr. Terrence Klopcic of the U.S. Army Ballistic Research Lab as "the ability of a military unit to perform its mission over time, including times following hostile attack." The term "reconstitute" is often used in conjunction with the concept of resiliency. "To reconstitute" refers to those actions taken by a military unit (upon completion of its current mission) to repair damage, reassign duties, and prepare for its next mission.

If you're uncertain about the meaning of any question, please call Prof. Tom Moore at autovon 878-2642/2471 or commercial (408) 646-2642/2471 between 1000 and 1700 PST for an explanation. If

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you need to clarify or qualify any of your responses, please do so on a separate sheet of paper, or on the survey, if there is space.

Section II: Demographic Information

1. Your name - ______________________________

2. Your autovon telephone number - ______________________

3. Your mailing address - ______________________
(Please include your
office symbol.) ______________________

____

4. Please indicate the category which best describes your present role in the TOE design process:

____ Determining the number and types of equipment, and number and types of soldiers to put in a TOE. This also includes these determinations when modifying existing TOEs.

____ Reviewing and evaluating the designs proposed by a TOE designer.

____ Approving the designs proposed by a TOE designer.

____ Other: (please describe)

5. Number of months you have been performing this role - ________

6. If you have also worked in any other category in Question 4, please indicate the number of months experience you have:

Number of
Months

____ Determining the number and types of equipment, and number and types of soldiers to put in a TOE. This also includes the making of these determinations when modifying existing TOEs.

____ Reviewing and evaluating the designs proposed by a TOE designer.

____ Approving the designs proposed by a TOE designer.

____ Other: (please describe)

Encl 2

7. How many of each of the following types of TOEs is your organization presently responsible for designing and maintaining?

Section/Squad _____

Platoon __________

Company __________

Battalion ________

Brigade __________

Division _________

8. How many new TOE designs did you work on between July 1, 1986 and July 1, 1987? How many new designs did your organization work on during the same period? What is your estimate of the yearly average number of new TOE designs done by your organization over the last 3 calendar years?

	You	Your Organization	Organization's Estimated Yearly Average
Section/Squad	_____	_____	_____
Platoon	_____	_____	_____
Company	_____	_____	_____
Battalion	_____	_____	_____
Brigade	_____	_____	_____
Division	_____	_____	_____

Encl 2

9. How many TOE modifications did you work on between July 1, 1986 and July 1, 1987? How many modifications did your organization work on during the same period? What is your estimate of the yearly average number of TOE modifications done by your organization over the last 3 calendar years?

	You	Your Organization	Organization's Estimated Yearly Average
Section/Squad	_____	_____	_____
Platoon	_____	_____	_____
Company	_____	_____	_____
Battalion	_____	_____	_____
Brigade	_____	_____	_____
Division	_____	_____	_____

Section III: Your Current TOE Design Procedures

10. When designing or modifying a TOE, you use several criteria to judge the design. Examine the criteria described below, and mark the ones you use. Indicate the most important criteria with a "1", the second most important with a "2", etc. If two criteria are nearly the same in importance, rank one above the other, but write us a note indicating that you feel they are close. Leave blank those criteria which you don't use.

____ Combat effectiveness of the TOE.

____ Total cost of the equipment and personnel in the TOE.

____ Resiliency of the TOE. (See definition in Section I.)

____ Annual personnel costs for the TOE.

____ Annual support (logistics, etc.) costs for the TOE.

____ Total of all annual operating costs for the TOE.

____ Cost of procuring the equipment for the TOE.

____ Whether or not the TOE is below its manpower ceiling.

____ Combat survivability of the TOE.

____ Combat supportability of the TOE.

____ How well the TOE conforms to applicable Regulations.

____ Other: (please describe)

Encl 2

11. If you primarily design or modify TOE's, please estimate the <u>average number of man-hours</u> it takes for your organization to do each of the following activities:

____ Design the TOE for a new platoon.

____ Design the TOE for a new company.

____ Design the TOE for a new battalion.

____ Modify a TOE to add or delete a major item of equipment.

____ Modify a TOE to add or delete personnel.

12. If you primarily review the TOE's designed by others, please estimate the <u>average number of man-hours</u> it takes for your organization to do each of the following activities:

____ Review the TOE design for a new platoon.

____ Review the TOE design for a new company.

____ Review the TOE design for a new battalion.

____ Review the modification of a TOE to add a major item of equipment.

____ Review the modification of a TOE to add or delete personnel.

Section IV: Resiliency and TOE Design

The questions in this section ask for your opinion about relationships between resiliency and certain characteristics of a TOE design. For each characteristic please indicate whether you believe its influence on resiliency is strongly positive, weakly positive, strongly negative, weakly negative, or no influence.

A positive influence is a characteristic which, when increased, leads to an increase in the resiliency of the TOE design. On the other hand, a characteristic which is a negative influence decreases resiliency when the characteristic increases.

13. Characteristic: Number of different MOSs in the TOE.

____	____	____	____	____
strongly positive	weakly positive	no influence	weakly negative	strongly negative

Encl 2

14. Characteristic: An average of the numbers of soldiers assigned to each MOS in the TOE, i.e. the number of people in the TOE divided by the number of MOSs in the TOE.

___	___	___	___	___
strongly positive	weakly positive	no influence	weakly negative	strongly negative

15. Characteristic: The degree of similarity between the tasks involved in the MOSs in the TOE.

___	___	___	___	___
strongly positive	weakly positive	no influence	weakly negative	strongly negative

16. Characteristic: The degree of vulnerability to combat damage and destruction possessed by the personnel in the TOE.

___	___	___	___	___
strongly positive	weakly positive	no influence	weakly negative	strongly negative

17. Characteristic: The degree of vulnerability to combat damage and destruction possessed by the equipment in the TOE.

___	___	___	___	___
strongly positive	weakly positive	no influence	weakly negative	strongly negative

18. Characteristic: The number of different kinds of major equipment (major end items) in the TOE.

___	___	___	___	___
strongly positive	weakly positive	no influence	weakly negative	strongly negative

19. Characteristic: The degree of substitutability (the ability to do the job of a different type of equipment) between the various types of equipment in the TOE.

___	___	___	___	___
strongly positive	weakly positive	no influence	weakly negative	strongly negative

Encl 2

20. Characteristic: The technical complexity of maintaining and repairing the equipment in the TOE.

___	___	___	___	___
strongly positive	weakly positive	no influence	weakly negative	strongly negative

21. Characteristic: The technical complexity of operating the equipment in the TOE.

___	___	___	___	___
strongly positive	weakly positive	no influence	weakly negative	strongly negative

22. Characteristic: The amount of time it takes to repair battle and usage related damage to the equipment in the TOE.

___	___	___	___	___
strongly positive	weakly positive	no influence	weakly negative	strongly negative

23. Characteristic: The average of the quantities of each type of major equipment in the TOE, i.e. the mean number of units of equipment per equipment type.

___	___	___	___	___
strongly positive	weakly positive	no influence	weakly negative	strongly negative

24. Characteristic: The degree of crosstraining (in the other MOSs in the TOE) possessed by the personnel in the TOE.

___	___	___	___	___
strongly positive	weakly positive	no influence	weakly negative	strongly negative

25. Characteristic: The skills and abilities of the personnel who will manage and/or command the unit.

___	___	___	___	___
strongly positive	weakly positive	no influence	weakly negative	strongly negative

Encl 2

26. Characteristic: The degree to which the unit plans and trains for reconstitution after a battle.

___	___	___	___	___
strongly positive	weakly positive	no influence	weakly negative	strongly negative

27. Characteristic: The morale of the unit's personnel, and/or their willingness to fight, immediately after the battle has ended.

___	___	___	___	___
strongly positive	weakly positive	no influence	weakly negative	strongly negative

28. Characteristic: The generic size of the unit, i.e. squad, platoon, company/battery/troop, battalion/squadron, brigade/regiment, or division. What effect does increasing size have on resiliency?

___	___	___	___	___
strongly positive	weakly positive	no influence	weakly negative	strongly negative

The next set of questions asks you to compare selected pairs of characteristics and indicate their relative influence upon resiliency. The characteristics are referred to by their original question number (from questions 13 - 28 above). FOR YOUR CONVENIENCE, all of the descriptions of the characteristics have been collected on a single page attached to the back of the survey. Please read, again, the description of each characteristic in the pair before answering each question below. (Each question has two parts. Circle the appropriate response(s). If you circle response 1) in part a., you may skip part b. of that question.)

29. Characteristic 17 and 22:

a. Which characteristic has more influence on resiliency?

1) They have equal influence on resiliency.
2) 17.
3) 22.

b. How much more influential is the characteristic you circled above than the other?

1) Slightly more influential.
2) Quite a bit more influential.
3) Immensely more influential.
4) Absolutely more influential.

Encl 2

30. Characteristic 17 and 23:

a. Which characteristic has more influence on resiliency?

1) They have equal influence on resiliency.
2) 17.
3) 23.

b. How much more influential is the characteristic you circled above than the other?

1) Slightly more influential.
2) Quite a bit more influential.
3) Immensely more influential.
4) Absolutely more influential.

31. Characteristic 17 and 24:

a. Which characteristic has more influence on resiliency?

1) They have equal influence on resiliency.
2) 17.
3) 24.

b. How much more influential is the characteristic you circled above than the other?

1) Slightly more influential.
2) Quite a bit more influential.
3) Immensely more influential.
4) Absolutely more influential.

32. Characteristic 17 and 26:

a. Which characteristic has more influence on resiliency?

1) They have equal influence on resiliency.
2) 17.
3) 26.

b. How much more influential is the characteristic you circled above than the other?

1) Slightly more influential.
2) Quite a bit more influential.
3) Immensely more influential.
4) Absolutely more influential.

33. Characteristic 22 and 23:

a. Which characteristic has more influence on resiliency?

1) They have equal influence on resiliency.
2) 22.
3) 23.

Encl 2

b. How much more influential is the characteristic you circled above than the other?

1) Slightly more influential.
2) Quite a bit more influential.
3) Immensely more influential.
4) Absolutely more influential.

34. Characteristic 22 and 24:

a. Which characteristic has more influence on resiliency?

1) They have equal influence on resiliency.
2) 22.
3) 24.

b. How much more influential is the characteristic you circled above than the other?

1) Slightly more influential.
2) Quite a bit more influential.
3) Immensely more influential.
4) Absolutely more influential.

35. Characteristic 22 and 26:

a. Which characteristic has more influence on resiliency?

1) They have equal influence on resiliency.
2) 22.
3) 26.

b. How much more influential is the characteristic you circled above than the other?

1) Slightly more influential.
2) Quite a bit more influential.
3) Immensely more influential.
4) Absolutely more influential.

36. Characteristic 23 and 24:

a. Which characteristic has more influence on resiliency?

1) They have equal influence on resiliency.
2) 23.
3) 24.

b. How much more influential is the characteristic you circled above than the other?

1) Slightly more influential.
2) Quite a bit more influential.
3) Immensely more influential.
4) Absolutely more influential.

Encl 2

37. Characteristic 23 and 26:

a. Which characteristic has more influence on resiliency?

1) They have equal influence on resiliency.
2) 23.
3) 26.

b. How much more influential is the characteristic you circled above than the other?

1) Slightly more influential.
2) Quite a bit more influential.
3) Immensely more influential.
4) Absolutely more influential.

38. Characteristic 24 and 26:

a. Which characteristic has more influence on resiliency?

1) They have equal influence on resiliency.
2) 24.
3) 26.

b. How much more influential is the characteristic you circled above than the other?

1) Slightly more influential.
2) Quite a bit more influential.
3) Immensely more influential.
4) Absolutely more influential.

The next set of questions deals in a more general way with resiliency and the TOE design process. Please answer these questions in accordance with your personal experience.

39. Which of the following statements most accurately describes your use of the concept of resiliency as it applies to the TOE design process (circle one):

a. Resiliency is an indispensable factor in the TOE design process.
b. Resiliency is a somewhat important factor in the TOE design process.
c. Resiliency comes into play in the TOE design process after all other major measures of design performance have been adequately addressed.
d. Resiliency is not a factor in the TOE design process.

Encl 2

40. Have you ever used a quantitative tool, process, procedure or software for resiliency analysis? (These might include such things as AMORE or AURA. You might have used these tools to measure or forecast the resiliency of a new or existing TOE.) (Circle one.)

   a. Yes.
   b. No.
   c. Not certain.

41. If you answered "Yes" to question 23, please describe, on the back of this page, the tool, procedure, process or software you used and how often you have used it. Please indicate the difficulty or ease of use you experienced, and the success or failure of the effort.

The last three questions ask about the personal computer hardware you use, and the computer software you are familiar with. This information is necessary to help us determine the best type of computer for which to write resiliency software.

42. Circle the type(s) of personal, office and desktop computer systems available to you at your office:

   a. IBM personal computer.
   b. IBM compatible Zenith PC (Z-150, Z-148, etc.).
   c. Non-IBM compatible Zenith PC (Z-100, Z-110, Z-120).
   d. Wyse terminals and Intel central processing unit.
   e. Wyse personal computer.
   f. DEC Rainbow 100 personal computer (A, B or + models).
   g. Apple MacIntosh personal computer.
   h. IBM-AT personal computer.
   i. Other: ______________________

43. Circle the type(s) of personal, office and desktop computer systems you have at least 10 hours of accumulated hands-on experience with:

   a. IBM personal computer.
   b. IBM compatible Zenith PC (Z-150, Z-148, etc.).
   c. Non-IBM compatible Zenith PC (Z-100, Z-110, Z-120).
   d. Wyse terminals and Intel central processing unit.
   e. Wyse personal computer.
   f. DEC Rainbow 100 personal computer (A, B or + models).
   g. Apple MacIntosh personal computer.
   h. IBM-AT personal computer.
   i. Other: ______________________

Encl 2

44. Circle the type(s) of software you have at least 5 hours of accumulated hands-on experience with:

a. Word Perfect word processor.
b. Word Star word processor.
c. Display Write word processor.
d. Multimate word processor.
e. Lotus 1-2-3 spreadsheet.
f. Visicalc spreadsheet.
g. Multiplan spreadsheet.
h. MS-DOS or PC-DOS operating system.
i. BASIC programming language.
j. FORTRAN programming language.
k. COBOL programming language.
l. PASCAL programming language.
m. PL1 programming language.
n. dBase II, III, or III Plus database system.

45. Of the TOEs which your organization is responsible for, please give the name and number of the one which you believe to have the **most** resiliency.

____

46. Of the TOEs which your organization is responsible for, please give the name and number of one which you believe to have a typical amount of resiliency.

____

47. Of the TOEs which your organization is responsible for, please give the name and number of the one which you believe to have the **least** resiliency.

____

Encl 2

LIST OF CHARACTERISTICS
(for use with Questions 29 - 38)

17. The degree of vulnerability to combat damage and destruction possessed by the equipment in the TOE.

22. The amount of time it takes to repair battle and usage related damage to the equipment in the TOE.

23. The average of the quantities of each type of major equipment in the TOE, i.e. the mean number of units of equipment per equipment type.

24. The degree of crosstraining (in the other MOSs in the TOE) possessed by the personnel in the TOE.

26. The degree to which the unit plans and trains for reconstitution after a battle.

APPENDIX B. WRITTEN SURVEY COMMENTS

- I believe we try to accomodate resiliency but it is extremely difficult in missile support units due to cost and limited density of equipment.

- As long as there are personnel and budget caps/constraints, neither resiliency, nor any other design criteria get to play in the design process. Any designer that tells you different is full of bull. That includes those who would say MARC and SGA have a degree of resiliency built in. Manpower reduction and/or zero sum game is the design criteria.

- We never used to use cost but decided toward the end of my tour to start using cost. The methodology is under study.

- R3 study, resiliency/redundancy/robustness study shot down in the early 80's; was found to be infeasible, costly in terms of goals.

- The question of equipment availability rates a 1 in modifying a TOE[9].

- Resiliency should be, but in my opinion is not a factor in designing TOE's. When we are constrained by manpower to the extent that adding personnel requires removing them in equal numbers from somewhere else, then resiliency is not a consideration. We design for "minimum essential combat requirements".

- People are about equally vulnerable- what differs is exposure to risk and organic equipment. We tend to give those so exposed more protection (exception, light infantry), but expose them more. Those less exposed get to live in CP tents instead of tracks. As the end result in a TOE-who knows?

- The bottom line: redundancy and back-up are always good!

- You train for skills but must select for ability. Once out of the realm of operating something ability is very hard to measure; (ie. above the level of crew chief or operator) ability becomes a judgement call.

- Obviously units can be too big, but if they are too small there is no resiliency. Must be large enough to offer several tactical options to combat situations (or courses of action for division or corps) but still be small enough to be managed and sustained.

- We used the AMORE process several years back. However, it was never a very useful tool for the TOEs we developed. We could predict what AMORE would tell us, without having ot do all of the research input required of the AMORE process. An AMORE or similar tool is useful (maybe) to a combat unit, but not for a service support type unit in the Corps (or above) area.

- I'm not sure I see how you can separate these into distinct characteristics of a TOE. One begets the other and vice versa.

---

[9] This comment is referring to question number 10 of the survey where respondents were asked to rank order design criteria from most important to least important. The rank of 1 is most important.

- Our experience has been too limited to point to specific TOEs, but it should be noted that any given TOE can appear resilient under certain circumstances and not-resilient under others.

- AURA analysts, by their nature, look at the "outliers", or choke points. These choke points tend to obscure other potential brittly personnel or equipment. Under a slightly different stress (combat damage in defferent place, longer combat hours, higher battlefield temperature or humidity, etc) these choke points "shift" and other personnel or equipment will surface. For this reason, "resiliency" should always be defined in the context of a particular study. Ideally, many different scenarios should be examined, but this takes more time and resources.

APPENDIX C. TABLES FROM CONSTRUCTING INTERVAL SCALES FROM ORDINAL DATA

Table 20. PIJ ARRAY FOR TOE DESIGN CRITERIA

	Q49	Q50	Q51	Q52	Q53	Q54	Q55	Q56	Q57	Q58	Q59	Q60
Q49	-	.611	.395	.771	.694	.771	.667	.318	.208	.250	.500	.889
Q50	.389	-	.433	.857	.625	.786	.500	.270	.361	.324	.231	.778
Q51	.605	.567	-	.741	.621	.703	.586	.467	.459	.463	.366	.839
Q52	.229	.143	.259	-	.455	.625	.250	.171	.229	.171	.182	.615
Q53	.306	.375	.379	.545	-	.818	.615	.189	.286	.257	.200	.786
Q54	.229	.214	.297	.375	.182	-	.333	.171	.229	.200	.182	.615
Q55	.333	.500	.414	.750	.385	.667	-	.297	.333	.306	.278	.750
Q56	.682	.730	.533	.829	.811	.829	.703	-	.605	.710	.341	.944
Q57	.792	.639	.541	.771	.714	.771	.667	.395	-	.317	.386	.943
Q58	.750	.676	.537	.829	.743	.800	.694	.290	.683	-	.385	.943
Q59	.500	.769	.634	.818	.800	.818	.722	.659	.614	.615	-	.970
Q60	.111	.222	.161	.385	.214	.385	.250	.056	.057	.057	.030	-

Table 21. ZIJ ARRAY FOR TOE DESIGN CRITERIA

	Q49	Q50	Q51	Q52	Q53	Q54	Q55	Q56	Q57	Q58	Q59	Q60
Q49	0	.28	-.26	.74	.51	.74	.43	-.47	-.81	-.67	0	1.2
Q50	-.28	0	-.14	1.7	.32	.79	0	-.61	-.34	-.45	-.73	.77
Q51	.26	.14	0	.64	.31	.53	.22	-.08	-.11	-.09	-.33	.99
Q52	-.74	-1.7	-.64	0	-.11	.32	-.67	-.95	-.74	-.95	-.90	.29
Q53	-.51	-.32	-.31	.11	0	.91	.29	-.88	-.56	-.65	-.84	.79
Q54	-.74	-.79	-.53	-.32	-.91	0	-.43	-.95	-.74	-.84	-.91	.29
Q55	-.43	0	-.22	.67	-.29	.43	0	-.53	-.43	-.52	-.59	.67
Q56	.47	.61	.08	.95	.88	.95	.53	0	.27	.55	-.42	1.5
Q57	.81	.35	.11	.74	.56	.74	.43	-.27	0	-.47	-.29	1.5
Q58	.67	.45	.09	.95	.65	.84	.52	-.55	.47	0	-.29	1.5
Q59	0	.73	.33	.90	.84	.915	.59	.42	.29	.29	0	1.8
Q60	-1.2	-.77	-.99	.29	-.79	-.29	-.67	-1.5	-1.5	-1.5	-1.8	0

APPENDIX D. TABLES CONSTRUCTING INTERVAL SCALES FROM CATEGORICAL JUDGMENTS

Table 22. RESILIENCY AND TOE DESIGN RAW FIJ FREQUENCY ARRAY

Var	Strongly Negative	Weakly Negative	No Influence	Weakly Positive	Strongly Positive
Q71	11	14	5	10	13
Q72	1	6	15	16	16
Q73	0	2	11	22	20
Q74	17	5	4	10	18
Q75	17	13	5	3	18
Q76	13	10	14	5	13
Q77	0	4	10	16	26
Q78	21	9	9	6	11
Q79	13	15	10	7	11
Q80	18	13	7	5	13
Q81	1	6	11	21	15
Q82	3	3	9	17	24
Q83	0	1	14	9	32
Q84	2	0	11	19	24
Q85	1	2	13	9	31
Q86	1	3	17	17	17

Table 23. CUMULATIVE RELATIVE FREQUENCY PIJ ARRAY

Var	Strongly Negative	Weakly Negative	No Influence	Weakly Positive	Strongly Positive
Q71	.2075	.4717	.566	.7547	1
Q72	.01856	.1296	.4074	.7037	1
Q73	0	.0363	.2364	.6364	1
Q74	.3148	.4074	.4815	.6667	1
Q75	.3036	.5357	.625	.6786	1
Q76	.2364	.4182	.6727	.7636	1
Q77	0	.0714	.25	.5357	1
Q78	.375	.5357	.6964	.8036	1
Q79	.2321	.5	.6786	.8036	1
Q80	.3214	.5536	.6786	.7679	1
Q81	.0185	.1296	.3333	.7222	1
Q82	.0536	.1071	.2679	.5714	1
Q83	0	.0179	.2679	.4286	1
Q84	.0357	.0357	.2321	.5714	1
Q85	.0179	.0536	.2857	.4464	1
Q86	.0182	.0727	.3818	.6909	1

Table 24. ZIJ ARRAY FOR RESILIENCY CHARACTERISTICS

Var	Strongly Negative	Weakly Negative	No Influence	Positive	Row Total	Row Av
Q71	-815	-.07	.17	.69	-.025	0062
Q72	-2.08	-1.13	-.24	.535	-2.915	.7287
Q73	-3.0	-1.79	-.72	.35	-5.16	-1.29
Q74	-.48	-.24	-.05	.43	-.34	-.085
Q75	-.515	.09	.32	.46	.355	.0887
Q76	-.71	-.21	.45	.72	.25	.0625
Q77	-3.0	-1.44	-.675	.09	-5.025	-1.2563
Q78	-.32	.09	.515	.855	1.78	.445
Q79	-.73	0	.465	.855	.59	.1475
Q80	-.455	.135	.46	.73	.87	.2175
Q81	-2.08	-1.13	-.43	.59	-3.05	-.7625
Q82	-1.61	-1.24	-.62	.18	-3.29	-.8225
Q83	-3.0	-2.11	-.62	-.18	-5.9	-1.475
Q84	-1.8	-1.8	-.73	.18	-4.15	-1.0375
Q85	-1.24	-1.61	-.56	-1.35	-3.545	-.8863
Q86	-2.09	-1.455	-.3	.5	-3.545	-.8362

APPENDIX E. 8 X 8 PAIRWISE COMPARISON MATRIX

1	29A 38C	30A	31A	32A	29C	30C	31C
1/29A 1/38C	1	33A	34A	35A	32C	33C	34C
1/30A	1/33A	1	36A	37A	1/35C	36C	37C
1/31A	1/34A	1/36A	1	38A 36B	1/30B	1/33B	37B
1/32A	1/35A	1/37A	1/38A 1/36B	1	1/31B	1/34B	38B
1/29C	1/32C	35C	30B	31B	1	29B	32B
1/30C	1/33C	1/36C	33B	34B	1/29B	1	35B
1/31C	1/30C	1/37C	1/37B	1/38B	1/32B	1/35B	1

Figure 8. Aggregated 8 x 8 Pairwise Comparison Matrix for All Surveys.: The letters A, B, and C refer to surveys 1,2, and 3 respectively. 33A represents the multiplicative n^{th} root of all survey 1 responses for question 33 and 1/33A represents the inverse.

APPENDIX F. APL PROGRAM TO COMPUTE CONSISTENT AHP COEFFICIENTS

```
⍝ INITIALIZE VARIABLES AND SET UP OUTPUT HEADER
⍝
⎕←'  INITIAL      ITERATIONS      LARGEST          LARGEST ROW      ROW NUMBER
   OF '
⎕←' CONSISTENCY       TO          AIJ VALUES      ROOT MEAN SQUARE      LARGEST
   '
⎕←'   INDEX       CONSISTENCY  1ST   2ND   3RD       DEVIATION            RMSD '
⎕←''
J←0
N←5
NSQ←N*2
K←1
L←1
COUNTCI←0
TERM←0
⍝
⍝ READ PAIRWISE VALUES FROM INDIVIDUAL SURVEY MATRICIES
⍝
LOOP1:
 COUNTCI←0
 I←1
 J←J+1
 →(J>14)/MODEL
 Y←AHP1
 Y← 10 14 ⍴Y
 Y1←Y[I;J]
 Y2←Y[I+1;J]
 Y3←Y[I+2;J]
 Y4←Y[I+3;J]
 Y5←Y[I+4;J]
 Y6←Y[I+5;J]
 Y7←Y[I+6;J]
 Y8←Y[I+7;J]
 Y9←Y[I+8;J]
 Y10←Y[I+9;J]
 YY1←1,Y1,Y2,Y3,Y4,(÷Y1),1,Y5,Y6,Y7,(÷Y2),(÷Y5),1,Y8,Y9,(÷Y3)
 YY2←(÷Y6),(÷Y8),1,Y10,(÷Y4),(÷Y7),(÷Y9),(÷Y10),1
 MAT← 5 5 ⍴YY1,YY2
 RT←0
⍝
⍝ COMPUTE EIGENVALUES AND EIGENVECTORS
⍝
LOOP2:
 EIG←EIGEN MAT
 LMAX←EIG[1;1;1]
 EVEC←EIG[1;1+⍳5;1]
 MDW←EVEC÷(+/EVEC)
 MDW← 1 5 ⍴MDW
 EVEC← 1 5 ⍴EVEC
 CI←(LMAX-N)÷(N-1)
 CR←CI÷(1.12)
 →(RT≠0)/CONTINUE
 ICI←CR
CONTINUE:
⍝
⍝ TEST IF CR IS LESS THAN TARGETED VALUE
⍝
 →(CR≤0.1)/BRANCH2
⍝
⍝ COMPUTE MODEL WEIGHTS
⍝
 W1←EVEC[1;1]
 W2←EVEC[1;2]
 W3←EVEC[1;3]
 W4←EVEC[1;4]
 W5←EVEC[1;5]
 W←W1,W2,W3,W4,W5
 C1←W÷W1
 C2←W÷W2
 C3←W÷W3
 C4←W÷W4
 C5←W÷W5
⍝
⍝ FORM WI/WJ MATRIX AND COMPUTE ABSOLUTE DIFFERENCE FROM AIJ MATRIX
⍝
 BW←⍉(5 5 ⍴C1,C2,C3,C4,C5)
 XX←(|MAT-BW)
 B←,XX
 BB←⍒B
 D1←(BB=NSQ)
 BIG1←D1⍳BB
 BIG1←(BIG1≠(NSQ+1))/BIG1
 D2←(BB=(NSQ-1))
 BIG2←D2⍳BB
 BIG2←(BIG2≠(NSQ+1))/BIG2
 D3←((BB=NSQ-2))
 BIG3←D3⍳BB
 BIG3←(BIG3≠(NSQ+1))/BIG3
 BIGV←BIG1,BIG2,BIG3
 K←1
⍝
⍝ DETERMINE AIJ ROW WITH LARGEST ROOT MEAN SQUARED DEVIATION
⍝
LOOP3:→(K>N)/BRANCH1
 R←(+/((MAT[K;]-BW[K;])*2))*0.5
 →(R>DUM)/COUNT
 DUM←R
 ROW←K
COUNT:K←K+1
```

```
 →LOOP3
⍝
⍝ REPLACE LARGEST MEAN SQUARED DEVIATION ROW WITH CORRESPONDING
⍝WI/WJ ROW AND CONTINUE ITERATING UNTIL CR≤ CONDITION
⍝
BRANCH1:
 MAT[ROW;]←BW[ROW;]
 COUNTCI←COUNTCI+1
 RT←1
 →LOOP2
⍝
⍝ AFTER CR CONDITION IS MET STORE INDIVIDUAL'S REVISED JUDGEMENTS
⍝
BRANCH2:→(TERM=1)/OUTPUT2
 MAT← 10 1 ⍴MAT
 →(J≠1)/GO1
 STOR←MAT
 →(J=1)/GO2
GO1:STOR←STOR,[2] MAT
GO2:FCOUNT←COUNTCI
⍝
⍝ PRODUCE TABLE OF FORMATED OUTPUT, RESET COUNTERS, AND GET NEXT
⍝INDIVIDUAL'S PAIRWISE RESPONSES
⍝
 ⎕←' ',(⍕ICI),' ',' ',(⍕FCOUNT),'          ',(⍕BIG1),'      ',(⍕BIG2)
  ,'     ',(⍕BIG3),'         ',(⍕DUM),'           ',(⍕ROW)
 COUNTCI←0
 ICI←0
 DUM←0
 →LOOP1
⍝
⍝ PRODUCE GROUP MODEL FROM STORED CONSISTENT INDIVIDUAL RESPONSES
⍝
MODEL:
 Q1←STOR[1;]
 Q2←STOR[2;]
 Q3←STOR[3;]
 Q4←STOR[4;]
 Q5←STOR[5;]
 Q6←STOR[6;]
 Q7←STOR[7;]
 Q8←STOR[8;]
 Q9←STOR[9;]
 Q10←STOR[10;]
 N1←÷(⍴Q1)
 N2←÷(⍴Q2)
 N3←÷(⍴Q3)
 N4←÷(⍴Q4)
 N5←÷(⍴Q5)
 N6←÷(⍴Q6)
 N7←÷(⍴Q7)
 N8←÷(⍴Q8)
 N9←÷(⍴Q9)
 N10←÷(⍴Q10)
 M1←((Q1×.×Q1)*0.5)*N1
 M2←((Q2×.×Q2)*0.5)*N2
 M3←((Q3×.×Q3)*0.5)*N3
 M4←((Q4×.×Q4)*0.5)*N4
 M5←((Q5×.×Q5)*0.5)*N5
 M6←((Q6×.×Q6)*0.5)*N6
 M7←((Q7×.×Q7)*0.5)*N7
 M8←((Q8×.×Q8)*0.5)*N8
 M9←((Q9×.×Q9)*0.5)*N9
 M10←((Q10×.×Q10)*0.5)*N10
⍝
⍝ FORM FINAL GROUP MATRIX
⍝
 M←M1,M2,M3,M4,M5,M6,M7,M8,M9,M10
 M← 10 1 ⍴M
 II←1
 JJ←1
 Y1←M[II;JJ]
 Y2←M[II+1;JJ]
 Y3←M[II+2;JJ]
 Y4←M[II+3;JJ]
 Y5←M[II+4;JJ]
 Y6←M[II+5;JJ]
 Y7←M[II+6;JJ]
 Y8←M[II+7;JJ]
 Y9←M[II+8;JJ]
 Y10←M[II+9;JJ]
 YY1←1,Y1,Y2,Y3,Y4,(÷Y1),1,Y5,Y6,Y7,(÷Y2),(÷Y5),1,Y8,Y9,(÷Y3)
 YY2←(÷Y6),(÷Y8),1,Y10,(÷Y4),(÷Y7),(÷Y9),(÷Y10),1
 MAT← 5 5 ⍴YY1,YY2
 TERM←1
⍝
⍝ RETURN TO EIGENVALUE/EIGENVECTOR BLOCK AND COMPUTE FINAL MODEL
⍝
 →LOOP2
OUTPUT2:
⍝
⍝ FINAL MODEL WEIGHTS PER CHARACTERISTIC
⍝
 V←NOW
 ⎕←''
 ⎕←'                    CHARACTERISTICS'
 ⎕←''
 ⎕←'        NO1            NO2            NO3              NO4            NO5'
 ⎕←'       ',(⍕(V[;1])),'         ',(⍕(V[;2])),'         ',(⍕(V[;3])),'         '
  ,(⍕(V[;4])),'          ',(⍕(V[;5]))
OVER:⎕←'PROGRAM IS OVER'
```

APPENDIX G. APL PROGRAM TO DERIVE GROUP AHP COEFFICIENTS

```
⍝  EXTRACT PAIRWISE COMPARISON ANSWER VECTOR FROM ALL SURVEYS
 ⎕←' '
 B←BIGSUR
 Q88A←B[88;⍳18]
 Q90A←B[90;⍳18]
 Q92A←B[92;⍳18]
 Q94A←B[94;⍳18]
 Q96A←B[96;⍳18]
 Q98A←B[98;⍳18]
 Q100A←B[100;⍳18]
 Q102A←B[102;⍳18]
 Q104A←B[104;⍳18]
 Q106A←B[106;⍳18]
 Q88B←B[88;18+⍳25]
 Q90B←B[90;18+⍳25]
 Q92B←B[92;18+⍳25]
 Q94B←B[94;18+⍳25]
 Q96B←B[96;18+⍳25]
 Q98B←B[98;18+⍳25]
 Q100B←B[100;18+⍳25]
 Q102B←B[102;18+⍳25]
 Q104B←B[104;18+⍳25]
 Q106B←B[106;18+⍳25]
 Q88C←B[88;43+⍳16]
 Q90C←B[90;43+⍳16]
 Q92C←B[92;43+⍳16]
 Q94C←B[94;43+⍳16]
 Q96C←B[96;43+⍳16]
 Q98C←B[98;43+⍳16]
 Q100C←B[100;43+⍳16]
 Q102C←B[102;43+⍳16]
 Q104C←B[104;43+⍳16]
 Q106C←B[106;43+⍳16]
⍝
⍝             ELIMINATE ALL NULL ENTRIES IN EACH ANSWER VECTOR
⍝
 Q88A←(Q88A≠¯1)/Q88A
 Q90A←(Q90A≠¯1)/Q90A
 Q92A←(Q92A≠¯1)/Q92A
 Q94A←(Q94A≠¯1)/Q94A
 Q96A←(Q96A≠¯1)/Q96A
 Q98A←(Q98A≠¯1)/Q98A
 Q100A←(Q100A≠¯1)/Q100A
 Q102A←(Q102A≠¯1)/Q102A
 Q104A←(Q104A≠¯1)/Q104A
 Q106A←(Q106A≠¯1)/Q106A
 Q88B←(Q88B≠¯1)/Q88B
 Q90B←(Q90B≠¯1)/Q90B
 Q92B←(Q92B≠¯1)/Q92B
 Q94B←(Q94B≠¯1)/Q94B
 Q96B←(Q96B≠¯1)/Q96B
 Q98B←(Q98B≠¯1)/Q98B
 Q100B←(Q100B≠¯1)/Q100B
 Q102B←(Q102B≠¯1)/Q102B
 Q104B←(Q104B≠¯1)/Q104B
 Q106B←(Q106B≠¯1)/Q106B
 Q88C←(Q88C≠¯1)/Q88C
 Q90C←(Q90C≠¯1)/Q90C
 Q92C←(Q92C≠¯1)/Q92C
 Q94C←(Q94C≠¯1)/Q94C
 Q96C←(Q96C≠¯1)/Q96C
 Q98C←(Q98C≠¯1)/Q98C
 Q100C←(Q100C≠¯1)/Q100C
 Q102C←(Q102C≠¯1)/Q102C
 Q104C←(Q104C≠¯1)/Q104C
 Q106C←(Q106C≠¯1)/Q106C
 Q88A←(Q88A≠¯2)/Q88A
 Q90A←(Q90A≠¯2)/Q90A
 Q92A←(Q92A≠¯2)/Q92A
 Q94A←(Q94A≠¯2)/Q94A
 Q96A←(Q96A≠¯2)/Q96A
 Q98A←(Q98A≠¯2)/Q98A
 Q100A←(Q100A≠¯2)/Q100A
 Q102A←(Q102A≠¯2)/Q102A
 Q104A←(Q104A≠¯2)/Q104A
 Q106A←(Q106A≠¯2)/Q106A
 Q88B←(Q88B≠¯2)/Q88B
 Q90B←(Q90B≠¯2)/Q90B
 Q92B←(Q92B≠¯2)/Q92B
 Q94B←(Q94B≠¯2)/Q94B
 Q96B←(Q96B≠¯2)/Q96B
 Q98B←(Q98B≠¯2)/Q98B
 Q100B←(Q100B≠¯2)/Q100B
 Q102B←(Q102B≠¯2)/Q102B
 Q104B←(Q104B≠¯2)/Q104B
 Q106B←(Q106B≠¯2)/Q106B
 Q88C←(Q88C≠¯2)/Q88C
 Q90C←(Q90C≠¯2)/Q90C
 Q92C←(Q92C≠¯2)/Q92C
 Q94C←(Q94C≠¯2)/Q94C
 Q96C←(Q96C≠¯2)/Q96C
 Q98C←(Q98C≠¯2)/Q98C
 Q100C←(Q100C≠¯2)/Q100C
 Q102C←(Q102C≠¯2)/Q102C
 Q104C←(Q104C≠¯2)/Q104C
 Q106C←(Q106C≠¯2)/Q106C
⍝
⍝  COMPUTE NTH ROOT POWER TRANSFORMATION FOR EACH ANSWER VECTOR
⍝
```

```
N88A←÷(ρQ88A)
N90A←÷(ρQ90A)
N92A←÷(ρQ92A)
N94A←÷(ρQ94A)
N96A←÷(ρQ96A)
N98A←÷(ρQ98A)
N100A←÷(ρQ100A)
N102A←÷(ρQ102A)
N104A←÷(ρQ104A)
N106A←÷(ρQ106A)
N88B←÷(ρQ88B)
N90B←÷(ρQ90B)
N92B←÷(ρQ92B)
N94B←÷(ρQ94B)
N96B←÷(ρQ96B)
N98B←÷(ρQ98B)
N100B←÷(ρQ100B)
N102B←÷(ρQ102B)
N104B←÷(ρQ104B)
N106B←÷(ρQ106B)
N88C←÷(ρQ88C)
N90C←÷(ρQ90C)
N92C←÷(ρQ92C)
N94C←÷(ρQ94C)
N96C←÷(ρQ96C)
N98C←÷(ρQ98C)
N100C←÷(ρQ100C)
N102C←÷(ρQ102C)
N104C←÷(ρQ104C)
N106C←÷(ρQ106C)
⍝
⍝        COMPUTE MULTIPLICATIVE NTH ROOT OF EACH ANSWER VECTOR
⍝
M88A←((Q88A×.×Q88A)*0.5)*N88A
M90A←((Q90A×.×Q90A)*0.5)*N90A
M92A←((Q92A×.×Q92A)*0.5)*N92A
M94A←((Q94A×.×Q94A)*0.5)*N94A
M96A←((Q96A×.×Q96A)*0.5)*N96A
M98A←((Q98A×.×Q98A)*0.5)*N98A
M100A←((Q100A×.×Q100A)*0.5)*N100A
M102A←((Q102A×.×Q102A)*0.5)*N102A
M104A←((Q104A×.×Q104A)*0.5)*N104A
M106A←((Q106A×.×Q106A)*0.5)*N106A
M88B←((Q88B×.×Q88B)*0.5)*N88B
M90B←((Q90B×.×Q90B)*0.5)*N90B
M92B←((Q92B×.×Q92B)*0.5)*N92B
M94B←((Q94B×.×Q94B)*0.5)*N94B
M96B←((Q96B×.×Q96B)*0.5)*N96B
M98B←((Q98B×.×Q98B)*0.5)*N98B
M100B←((Q100B×.×Q100B)*0.5)*N100B
M102B←((Q102B×.×Q102B)*0.5)*N102B
M104B←((Q104B×.×Q104B)*0.5)*N104B
M106B←((Q106B×.×Q106B)*0.5)*N106B
M88C←((Q88C×.×Q88C)*0.5)*N88C
M90C←((Q90B×.×Q90B)*0.5)*N90B
M92C←((Q92B×.×Q92B)*0.5)*N92B
M94C←((Q94B×.×Q94B)*0.5)*N94B
M96C←((Q96B×.×Q96B)*0.5)*N96B
M98C←((Q98B×.×Q98B)*0.5)*N98B
M100C←((Q100B×.×Q100B)*0.5)*N100B
M102C←((Q102B×.×Q102B)*0.5)*N102B
M104C←((Q104B×.×Q104B)*0.5)*N104B
M106C←((Q106B×.×Q106B)*0.5)*N106B
⍝
⍝  COMPUTE MULTIPLICATIVE NTH ROOT OF COMMON SURVEY QUESTIONS
⍝
Q88106←Q88A,Q106C
M88106←((Q88106×.×Q88106)*0.5)*(÷33)
Q106102←Q106A,Q102B
M106102←((Q106102×.×Q106102)*0.5)*(÷39)
⍝
⍝          CREATE 8 X 8 PAIRWISE COMPARISON MATRIX
⍝
R1←1,M88106,M90A,M92A,M94A,M88C,M90C,M92C
R2←(÷M88106),1,M96A,M98A,M100A,M94C,M96C,M98C
R3←(÷M90A),(÷M96A),1,M102A,M104A,(÷M100C),M102C,M104C
R4←(÷M92A),(÷M98A),(÷M102A),1,M106102,(÷M90B),(÷M96B),M104B
R5←(÷M94A),(÷M100A),(÷M104A),(÷M106102),1,(÷M92B),(÷M96B),M106B
R6←(÷M88C),(÷M94C),M100C,M90B,M92B,1,M88B,M94B
R7←(÷M90C),(÷M96C),(M102C),M96B,M98B,(÷M88B),1,M100B
R8←(÷M92C),(÷M98C),(÷M104C),(÷M104B),(÷M106B),(÷M94B),(÷M100B),1
BIGMAT←R1,R2,R3,R4,R5,R6,R7,R8
BIGMAT← 8 8 ρBIGMAT
⍝
⍝          COMPUTE WEIGHTS OF RESILIENCY ATTRIBUTES
⍝
EIG←EIGEN BIGMAT
LMAX←EIG[1;1;1]
EVEC←EIG[1;1+ι8;1]
MCW←EVEC÷(+/EVEC)
MCW← 1 8 ρMCW
EVEC← 1 8 ρEVEC
CI←(LMAX-8)÷7
CR←CI÷(1.41)
⎕←' THE MODEL WEIGHTS ARE'
⎕←' '
⎕←MCW
⎕←' '
⎕←'THE CONSISTENCY RATIO IS  ',(⍕CR)
```

APPENDIX H. APL PROGRAM TO COMPUTE RESILIENCY INDEX

```
 ⍝ ESTABLISH THE NUMBERS OF SOLDIERS IN EACH MOS FOR THE UNIT
  X← 54 19 9 3 1 4 1 1 9 1 1 1 1
  N←⍴X
  NINIT←+/X
 ⍝⎕←'CASE NO.'
 ⍝CASE←⎕
  ⎕←'THE FOLLOWING IS A LIST OF THE AUTHORIZED ALO1 PERSONNEL'
  ⎕←'STRENGTH LEVELS FOR EACH MOS SPECIFIED IN THE TOE.'
  ⎕←' '
 LOOP1:
  ⎕←'ITEM NO.          MOS          STRENGTH'
  ⎕←'  1              11B10             ',(⍕(X[1]))
  ⎕←'  2              11B20             ',(⍕(X[2]))
  ⎕←'  3              11B30             ',(⍕(X[3]))
  ⎕←'  4              11B40             ',(⍕(X[4]))
  ⎕←'  5              11B50             ',(⍕(X[5]))
  ⎕←'  6              11H10             ',(⍕(X[6]))
  ⎕←'  7              11H20             ',(⍕(X[7]))
  ⎕←'  8              11H30             ',(⍕(X[8]))
  ⎕←'  9              11M10             ',(⍕(X[9]))
  ⎕←' 10              76Y20             ',(⍕(X[10]))
  ⎕←' 11              76Y30             ',(⍕(X[11]))
  ⎕←' 12              31V30             ',(⍕(X[12]))
  ⎕←' 13              54E20             ',(⍕(X[13]))
  ⎕←'DO YOU WISH TO CHANGE A STRENGTH LEVEL FOR AN MOS? (1 FOR YES'
  'OR 0 FOR NO'
  ANS←⎕
  →(ANS=0)/TRANSFER1
  ⎕←'ENTER THE ITEM NUMBER OF THE MOS STRENGTH LEVEL TO BE CHANGED.'
  ANS1←⎕
  ⎕←'WHAT IS THE NEW STRENGTH LEVEL OF THE ITEM?'
  ANS2←⎕
  X[ANS1]←ANS2
  →LOOP1
 TRANSFER1:
  MEN←+/X
  SIJI←CTASK÷TTASK
  SIJ←SIJI
  X←,X
  MAXMOE1←35.625
  MINMOE1←1
  MAXMOE3←30
  MINMOE3←1
  MAXMOE4←10
  MINMOE4←0
  MOE1←MEN÷NUMMOS
  NUMMOS←⍴((X≠0)/X)
 ⍝ ESTABLISH PARAMETER BOUNDS AND NORMAL SCALING VARIABLES
  ⎕←'DO YOU WISH TO MODEL THE AFFECTS OF ESTABLISHING SECONDARY'
  ⎕←'MILITARY OCCUPATIONAL SPECIALTIES?'
  ANS←⎕
  →(ANS=0)/TRANSFER11
  X←,X
  ⎕←'SPECIFY THE ITEM NO. FOR THE MOS THAT WILL RECEIVE THE'
  ⎕←'SECONDARY MOS, THE NUMBER OF SOLDIERS TO RECEIVE THIS'
  ⎕←'DESIGNATION, AND THE ITEM NO. CORRESPONDING TO THE SECONDARY'
  ⎕←'MOS TO BE DESIGNATED (ENTER ONE SPACE BETWEEN EACH ENTRY).'
  ⎕←'ITEM NO.          MOS          STRENGTH'
  ⎕←'  1              11B10             ',(⍕(X[1]))
  ⎕←'  2              11B20             ',(⍕(X[2]))
  ⎕←'  3              11B30             ',(⍕(X[3]))
  ⎕←'  4              11B40             ',(⍕(X[4]))
  ⎕←'  5              11B50             ',(⍕(X[5]))
  ⎕←'  6              11H10             ',(⍕(X[6]))
  ⎕←'  7              11H20             ',(⍕(X[7]))
  ⎕←'  8              11230             ',(⍕(X[8]))
  ⎕←'  9              11M10             ',(⍕(X[9]))
  ⎕←' 10              76Y20             ',(⍕(X[10]))
  ⎕←' 11              76Y30             ',(⍕(X[11]))
  ⎕←' 12              31V30             ',(⍕(X[12]))
  ⎕←' 13              54E20             ',(⍕(X[13]))
  ANS←⎕
  →(ANS=0)/TRANSFER11
  REC←ANS[1]
  ⎕←REC
  MOSRECNO←ANS[2]
  SEC←ANS[3]
  X← 1 13 ⍴X
  REMAIN←X[1;REC]-MOSRECNO
  X[1;REC]←REMAIN
 ⍝ THIS PORTION OF THE PROGRAM CREATES A NEW SIJ MATRIX BY APPENDING A
 ⍝ COLUMN AND ROW REPRESENTING THE SIJ VALUES OF THE PRIMARY/SECONDARY
 ⍝ MOS. THE ALGORITHM COMPUTES THE SIJ VALUES AS BEFORE FOR THE
 ⍝ SOLDIERS REMAINING IN THE MOS THAT RECEIVED THE SECONDARY MOS
 [illegible]
  ZEROR← 14 1 ⍴(14⍴0)
  ZEROC← 13 1 ⍴(13⍴0))
  SIJ←SIJ AND ZEROC
  SIJ←⍉SIJ AND ZEROR))
  J←1
  SHAPE←⍴CTASK
  IF←1+SHAPE[2]
  SIJ[IF;REC]←1
  SIJ[IF;IF]←1
  SIJ[IF;SEC]←1
  DENOM2←(TTASK[REC;REC]+TTASK[SEC;SEC])-CTASK[REC;SEC])
  SIJ[REC;IF]←TTASK[REC;REC]÷DENOM2
  SIJ[SEC;IF]←TTASK[SEC;SEC]÷DENOM2
  [illegible]
  [illegible]
  SHAPE←⍴SIJ
  [illegible]SHAPE[2]
  J←1
```

```
LOOPSIJ:
 →(J>NZ)/PEINITIAL
 →(I>NZ)/STOP
 SIJ[I;J]←SIJ[I;J]
 J←J+1
 →LOOPSIJ
PEINITIAL:I←I+1
 J←1
 →LOOPSIJ
STOP:
 I←1
LOOPA:→(I>CI)/R1
 →((I=REC)∨(I=SEC))/C1
 →(CTASK[I;REC]>CTASK[I;SEC])/BIG1
 BIGEST←CTASK[I;SEC]
 →BIG2
BIG1:BIGEST←CTASK[I;REC]
BIG2:
 ADJCTASK1←(BIGEST+CTASK[I;REC]+CTASK[I;SEC])÷2
 ADENOM3←(TTASK[REC;REC]+TTASK[SEC;SEC])-ADJCTASK1
 →(DENOM3=0)/C1A
 SIJ[I;CF]←ADJCTASK1÷DENOM2
 →(SIJ[I;CF]≤1)/C1
 SIJ[I;CF]←1
C1:I←I+1
 →LOOPA
C1A:SIJ[I;CF]←0
 I←I+1
 →LOOPA
R1:J←1
LOOPB:→(J>CI)/R2
 →((J=REC)∨(J=SEC))/C2
 →(CTASK[REC;J]>CTASK[SEC;J])/BIG3
 BIGEST2←CTASK[SEC;J]
 →BIG4
BIG3:BIGEST2←CTASK[REC;J]
BIG4:
 ADJCTASK2←(BIGEST2+CTASK[REC;J]+CTASK[SEC;J])÷2
 DENOM4←TTASK[J;J]
 →(DENOM4=0)/C2A
 SIJ[CF;J]←ADJCTASK2÷DENOM4
 →(SIJ[CF;J]≤1)/C2
 SIJ[CF;J]←1
C2:J←J+1
 →LOOPB
C2A:SIJ[CF;J]←0
 J←J+1
 →LOOPB
R2:
 X←,X
 X←X,MOSPECNO
 X← 1 14 ⍴X
 NZ←NZ+1
 MOE1←(MEN+(0.5×MOSPECNO))÷NUMMOS
TRANSFER11:
 TERM1B←+/((,SIJ)×(,(X∘.×X)))
 N3←+/(,X)
 MOE2←(TERM1B-N3)÷(N3×(N3-1))
 TRIP←0
⍝ MOE3
⍝ ESTABLISH QUANTITIES OF WEAPONS SYSTEMS AND FIREPOWER SCORES
⍝ WHERE FP IS THE VECTOR OF FIREPOWER SCORES AND WQ IS THE VECTOR
⍝ OF THE NUMBER OF WEAPONS PER WEAPON TYPE.
 FP← 6 5 6 3 1 2 3 1
 WQ← 9 14 2 5 20 107 22 4
 NZ←+/WQ
 ⎕←'THE NUMBERS OF WEAPON SYSTEMS SPECIFIED IN THE TOE ARE BELOW.'
 ⎕←'FOR EACH WEAPON SYSTEM A FIREPOWERSCORE HAS BEEN ASSIGNED.  THE'
 ⎕←'SCORE REPRESENTS THE RELATIVE FIREPOWER OF THE SYSTEM.  A VALUE'
 ⎕←'OF 10 IS MAXIMUM AND 1 IS MINIMUM.'
LOOP3:
 ⎕←'ITEM  WEAPON SYSTEM   QUANTITY       FIREPOWERSCORE'
 ⎕←'  1   DRAGON           ',(⍕(WQ[1])),'                 ',(⍕(FP[1]))
 ⎕←'  2   M113 W/50 CAL    ',(⍕(WQ[2])),'                 ',(⍕(FP[2]))
 ⎕←'  3   TOW W/VEHICLE    ',(⍕(WQ[3])),'                 ',(⍕(FP[3]))
 ⎕←'  4   7.62 CAL         ',(⍕(WQ[4])),'                 ',(⍕(FP[4]))
 ⎕←'  5   45 CAL PISTOL    ',(⍕(WQ[5])),'                 ',(⍕(FP[5]))
 ⎕←'  6   M16A1 RIFLE      ',(⍕(WQ[6])),'                 ',(⍕(FP[6]))
 ⎕←'  7   M203 GRENADE L.  ',(⍕(WQ[7])),'                 ',(⍕(FP[7]))
 ⎕←'  8   M243 SMOKE L.    ',(⍕(WQ[8])),'                 ',(⍕(FP[8]))
 ⎕←'DO YOU WISH TO CHANGE A FIREPOWER SCORE? (1 FOR YES 0 FOR NO)'
 ANS←⎕
 →(ANS=0)/TRANSFER3
 ⎕←'ENTER THE ITEM NUMBER OF THE WEAPON SYSTEM TO CHANGE.'
 ANS1←⎕
 ⎕←'WHAT IS THE NEW FIREPOWER SCORE?'
 ANS2←⎕
 FP[ANS1]←ANS2
 ⎕←'THE FIREPOWER SCORES PER WEAPON SYSTEM ARE NOW:'
 ⎕←' '
 ⎕←'ITEM  WEAPON SYSTEM   QUANTITY       FIREPOWERSCORE'
 ⎕←'  1   DRAGON           ',(⍕(WQ[1])),'                 ',(⍕(FP[1]))
 ⎕←'  2   M113 W/50 CAL    ',(⍕(WQ[2])),'                 ',(⍕(FP[2]))
 ⎕←'  3   TOW W/50 CAL     ',(⍕(WQ[3])),'                 ',(⍕(FP[3]))
 ⎕←'  4   7.62 CAL         ',(⍕(WQ[4])),'                 ',(⍕(FP[4]))
 ⎕←'  5   45 CAL PISTOL    ',(⍕(WQ[5])),'                 ',(⍕(FP[5]))
 ⎕←'  6   M16A1 RIFLE      ',(⍕(WQ[6])),'                 ',(⍕(FP[6]))
 ⎕←'  7   M203 GRENADE L.  ',(⍕(WQ[7])),'                 ',(⍕(FP[7]))
 ⎕←'  8   M243 SMOKE L.    ',(⍕(WQ[8])),'                 ',(⍕(FP[8]))
 →LOOP3
TRANSFER3:
 ⎕←'ITEM  WEAPON SYSTEM   QUANTITY       FIREPOWERSCORE'
 ⎕←'  1   DRAGON           ',(⍕(WQ[1])),'                 ',(⍕(FP[1]))
 ⎕←'  2   M113 W/50 CAL    ',(⍕(WQ[2])),'                 ',(⍕(FP[2]))
 ⎕←'  3   TOW W/50 CAL     ',(⍕(WQ[3])),'                 ',(⍕(FP[3]))
 ⎕←'  4   7.62 CAL         ',(⍕(WQ[4])),'                 ',(⍕(FP[4]))
 ⎕←'  5   45 CAL PISTOL    ',(⍕(WQ[5])),'                 ',(⍕(FP[5]))
 ⎕←'  6   M16A1 RIFLE      ',(⍕(WQ[6])),'                 ',(⍕(FP[6]))
 ⎕←'  7   M203 GRENADE L.  ',(⍕(WQ[7])),'                 ',(⍕(FP[7]))
 ⎕←'  8   M243 SMOKE L.    ',(⍕(WQ[8])),'                 ',(⍕(FP[8]))
 ⎕←'DO YOU WISH TO CHANGE THE QUANTITY OF A WEAPON SYSTEM? (1 FOR'
 ⎕←'YES OR 0 FOR NO'
 ANS←⎕
```

```
 →(ANS=0)/TRANSFER4
 ⎕←'WHAT IS THE ITEM NUMBER OF THE SYSTEM TO BE CHANGED?'
 ANS1←⎕
 ⎕←'WHAT IS THE NEW QUANTITY?'
 ANS2←⎕
 WQ[ANS1]←ANS2
 ⎕←'THE QUANTITIES OF THE WEAPON SYSTEMS ARE NOW:'
 TRIP←1
 →TRANSFER3
TRANSFER4:
⍝ THIS SECTION COMPUTES MOE3. E IS THE VECTOR OF THE NUMBER OF
⍝ NON-WEAPON SYSTEM EQUIPMENT PER TYPE.
 E← 2 2 14 17 13
 FPE← 1 1 1 1 1
 N3←+/E
LOOP4:
 ⎕←'THE NON-WEAPON SYSTEM MAJOR EQUIPMENT ITEMS ARE:'
 ⎕←' '
 ⎕←'ITEM NO      EQUIPMENT                      QUANTITY'
 ⎕←'  1          TRUCK CARGO 2 1/2 TON          ',(⍕(E[1]))
 ⎕←'  2          TRUCK CARGO   1/4 TON          ',(⍕(E[2]))
 ⎕←'  3          RADIO AN/GRC-150               ',(⍕(E[3]))
 ⎕←'  4          RADIO AN/PRC-77                ',(⍕(E[4]))
 ⎕←'  5          RADIO AN/VRC-45                ',(⍕(E[5]))
 ⎕←'DO YOU WISH TO CHANGE THE QUANTITY OF AN ITEM OF NON-'
 ⎕←'WEAPON SYSTEM EQUIPMENT? (1 FOR YES 0 FOR NO)'
 ANS←⎕
 →(ANS=0)/TRANSFER5
 ⎕←'ENTER THE ITEM NUMBER OF THE EQUIPMENT TO BE CHANGED.'
 ANS1←⎕
 ⎕←'WHAT IS THE QUANTITY?'
 ANS2←⎕
 E[ANS1]←ANS2
 ⎕←'THE QUANTITIES OF NON-WEAPON SYSTEM EQUIPMENT ARE NOW:'
 →LOOP4
TRANSFER5:
 TOTEQUIP←N2+N3
 TYPES←(⍴WQ)+(⍴E)
 MOE3←((+/(FP×WQ))+(+/(FPE×E)))÷((+/FPE)+(+/FP))
⍝ MOE4 TECHNICAL COMPLEXITY OF EQUIPMENT MOE
⍝ THE DF VECTOR IS THE DIFFICULTY FACTOR ASSOCIATED WITH THE OPERATION
⍝ OF EACH TYPE OF EQUIPMENT IN THE TOE.
 DF← 4 5 4 8 8 8 7 8 9 8 8 7 8
 ⎕←'ALL THE EQUIPMENT OF THE TOE IS GIVEN A TECHNICAL COMPLEXITY'
 ⎕←'OF OPERATION VALUE.  A VALUE OF 1 REPRESENTS THE MOST COMPLEX'
 ⎕←'ITEM OF EQUIPMENT (IE. APACHE HELICOPTER), AND A VALUE OF 10'
 ⎕←'REPRESENTS THE LEAST COMPLEX (IE. WATER BUFFALO) TO OPERATE.'
 ⎕←'THE FOLLOWING ARE THE COMPLEXITY VALUES FOR EACH PIECE OF'
 ⎕←'EQUIPMENT.'
LOOP5:
 ⎕←'ITEM NO.       WEAPON SYSTEM           TECHNICAL COMPLEXITY VALUE'
 ⎕←'  1            DRAGON                              ',(⍕(DF[1]))
 ⎕←'  2            M113 W/50 CAL                       ',(⍕(DF[2]))
 ⎕←'  3            TOW W/50 CAL                        ',(⍕(DF[3]))
 ⎕←'  4            7.62 CAL                            ',(⍕(DF[4]))
 ⎕←'  5            45 CAL PISTOL                       ',(⍕(DF[5]))
 ⎕←'  6            M16A1 RIFLE                         ',(⍕(DF[6]))
 ⎕←'  7            M203 GRENADE L.                     ',(⍕(DF[7]))
 ⎕←'  8            M243 SMOKE L.                       ',(⍕(DF[8]))
 ⎕←'  9            TRUCK CARGO 2 1/2 TON               ',(⍕(DF[9]))
 ⎕←' 10            TRUCK CARGO   1/4 TON               ',(⍕(DF[10]))
 ⎕←' 11            RADIO AN/GRC-150                    ',(⍕(DF[11]))
 ⎕←' 12            RADIO AN/PRC-77                     ',(⍕(DF[12]))
 ⎕←' 13            RADIO AN/VRC-45                     ',(⍕(DF[13]))
 ⎕←'DO YOU WISH TO CHANGE A COMPLEXITY VALUE?'
 ANS←⎕
 →(ANS=0)/TRANSFER6
 ⎕←'ENTER THE ITEM NUMBER OF THE EQUIPMENT FOR WHICH THE'
 ⎕←'COMPLEXITY FACTOR IS TO BE CHANGED.'
 ANS1←⎕
 ⎕←'WHAT IS THE NEW QUANTITY?'
 ANS2←⎕
 DF[ANS1]←ANS2
 →LOOP5
TRANSFER6:
 EQUIP←WQ,E
 MOE4←((+/DF×EQUIP))÷(TOTEQUIP)
 AHP← 0.2147995 0.317297 0.2531023 0.2147995
 SC1←(MOE1-MINMOE1)÷(MAXMOE1-MINMOE1)
 SC2←MOE2
 SC3←(MOE3-MINMOE3)÷(MAXMOE3-MINMOE3)
 SC4←(MOE4-MINMOE4)÷(MAXMOE4-MINMOE4)
 SC←SC1,SC2,SC3,SC4
 WTS←(,AHP)×SC
 PR←100×(+/WTS)
 ⎕←'CASE        MOE1        MOE2        MOE3        MOE4        RI'
 ⎕←' ',(⍕CASE),'    ',(⍕SC1),'    ',(⍕SC2),'    ',(⍕SC3),'    ',(⍕SC4),'
   ',(⍕PR)
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