AD-A236 178

(2)

SUSTAINABILITY SURVIVABILITY SUPPORTABILITY

TECHNICAL REPORT
NATICK/TR-91/026

AD ________________

FRONT END ANALYSIS OF ADVANCED COMBAT FEEDING CONCEPTS

By
George S. Levesque

May 1991

Final Report
October 1986 - September 1989

UNITED STATES ARMY NATICK
RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
NATICK, MASSACHUSETTS 01760-5000

ADVANCED SYSTEMS CONCEPTS DIRECTORATE

91 ... 010

DISCLAIMERS

The findings contained in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of trade names in this report does not constitute an official endorsement or approval of the use of such items.

DESTRUCTION NOTICE

For Classified Documents:

Follow the procedures in DoD 5200.22-M, Industrial Security Manual, Section II-19 or DoD 5200.1-R, Information Security Program Regulation, Chapter IX.

For Unclassified/Limited Distribution Documents:

Destroy by any method that prevents disclosure of contents or reconstruction of the document.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)

2. REPORT DATE
May 1991

3. REPORT TYPE AND DATES COVERED
Final October 1986-September 1989

4. TITLE AND SUBTITLE
Front End Analysis of Advanced Combat Feeding Concepts

5. FUNDING NUMBERS
PE 62786
PR AH99
TA AA
DA 311420
AG FTB1252

6. AUTHOR(S)
GEORGE S. LEVESQUE

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Natick RD&E Center
ATTN: STRNC-AA
Natick, MA 01760-5015

8. PERFORMING ORGANIZATION REPORT NUMBER
NATICK/TR-91/026

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

The objective of this front-end analysis (FEA) was to develop a methodology for increasing the participation of the "user community" (military users of rations) in the Natick RD&E technology base program. A cost/benefit approach was taken, augmented with quantitative estimates of the value users place on certain benefits of rations and utilizing cluster analysis to allow for differing priorities within DOD.

A prioritization exercise was conducted. Hundreds of surveys from throughout DOD were collected. Government and civilian scientists participated in a technological evaluation of research proposals. The results of applying this input to the cost/benefit model suggest that it works best when applied to research proposals whose objectives are clearly linked to benefits, have similar levels of difficulty, and address a particular time orientation (e.g., all proposals focused on near-term objectives). Under such circumstances, the model produces useful input to the prioritization process.

14. SUBJECT TERMS
Priority Setting, Economic Analysis, Military Rations, Military Personnel, Models, Advanced Combat Feeding, Rations, Surveys, Cost/Benefit, Cost Models

15. NUMBER OF PAGES
41

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	

TABLE OF CONTENTS

FIGURES

TABLES

PREFACE

The Front End Analysis (FEA) of Advanced Combat Feeding Concepts was conducted during the period October 1986 through September 1989, and was funded under Program Element 62782, Project AH99, Task AA, Accession No. DA311420.

The author wishes to acknowledge the contributions of the following personnel/organizations:

Under the Army Research Office's Scientific Services Program (contract # DAAL 03-86-D-0001), Battelle Memorial Institute, Columbus Laboratories, Columbus, OH performed two tasks (task control numbers 88-436 and 89-229) supporting the FEA of Advanced Combat Feeding Concepts. The author wishes to thank this organization, and particularly Dr. William E. Judnick, for this assistance.

MAJ Thomas Theaux (Chief) and CPT David Armor, Soldiers Requirements and Support Division, Advanced Systems Concepts Directorate (ASCD), for their input to the development of the survey of military users, the list of benefits users expect from military rations, and identification of Army organizations and points-of-contact to be included in the survey. Additionally, the author wishes to acknowledge the analogous contributions of the Natick Joint Technical Staff, including MAJ Steven L. Auerback, USA, LT Dennis Grey, USN, MAJ Deborah S. Page, USAF, and MAJ R.S. Navarre, USMC.

Dr. Irwin A. Taub, Chief, Technology Acquisition Division, Food Engineering Directorate, for his input to the development of the user survey and list of benefit from military rations, his development of the definitions of technological categories and technologies, and his administration of the in-house segment of the technological evaluations.

Drs. Herbert L. Meisselman, Chief, and Richard Popper, Behaviorial Sciences Division, Soldier Science Directorate, for their contributions to the list of ration benefits and development of the user survey.

Ms. Melinda J. Loftin, Esq., for administering the review of the user survey required by the Office of Chief Counsel.

Mr. Peter Bolan, Director of ASCD, and Mr. Richard P. Richardson, former director of ASCD, Mr. Paul Short, Acting Chief, and Dr. D. Paul Leitch, Chief, Food Systems Division, ASCD, for their administrative guidance. To Mr. Dennis Tavano, ASCD, for his program analysis support. To Ms. Julie Matondi, ASCD, for her administrative support. Special thanks is extended to Dr. James Sampson of ASCD's Clothing & Individual Equipment Division, (CIE) for his many insights regarding survey development and analysis, and to Mr. Raymond Spring, CIE, for his review of the statistical concepts put forth in this report.

Ms. Marcia Lightbody and Mr. Michael Statkus, ASCD, for their editorial expertise in developing this report.

SUMMARY

The objective of the Front End Analysis of Advanced Combat Feeding Concepts was to develop a methodology capable of increasing the degree and directness of influence of the 'user community' (military users of rations) on the development of the Natick RD&E technology base program. An analytical approach, consisting of the development of a quantitative model and the determination of forms of compatible data, was selected. Since the expense of conducting projects, in relation to their anticipated benefits, are fundamental concerns in establishing relative value, a cost/benefit approach was taken. This approach is augmented by identifying and applying quantitative estimates of the value users place on certain benefits of rations. Such figures of relative merit, or priority values, are then incorporated into the basic cost/benefit model, to reflect such user-priorities. Finally, to allow for differing priorities within the Department of Defense (DOD) community, the K-Means clustering algorithm is employed to identify these different priorities, the magnitude of the sample which each set of priorities reflects, and includes these factors in the finalized model.

A prioritization exercise was conducted, as a means of testing the methodology's utility under real-world conditions. Input from the user community consisted of approximately 450 completed surveys from organizations representing each military service within DOD. Using existing projects as 'surrogate' research proposals, technological evaluations were conducted by both Natick scientists as well as by technological experts from the civilian community. This input was applied to the model and the results analyzed, forming the basis for several conclusions. When used to evaluate both Military Service Requirements, as well as technology base proposals, the input from the user community almost always resulted in the former type of proposals being ranked higher. This suggests that the model is better suited to evaluating a single type of proposal (e.g. only technology base proposals), rather than an entire candidate food program. Other factors which must be considered when evaluating the model's output are a proposal's emphasis on areas which may not be viewed as benefits by end-users (e.g. shelf life is more a prerequisite than a benefit), as well as potential lack of uniformity regarding the level of difficulty of each proposal's objective. However, the proposed methodology can produce valuable input regarding the prioritization of a set of proposals.

FRONT END ANALYSIS OF ADVANCED COMBAT FEEDING CONCEPTS

I. Introduction

1. Background

The Natick Research, Development and Engineering Center's DOD Food Program consists of several generic types of research. Military Service Requirements (MSR's) and Joint Service Requirements (JSR's), are usually oriented toward near-term military requirements, while the objectives of 'Technology Base' research have a more futuristic time orientation.

The development of a technology base program commences with solicitations of proposed research from the Natick scientific community. A technology base committee then analyzes the set of proposals based on such criteria as military relevance, cost, etc. The proposals recommended for funding by the committee are then considered in conjunction with MSR's/JSR's by the DOD Food & Nutrition Research & Engineering Board, who determine a finalized 'program' of proposals which have survived the transition into funded projects.

2. Objective

The objective of this Front End Analysis (FEA) was to develop a methodology to facilitate greater involvement by the 'user community' (military users of rations) in the development of the technology base program. This methodology was not intended to replace the current system, but rather to augment it.

3. Approach

An analytical approach, consisting of the development of a quantitative model and the determination of forms of compatible data, was selected. An overview of the approach is provided in Figure 1.

The first activity in Figure 1 lists benefits from improving rations. These benefits provide linkage between the users (what they want), and what technologies, through the proposals which will pursue them, may provide. The second initial activity, compiling a set of technology base proposals, provides alternative means by which one or more benefits may occur. The list of benefits is then used as the basis for a survey whose objective is to determine the relative value of each benefit to users. The survey responses are analyzed to determine these relative values, which will subsequently be used as 'weighting factors' in the final cost/benefit equation.

```
I----------------------------I         I------------------I
I  Compile list of           I         I  Compile set of  I
I  ration benefits           I         I  technology base I
I  of importance to          I         I  proposals.      I
I  military ration consumers. I        I------------------I
I----------------------------I                  I
            I                                   I
            I                                   I
            I---------------------------------> I
            I                                   I
            I                                   I
I--------------------------I           I----------------------------I
I Representatives of       I           I For each proposal,         I
I military 'user community' I          I estimate probability of:   I
I complete survey on       I           I - overall technical success I
I relative importance of   I           I - a technology's           I
I each ration benefit.     I           I   contribution to success  I
I--------------------------I           I - producing each           I
            I                          I   ration benefit.          I
            I                          I----------------------------I
            I                                   I
            I                                   I
I-------------------------I                     I
I Analyze survey responses I                    I
I to determine a          I            I-------------------------------I
I 'weighting factor'      I            I for each proposal,            I
I for each benefit.       I            I calculate aggregate probabilityI
I-------------------------I            I of each technology-benefit    I
            I                          I combination.                  I
            I                          I                               I
            I                          I-------------------------------I
            I                                   I
            I                                   I
            I                                   I
            I-----------------------------------I
                             I
                             I
                             I
                    I-------------I
                    I  Prioritize I
                    I  proposals. I
                    I-------------I
```

Figure 1. Overview of Prioritization Process

Independently, a committee of scientists evaluates the proposals, estimating the likelihood that each proposal will produce at least one benefit, the probabilities that particular technologies will produce a benefit and the likelihood that each benefit will be among those produced.

The committee's collective judgements are then analyzed to develop aggregate probabilities for every technology-benefit combination applicable to each proposal.

In the last major step of the process, data from the previous steps are applied to a weighted cost/benefit equation, to produce a score for each proposal. The magnitude of these scores determines each proposal's place in a ranking, or prioritization, of the proposals.

This type of approach had several advantages. It is relatively economical, is highly compatible with more objective forms of data collection, and promotes clarity regarding the rationale underlying subsequent analysis. By contrast, alternatives such as soliciting input from users by providing them with an actual set of technology base proposals would be extremely expensive, administratively burdensome, and might result in incompatible forms of input (from simple ranks of the proposals to highly qualitative statements), thus making subsequent analysis of the user community's collective preferences virtually impossible to estimate.

II. Specifics of the Analytical Methodology

1. Basic Model

The need to prioritize a set of proposals is based, at least in part, on the recognition that resources are not unlimited and must therefore be employed judiciously. However, the cheapest proposals are not necessarily the best. The cost of a project should logically be evaluated in relation to the benefits to be derived from it. This relativity suggested a basic 'cost/benefit' approach to the prioritization model.

All benefits are not necessarily equal. A user may attach enormous importance to some benefits, while perceiving relatively little utility in others. To accommodate such priorities among benefits, the basic cost/benefit approach was modified as illustrated in Equation 1:

$$\frac{\text{Benefit}}{\text{Cost}} * \text{Benefit's Importance to User} \qquad \text{Equation 1}$$

Since a proposal may be expected to yield multiple benefits, its total 'score' is calculated as the sum of the ratios introduced in Equation 1. Analogously, when there are multiple proposals, their total scores are ranked; to produce a 'one-to-one' prioritization.

2. Estimating Costs

As part of the current program-development process, an estimate of a proposal's cost and a general description of its anticipated benefits are available. However, if quantitative evaluations of the proposals are to be conducted, a more specific linkage between costs and benefits is required.

As a first step, the total funding of all candidate proposals is calculated. Each proposal's funding is compared to this total, to produce a 'normalized' cost estimate for that proposal.

Proposals which are funded become 'projects'. Projects, in turn, consist of one or more 'work units'. These work units address differing aspects of the overall project's objective. The application of specific technologies, in conjunction with the project's goals and the work unit's supporting objective and approach, constitutes the path through which benefits attributable to that project will ultimately be derived. A general description of this linkage is provided in Figure 2.

Next, a proposal's normalized funding is distributed proportionally among its work units. For example, if a particular proposal requests $300,000 out of total amounting to $1,000,000, its proportion of total requested technology base resources is 30%. If one of its work

```
                                            I- Benefit #a
                                            I
                                            I- Benefit #b
                          I--Technology #1---
                          I                 I      *
                          I                 I      *
                          I                 I      *
                          I                 I-i  Benefit
                          I                    th
                          I
                          I                 I- Benefit #b
                          I                 I
                          I                 I- Benefit #c
                          I--Technology #2---
                          I                 I      *
                          I                 I      *
                          I                 I      *
                          I                 I-j  Benefit
                          I                    th
                          I
                  Work    I       *
Proposal----I-----Unit----I       *
   #1       I      x      I       *
            I             I
            I             I
            I             I
            I             I                 I- Benefit #d
            I             I                 I
            I             I                 I- Benefit #e
            I             I--n Technology ---
            I                 th            I      *
            I                               I      *
            I                               I      *
            I                               I-k  Benefit
            I                                  th
            I
            I    Work
            I----Unit--- * * *
                  y

                  *
                  *
                  *
```

Figure 2. Generic Description of Proposal-Benefit Relationship

Note: Progressing rightward, the subdivisions (combinations of particular work units-technologies-benefits) in such a network or 'tree' diagram are referred to as its 'branches.'

units will receive $30,000 (10% of the proposal's funds), the proportion attributable to this work unit is (30%) * (10%), or 3% to total technology base resources.

At the work unit level, estimation of funds to be spent pursuing each technology is not currently required. In lieu of such funding stipulations, the proportion of time or effort (i.e. man-years) expended on each technology must be estimated. Of course, the first step in such a process is to specify a collectively exhaustive set of those technologies. From this, a process combining inductive reasoning with intuitive insight is then applied.

For example, assume that a particular work unit will pursue three technologies. In lieu of any evidence to the contrary, they will be presumed to all contribute proportionately. In the current example, this would amount to dividing their collective effort (100%) by the number of technologies; that is, 1/3 or 33 1/3 % per technology. Alternatively, some distinction between the relative contributions of technologies may be possible. Continuing the example, suppose that one technology can be described as the 'major contributor' to this work unit. 'Major' can be interpreted as anything over 50%. Thus, as a minimum, .51 could be assigned as the estimated contribution of this technology, with each member of the residual subset assigned (1-.51)/(3-1) or .245 for each of the remaining two technologies.

Care must be exercised during this process, to avoid logical contradictions. In the previous example, assume that two of the three technologies constitute the majority of effort. Under such circumstances, the proportion assigned to each majority-technology would by .51/2 or .255. Yet the remaining 'minority' technology would have to be evaluated as 1-.51 or .49, which is greater than the proportion being individually attributed to each majority technologies. Since this problem will only arise when the number of technologies in the majority-contribution subset is greater than or equal to 50% to the total number of technologies, the following formula may be employed to determine a minimum proportion for defining 'majority':

$$P = S/(S+s) + a$$

where:

P = proportion defining majority contribution

S = number of technologies belonging to the majority-contribution's subset

s = number of technologies in the residual subset

a = any real number, proper fraction which satisfies: $1>P>.5$, $.5>1-P>0$

Many other schemes for weighting technologies within a work unit are available in management science and related literature, should a particular application prove too demanding for the approaches just discussed. The only absolute prerequisite is that the weighting scheme produce positive-valued proportions which sum to one.

Finally, the proportional cost of a project, work unit, and the estimate of effort applicable to a technology are multiplied. This produces an estimate of cost of pursuing that technology in the manner indicated by the project and work unit's description.

3. Estimating Benefits

The approach taken in this FEA to the quantification of estimated benefits began by recognizing that research is inherently a risk-oriented endeavor. Thus, a decision was made to state benefits in terms of the probability that a given type of benefit would be forthcoming, if a technology were applied in the manner suggested by a project and work unit's description. In terms of classical statistics, this is represented by:

P(p and w and t and b) where: p = project
w = work unit
t = technology
b = benefit

Figure 2 demonstrated that work units are more directly linked to benefits than projects. Therefore, probabilities will henceforth be stated in terms of work units. Note that this provides the flexibility to prioritize the work units themselves, while preserving the capability to rank projects, since the value of a project can be interpreted as the sum of the cost/benefit ratios of its work units. This interpretation reduces the objective to:

P(w and t and b)

Table 1 provides a generalized illustration of these probabilistic relationships. The cells of this table's matrix correspond to the joint probability introduced above, within the context of a specific work unit, technology and benefit.

Theoretically, there is no reason why evaluators could not specify their judgements on a cell-by-cell basis. However, such judgements would have to be made within the context of the work unit's objective and approach. This means such judgements are conditional probabilities, based upon an implicit judgement about the work unit as a whole. One potential problem is that when dealing with such large numbers of estimates, the same technology-benefit combinations may receive similar evaluations, without allowing for the fact that they appear in work units having substantially different overall probabilities. Note that if there are 'm' work units, 'n' technologies, and 'i' benefits, the gross number of cells is the product m*n*i. As these numbers become larger, the administrative burden could become staggering. This administrative consideration, in turn, could result in the reluctance of qualified evaluators to participate in the process.

Table 1. Generic Work Unit-Technology-Benefit Matrix

Work Unit x: $P(w)$

	P(t I w)		
P(b I w) BENEFITS	Technology #1	Technology #2 ***	n_{th} Technology
a:	$P(w_x \text{ and } t_1 \text{ and } b_a)$	$P(w_x \text{ and } t_2 \text{ and } b_a)$	$P(w_x \text{ and } t_n \text{ and } b_a)$
b:	$P(w_x \text{ and } t_1 \text{ and } b_b)$	$P(w_x \text{ and } t_2 \text{ and } b_b)$	$P(w_x \text{ and } t_n \text{ and } b_b)$
		* * *	
k:	$P(w_x \text{ and } t_1 \text{ and } b_k)$	$P(w_x \text{ and } t_2 \text{ and } b_k)$	$P(w_x \text{ and } t_n \text{ and } b_k)$

An alternative approach taken by this FEA was to define the cell values through an extension of classical statistical calculations regarding joint probability. This defined a cell value as follows:

P(w and t and b) - P(w) P(t I w) P(b I t and w) Equation Two

where: w - work unit, t - technology, b - benefit

P(w) - probability that a work unit will produce at least one benefit

P(t I w) - probability that a technology produced the benefit, given that a benefit occurs

P(b I t and w) - probability that a particular benefit will be among those which occur, given that at least one benefit has occurred and a particular technology produced it.

The first two factors of Equation Two can be solicited directly from each evaluator. However, obtaining values for P(b I t and w) would be as administratively burdensome as the cell-by-cell approach. The compromise was to approximate this value using P(b I w); an estimate which required only one response per benefit. Hence, the approximation formula employed in the FEA process was:

P(w and t and b) P(w) P(t I w) P(b I w) Equation Three

where: P(b I w) - probability that a particular benefit will occur, given that at the work unit produces at least one benefit

The administrative expedience of this approach had its disadvantages. However, certain considerations must be taken into account before arriving at a final judgement concerning the reasonability of employing Equation Three. First, since equations two and three are otherwise identical, the difference between the two equations' last factor constitutes the only source of inter-equation error. The maximum potential error in P(w and t and b) will occur when the other two factors are at their maximum and P(b I w) is either very large or very small. Secondly, the value used in the equation is arrived at by computing a 'consensus' estimate from the individual responses of multiple evaluators. Hence, in order for p(b I w) to be a poor approximation of P(b I t and w), the majority of the evaluators must have made the same error, and done so consistently (e.g. all over-estimation, by a substantial magnitude). Lastly, the consensus estimate employed was the median, rather than the mean, which helps minimize the effect of extreme judgements which are in the minority.

The principal administrative benefit of this approach is that it reduces the number of responses from m*n*i to m*(n+i+1). However, as will be seen in Section III, the required number of responses can, in actual practice, be reduced still further.

4. Estimating User Priorities

The approach chosen for this FEA was that proposed by Saaty, as part of his 'Analytic Hierarchy Process'. Basically, this entails soliciting data in the form of paired comparisons, while requiring that the responses be quantified in relation to a 9-point hedonic scale:

1	3	5	7	9
Equality	Slightly	Moderately	Substantially	Absolutely

The elements being compared are called 'characteristics'; the traits or qualities which are to be prioritized. In relation to the FEA, such characteristics are what have previously been referred to as benefits; i.e. those traits or qualities of rations which users are likely to deem desirable.

For example, military personnel have historically considered the reduction of a ration's weight and volume to be important benefits of research. If a respondent considers these benefits to be equal, the applicable response is symbolized by the number '1'. However, if he considers reducing a ration's weight to be 'substantially' more important than reducing its volume, the number '7' must be associated with 'weight', when responding to that pair of alternatives.

Once such data has been solicited, it is analyzed as depicted in Table 2:

Table 2. Calculating User Priorities

Example One:

	Weight	Volume	Row Sums		Row Sum/Matrix = Priority
Weight	1	1	2	Weight:	2 / 4 = .5
Volume	1	1	2	Volume:	2 / 4 = .5
		Matrix:	4		

Example Two:

	Weight	Volume	Row Sums		Row Sum/Matrix = Priority
Weight	1	7	8	Weight:	8 / 9.143 = .875
Volume	.143	1	1.143	Volume:	1.143 / 9.143 = .125
		Matrix:	9.143		

Regarding Table 2, note that cells corresponding to the intersection of the same characteristic (e.g. row 'weight', column 'weight') are automatically presumed to equal one; signifying that a characteristic is always 'equal' to itself. Value in cells correspond to judgements made about them. For example, in Example Two, weight was judged to be 'substantially' more important than volume. Thus, the number '7' was entered in cell (weight, volume). The inverse relationship is inferred for cell (volume, weight). Thus, 1/7 or .143 occupies that cell. The cell values are summed rowwise, and a total for all cells is computed. The right side of Table 2 shows how these computations are then used to develop priority values for each benefit.

Although the previous discussion highlights the basic process of calculating user priorities, it must be acknowledged that not all users have the same priorities. The procedure selected to deal with this expected diversity was Hartigan's K-Means approach. This form of multi-variate clustering algorithm partitions an initial set of data into the best statistical 'fit' (considering multiple criteria of classification); given a specified number of groups, 'K'. For example, if 'K' is set equal to two, the algorithm will partition all responses into one of two subsets it will create, according to the overall similarity among responses.

In conjunction with the FEA process, the next step (after clustering) is to develop aggregate responses for each cluster. The reader should keep in mind that although the clustering phase partitions the data into their 'best fit', this does not mean that the cluster now contains identical responses to any given question. Some dispersion usually exists among each set of responses. Thus, a 'typifying' response must be developed. The median is the preferred measure of central tendency to accomplish this goal, because it is relatively unaffected by extreme responses which are in the minority.

Finally, the proportion of respondents to the total sample size corresponding to each cluster is calculated. After the group-responses of each of the two clusters has been calculated by the Saaty process discussed earlier, the sample-size proportions are used to adjust the respective user-evaluations. This has the effect of limiting the influence of each set of priorities on the overall cost/benefit equation according to the proportion of the sample each set of priorities represents.

Since there are a number of steps in the FEA process, and since some of these procedures may be unfamiliar to the reader, this section will conclude by presenting a succinct hypothetical example of the overall process in a start-to-finish manner.

The top section of Table 3 depicts two cost estimations of technology 'a'. The first example (work unit x) was previously introduced in Section II.2, where it was shown that work unit x requests 3% of all resources requested, and technology 'a' will consume 25% of these resources; or .0075 of total requested resources. Analogously, work unit y also will receive 3% of total resources, but plans to spend 50% pursuing technology a; or .015 of total resources.

The next section describes the 'raw' (prior to including user-priorities) cost/benefit ratios, in relation to the benefit 'reducing ration weight'. In practice, these estimates would have come from

Table 3. Example of the FEA Prioritization Process

Cost of work unit-technology 'branch':

	Work Unit Resources	*	Technology 'a' % of Work Unit	=	Technology 'a' Resources
Work Unit x:	3%		25%		.0075
Work Unit y:	3%		50%		.015

'Raw' (unadjusted) Cost/Benefit Relationship:

Work Unit	Benefit Type	Branch's Benefit	/	Branch's Resources	=	Branch's Raw Score
x:	Weight	.5		.0075		66.67
x:	Volume	.2		.0075		26.67
					Total Score:	93.34
y:	Weight	.5		.015		33.33
y:	Volume	.7		.015		46.67
					Total Score:	80.00

User-Adjusted Cost/Benefit Ratios:

Work Unit	Benefit Type	Branch's Benefit	*	User 1's Priority	/	Branch's Resources	=	Adjusted Score
x:	Weight	.5		.5		.0075		33.33
x:	Volume	.2		.5		.0075		13.33
						Total Score:		46.67
y:	Weight	.5		.5		.015		16.67
y:	Volume	.7		.5		.015		23.33
						Total Score:		40.00

Work Unit	Benefit Type	Branch's Benefit	*	User 2's Priority	/	Branch's Resources	=	Adjusted Score
x:	Weight	.5		.875		.0075		58.33
x:	Volume	.2		.125		.0075		3.33
						Total Score:		61.67
y:	Weight	.5		.875		.015		29.17
y:	Volume	.7		.125		.015		5.83
						Total Score:		35.00

Adjustment for Sample Size Proportion:

	Before Sample Size Adjustment		% of	After Sample Size Adjustment	
	Work Unit x	Work unit y	Sample	Work Unit x	Work unit y
User #1:	46.67	40	90	42.00	36.00
User #2:	61.67	35	10	6.17	3.5
Total :	108.34	75		48.17	39.5

technological evaluations, as discussed in Section II.3 Under the column labeled 'Branch's Raw Score' note that work unit x's score for the row 'weight' is exactly double that of work unit y. This occurs because although they produce equal benefits, work unit x does so with resources half the size of work unit y's. The total scores are relatively close because work unit y's anticipated benefit 'volume' is substantially larger than that of work unit x, which compensates somewhat for its relative inefficiency in regard to weight.

The section entitled 'User-Adjusted Cost/Benefit Ratios' is further divided into two subordinate sections. The first reflects the influence of User #1 on the raw scores. The second subsection demonstrates the effect of User #2's priorities on the raw scores. These user-priorities are the same as those in Table 2, to facilitate the reader's understanding of how such priorities were arrived at, and how they fit into the overall process. Compare the total scores for the two work units which appear in the first subsection to those of the latter subsection. The scores resultant from User #1's priorities are proportionately identical to those of the raw totals. This occurs because user 1 does not favor either benefit. However, since User #2 has expressed a substantial priority regarding the reduction of weight rather than volume, work unit x's relative efficiency in expending resources to achieve the former benefit contributes highly to its total score.

The final subsection of Table 3 demonstrates the effect of hypothetically clustering. User #1's priorities are assumed to represent 90% of the total sample, while the priorities of User #2 account for the remaining 10%. The left side shows the sums of scores from both users (taken directly from the previous subsection). The right shows the effect of further adjusting these scores by the proportion of sample size each priority represents. For example, in the row labeled 'User #1', the previous scores are multiplied by .9, to produce adjusted scores for Work Units 1 and 2 of 42 and 36, respectively. Although in this example, work unit x retains its superior score, note the substantial drop in magnitude between scores. This indicates that when the priorities of the second group are recognized as being an extreme minority point of view, the implied preference of the user community, as a whole, for work unit x is not substantial.

III. Prioritization Exercise

1. Objective

Although the methodology presented in Section II proposed a logical series of steps to accomplish the FEA's stated objectives, it was felt that the practicality of implementing the approach under real-world conditions would add to its credibility. Therefore, the objective of the prioritization exercise was to demonstrate its execution under the most realistic conditions possible.

2. Scope

a. Orientation Away From Immediate/Near-Term Perspective

As previously addressed (see Section I.1.), the technology base is primarily concerned with military food research which is not as closely linked to immediate needs as other segments of the DOD Food Program. As such, it was deemed desirable to focus the exercise toward a 'long term' perspective. That is, to recruit representatives from the user community who could orient their thinking away from immediate concerns regarding military subsistence. Likewise, technological evaluators would have to be recruited who possessed both the expertise and willingness to evaluate proposals developed from 'notional systems'; highly theoretical concepts based on attempts to anticipate user requirements of the future.

b. DOD-Wide Perspective

Since all military services utilize subsistence-related items developed by Natick, it was felt that all should be given an opportunity to participate in this exercise. In conjunction with the long-term perspective previously discussed, it was decided to recruit these 'user representatives' from those organizations within each military service which were anticipated to be the most capable of taking the 'long term' view. Hence, organizations involved in military planning were targeted. Appendix A lists these organizations.

c. Concentration on the 'Individual' Mode of Feeding

A DOD-wide survey, alone, could be anticipated to require considerable time to develop, administer, and analyze. Additionally, a set of proposals would have to be selected and evaluated. Limiting the exercise to consider only 'individual' forms of subsistence (those carried by troops, as opposed to subsistence systems where food is prepared in bulk) could vastly simplify matters. Since this restricted scope could help keep resource expenditures within budget, while still achieving the objective of the exercise, a decision was made to do so.

3. Development of the Set of Benefits

Benefits provide the linkage between what users can be anticipated to want and what technologies (i.e. the proposals which pursue them) may provide. For this reason, considerable time and thought was invested in the development of the set of benefits. Guidance and input was sought from a number of vantage points, including behavioral science, food science and operations research, as well as that of active duty military personnel. The final set of benefits and their definitions represents both compromise and consensus among the parties involved in its development. The set is not all-inclusive. However, it was felt that the set did constitute a good core representation of the types of benefits the user community, as a whole, would be likely to find most relevant. Moreover, behavioral specialists and others having expertise in survey-development counseled against a more expansive set, since, historically, there appears to be a high inverse correlation between a survey's size and the willingness of respondents to participate in it. The final set of benefits and their definitions are shown in Table 4.

4. Administration of the User Survey

The user community's response to the survey was extremely positive. Of the approximately 500 surveys sent out, about 90% were returned completed. Of these, only about 3% were incorrectly completed. A number of factors contributed to this. Mailing the surveys allowed a large number of them to be disseminated economically. In addition to the care exercised in the development of the set of benefits, considerable attention was paid to the development of the survey instrument itself.

The survey consisted of three sections. The first briefly reviewed the objectives of the survey and the FEA in general. This served to immediately orient the respondents' thinking away from the near term. The second section contained detailed instructions. The last section, which contained the actual benefits to be compared, was further divided into four subsections. The reason for this can be seen by recognizing that the number of required paired comparisons is exponentially related to the number of benefits; that is:

$$\text{Required Paired Comparisons} = \frac{(\#\text{ of benefits})\hat{\ }2 - (\#\text{ of benefits})}{2}$$

Thus, the 13 benefits constituting the finalized set would have required 78 paired comparisons. A compromise was reached by making use of the fact that some of the 13 characteristics are inherently related. For example, ease of preparation, as a general concept, is to a large degree defined by ease of opening and ease of heating. Likewise, durability, decontamination and disposal are all attributes of packaging, while variety, taste and recognizability are all 'acceptance' characteristics. Hence, preparation (as a general concept), packaging, and acceptability were initially substituted for their respective subsets. This reduced the set of 'major' benefits to 7, and thus the initial number of required paired comparisons to 21. Each of the succeeding subsections addressed one of the three 'subordinate' subsets of benefits. Each subset required three paired comparisons; for a total of nine. This brought the total comparisons required by the survey to 30, or about 40% of what would have otherwise been required.

Table 4. Set of Benefits

1. Reducing Weight: This benefit refers to the total weight of a ration; that is, the combined weight of its food and packaging.

2. Reducing Volume: As with 'reducing weight', the meaning of this benefit relates to total volume, including the influence on volume of both the food and its packaging.

3. Maintaining Strength and Alertness (S & A): It is recognized that all combatants have a basic need to maintain their physical strength, as well as to remain mentally alert. Assessments of this benefit seek an indication of its relative importance, within the context of the specific operational conditions applicable to a particular user-group.

4. Satiety: As was the case with S & A, it is recognized that the alleviation of hunger is a basic motivation for eating. Again, the judgement being sought is one of relativity, in relation to the other benefits.

5. Increasing Ease of Preparation: 'Preparation' is defined as all activities which are normal and necessary to bring a ration from its fully packaged state, to a condition in which it is ready for immediate consumption. However, ease of preparation is a very general term. Therefore, this benefit is followed by three 'subordinate' benefits, each of which further defines a specific aspect involved in making rations easier to prepare:

5a. Reducing Preparation Time/Steps, in General: Preparing individual rations may require a number of activities, such as mixing, stirring, etc. In evaluating this benefit, its importance in relation to the remaining two specific aspects of easy preparation, ease of opening and heating, should be considered.

5b. Increasing Ease of Opening: Although the meaning of this benefit may appear self-evident, the operational circumstances under which a ration will be used must be taken into consideration. For example, during cold weather operations, during which gloves will probably be worn, the importance of easy opening may be expected to increase.

5c. Ease of Heating: The availability of required time to a particular user-group, as well as the logistical impact and battlefield practicality of providing fuel, equipment, etc. must be taken into account when assessing the relative value of this benefit.

6. Improving Packaging: Like preparation, packaging has been further defined by the following three subordinate benefits:

6a. Increasing Packaging Durability: The primary factor to be considered in evaluating this benefit is the degree of rough handling which can be anticipated.

Table 4. Set of Benefits (Cont'd.)

6b. Increasing Ease of Packaging's Decontamination: Factors effecting the relative importance of this benefit are the likelihood of the need to decontaminate individual rations, the speed and ease with which standard decontamination procedures may be applied, and the applicability of commonly available decontamination materials (e.g. soap and water).

6c. Increasing Ease of Disposal: The importance of avoiding a 'trash signature' must be considered in evaluating this benefit. For example, the mission of reconnaissance forces are inherently clandestine, necessitating that the risk of signatures of any kind be minimized. Alternatively, support forces may evaluate disposal's importance in terms of the time, steps and/or equipment (e.g., entrenching tool) required to deal with refuse from rations.

7. Improving Acceptability: This benefit addresses the importance of the qualitative aspects of food. Again, it is further defined by subordinate benefits:

7a. Maintaining Recognizability: Some food items currently available in individual rations such as the Meal, Ready-to-Eat do not look the same as 'everyday' food (e.g. freeze-dried, compressed meat bars). The foods in future rations may look even less familiar, as a result of technological applications intended to achieve other benefits. Therefore, the importance of food's recognizability, relative to other anticipated benefits, must be estimated.

7b. Improving Taste: Future rations' foods could have a totally unfamiliar taste, taste very bland, or otherwise differ from the that of everyday subsistence. Alternatively, very 'tasty' items may be counterproductive to the pursuit of other benefits. Thus, the relative importance of food's taste must be considered.

7c. Increasing Variety: The number of different menus, as well as the number of different components within each menu, can collectively be thought of as a ration system's variety. Once again, its relative importance to a particular user-group may depend upon the battlefield conditions under which it is intended to be eaten.

Table 5 shows the distribution of the major benefits' initial scores to their subordinate benefits; to arrive at priority values for the final set of thirteen benefits. For example, preparation initially attained a relative score of .107, in comparison to the other major benefits. Next, an estimate is made to distinguish between the respondents attraction toward preparation as a general concept, as opposed to the specific attributes of easy opening or heating. Thus, .107 is multiplied, respectively, by .2,.3, and .5, to arrive at a distribution of this major benefit's score to its subordinates. The products (.021,.032, and .054) associated with these subordinate benefits appear in the finalized priorities on the right of Table 5.

TABLE 5. Example of Distributing Major Benefits' Priorities to their Subordinates

Major Characteristics	Major Values	Sub-Characteristics	Sub-Values	Final Characteristics	Final Values
Weight	.15			Weight	.15
Volume	.12			Volume	.12
S & A	.21			S & A	.21
Hunger	.20			Hunger	.20
		I--> (general) Prep	.200	(general) Prep	.021
Preparation	.107---I-->	Opening	.300	Opening	.032
		I--> Heating	.500	Heating	.054
		I--> Durability	.747	Durability	.072
Packaging	.096---I-->	Decontamination	.250	Decontamination	.024
		I--> Disposal	.003	Disposal	.0003
		I--> Taste	.450	Taste	.053
Acceptability	.117---I-->	Variety	.367	Variety	.043
		I--> Recognizability	.183	Recognizability	.021

5. Administration of the Technical Evaluations

The first step in this activity was to select a set of candidate proposals. It was felt that using the FEA process to evaluate actual proposals would be premature. Therefore, a set of 'surrogate' proposals, compiled from existing work units, was selected. Another advantage of this decision was the immediate availability of descriptions (objective and scope) and funding levels for these candidates. This decision, in turn, led to a decision to employ not only technology base projects, but existing MSR's as well. It was felt that if a reasonably flexible interpretation of the term 'technology' was applied, these types of proposals could also be included, since they too utilize technological means to pursue their near-term objectives. The advantage being that the FEA process might subsequently be utilized not only to influence the technology base, but also the entire DOD Food Program. The finalized set of work units which served as surrogate proposals is listed in Table 6:

Table 6. Work Units Employed in the Technological Evaluation Exercise

PROPOSAL NUMBER	TITLE
FTB1259	Universal Nutrient Dense Components
FTB1260	High Efficiency Preservation Technologies
FTB1262	Energy Optimization in Food Service
FTB1265	Human Factors of Ration Consumption
FTB1266	Sensory Engineering of Rations
FTB1270	Quality Retention & Nutrient Bioavailability
FTB1271	Attainments and Validation of Microbial Control
FTB1276	Thermostabilized Meals for Combat Vehicle Crews
FTB1279	Development of Polymeric Packaging Materials
MSR1426	Design of USAF/USN Flight Feeding System
MSR1449	Nutritional Sustainment Module
MSR1485	Thermostabilized Meals for Remote Areas
MSR1486	Develop Compact/Springback Bread
MSR1497	Lowfat Instantized Operational Ration Milk
MSR1498	New Generation Survival Rations
MSR1509	Food Service for Rail Garrison Mobile Missiles
MSR1511	Self-heating for the Year 2000

The specification of technologies used in the technological evaluation exercise appear in Table 7. Note that the 30 technologies were placed into specific categories, which were defined for the evaluators. This approach was undertaken, despite the high likelihood that qualified evaluators should already be familiar with most or all of the technologies, to ensure that they considered each technology within the intended context provided under the category's description.

Moreover, during preparation of the survey material, it was noted that not every technology listed in Table 7 applied to every work unit. For example, the technologies of the 'protection' category were deemed to have little relevance to work unit FTB1259 (Universal Nutrient Dense Components), since this effort was not directly related to packaging. By the same logic, the packaging benefits were deemed equally inappropriate. The effect of such eliminations was to reduce the administrative burden on respondents still further, in instances where either P(t I w) or P(b I w) was anticipated to be virtually zero. In the case of FTB1259, 22 technologies and 9 benefits were ultimately presented to the evaluators.

During the evaluation process, itself, one further step was taken. The applicability of a technology and a benefit to a work unit does not necessarily imply a relationship between all technologies and benefits. Continuing the example, although the technology 'preservatives' and the benefit of reducing a ration's weight were both deemed appropriate to the evaluation of FTB1259, that particular combination of technology-benefit was not. While this recognition provided no administrative advantage during the evaluation process, such irrelevant combinations were later filtered out electronically, during the analysis of the evaluations.

The selection of participants included both Natick scientists as well as technologists from the civilian community. In these latter instances, the 'recruiter' (Battelle Corp, under an Army Research Office contract to support this FEA) provided a list of potential evaluators to Natick, along with evidence of each candidate's technological credentials. From this list, four out-of-house evaluators were selected and added to the six Natick participants, for a total of ten members composing the finalized evaluation team.

Table 7. Technologies Applied to Individual Ration Development

Category	Description	Technologies
Process	Process and techniques by which principles of food engineering and process control are applied to produce foods stabilized by adding preservatives and/or by heating, drying, extruding/infusing, and irradiating to retard or destroy microbial contaminants.	Preservatives Thermoprocessing Dehydration Extrusion/Infusion
Design	Procedures and approaches by which principles of nutrition, food formulation, sensory attribute control, and consumer marketing are applied to produce rations of suitable nutrition, acceptance, and modularity.	Nutritional Engineering Ingredient Formulation Sensory Engineering Consumer Marketing Modularization
Protection	Methods and processes by which the principles of material science and physical chemistry are applied to the development of coatings, films, flexible and rigid containers, and modified gaseous atmospheres to control the transmission of molecular components between the ration and its environment and to protect the ration from physical abuse.	Coatings Films Containers Gaseous Overwrap
Assessment	Procedures and methods by which the principles of quality assurance, human behavior, and operations research are applied to assess the safety, bioavailability of proteins/carbohydrates, enhancement of physical and mental performance, retention of quality, and overall system effectiveness of all operational rations.	Safety Factors Nutrient Availability Performance Enhancement Quality Limitations Systems Effectiveness

Table 7. Technologies Applied to Individual Ration Development (Cont'd)

Category	Description	Technologies
Human Factors	Methods by which the principles of human factors engineering and biodynamics are applied in developing artificial intelligence (AI) and optimization programs for selecting proper ration components convenient-to-handle rations, efficient and safe heating /cooling devices, and package disposal procedures.	AI Selection Handling Heating/Cooling Disposal
Logistics	Procedures and practices by which the principles of operations research and management science are applied in devising systems for tailoring modules into scenario -specific rations, for efficiently distributing/delivering rations, and for automatically monitoring and managing the stored rations.	Tailoring Distribution/ Delivery Monitoring/ Management
Equipment	Methods and techniques by which principles of material science, energy utilization, and operations research are applied in developing food service equipment that is lightweight and durable, that operates with minimum energy input, and that is configured for optimum human use.	Materials Engineering Energy Utilization Functional Optimization
Biotechnology	Techniques by which principles of chemical extraction/absorption, marine biology, plant physiology, and microbial conversion of biomass are applied by an individual to obtain sustenance from the land, air, or ocean.	Biotechnology

6. Evaluating the Results of the Exercise

The results of analyzing the entire (DOD-wide) sample by the method explained in Section II.4 is shown in Table 8:

Table 8. DOD-Wide Priorities

Priority Value	Benefit	Priority Value	Benefit
.327	Strength & Alertness	.02955	(general) Preparation
.28273	Satiety	.02529	Opening
.07539	Weight	.0208	Decontamination
.06963	Volume	.01897	Durability
.05608	Taste	.01605	Disposal
.03535	Heating	.01141	Recognizability
.03171	Variety		

Examples of partitioning the total sample into K=two, and three groups are shown in Appendix B.

Next, Table 9 shows the funding and normalized funding applicable to the 17 proposals, as was introduced in Section II.2:

Table 9. Normalization of Funding

PROPOSAL NUMBER	FUNDING	% FUNDING (FUNDING/TOTAL FUNDS)
FTB1259	73	4
FTB1260	210	12
FTB1262	95	5
FTB1265	185	10
FTB1266	104	6
FTB1270	125	7
FTB1271	104	6
FTB1276	104	6
FTB1279	90	5
MSR1426	144	8
MSR1449	80	5
MSR1485	35	2
MSR1486	70	4
MSR1497	52	3
MSR1498	75	4
MSR1509	95	5
MSR1511	123	7
	TOTAL FUNDS: 1764	AVERAGE: 5.8

Figure 3 recapitulates the remaining steps taken to arrive at a total score for work unit FTB1259. Note that although it is more detailed than Figure 2, the same basic form applies.

Within the context of the report, space limitations became a concern regarding the depiction of the FEA process. The total number of branches extending from a work unit is the product of the applicable technologies times the benefits. Thus, up to 390 branches would be required. Obviously, this would have resulted in an impossibly complex diagram. The compromise used was to select a small number of technologies, and compute findings on that basis. However, this action was taken for reporting purposes only. Since electronic data processing techniques allow the evaluation of large numbers of technologies and/or benefits, no such compromise is necessary during actual applications of the FEA process. Moreover, it is again emphasized that the goal of the exercise, rather than concentrating on perfection of examples, was to demonstrate the process, itself, in a start-to-finish manner.

Proceeding from the left, Figure 3 follows the process described in Section II. The initial 4% of total requested technology base resources comes from Table 9. These resources are then distributed to its technologies as indicated by the proportion beneath each technology. Hence, Dehydration's share of FTB1259's resources is 4% * 10% or .4% of all technology base resources. This is the estimated cost of pursuing that branch, and is applied to all benefits anticipated to result from this work unit-technology combination. The next column identifies the benefits by name. Following this, the median probabilites applicable to each work unit-technology-benefit branch provided by the technological evaluations are listed under 'RAW' BENEFIT. The 'Raw' Benefit/Cost column, which is the quotient of the 'RAW Benfit' column divided by the main branch's resources, is included to allow the reader a preliminary look at these relationships; before being multiplied by the DOD-Wide Priorities, to arrive at each branch's final 'Score'. The sum of these branch scores is the score attained by work unit FTB1259, and is listed at the lower-right corner of Figure 3.

Analogous computations determined scores for the remaining 16 work units. The results are listed in Table 10.

```
                                                              'RAW'
                               Benefit           'RAW'     Benefit/    DOD       Branch
        TECHNOLOGY             Name              Benefit    Cost       Priority  Score

                       I->  Weight              .446      111.50     0.07539    8.406
                       I->  Volume              .446      111.50     0.06963    7.764
        Dehydration    I-> (general) Prep       .396       99.00     0.02955    2.925
      I--> .4% --------I->  Opening             .244       61.00     0.02529    1.543
      I  (10% of       I-> Recognizability      .208       52.00     0.01141    0.593
      I  FTB 1259)     I->  Taste               .254       63.50     0.05608    3.561
      I                I->  Variety             .236       59.00     0.03171    1.871
      I                                                              Sub-Total: 26.663
      I
      I                I->  Weight              .592       74.00     0.07539    5.579
      I  Nutritional   I->  Volume              .592       74.00     0.06963    5.153
      I  Engineering   I->  S & A               .528       66.00     0.32700   21.582
      I--> .8% --------I->  Satiety             .414       51.75     0.28273   14.631
      I  (20% of       I-> Recognizability      .236       29.50     0.01141    0.337
      I  FTB 1259)     I->  Taste               .264       33.00     0.05608    1.851
F     I                I->  Variety             .264       33.00     0.03171    1.046
T     I                                                              Sub-Total: 50.178
B     I
      I                I->  Weight              .464      116.00     0.07539    8.745
1     I Modularization I->  Volume              .464      116.00     0.06963    8.077
2 --> I--> .4 % -------I-> (general) Prep       .350       87.50     0.02955    2.586
5     I  (10% of       I->  Opening             .336       84.00     0.02529    2.124
9     I  FTB 1259)     I-> Recognizability      .208       52.00     0.01141    0.593
      I                I->  Variety             .236       59.00     0.03171    1.871
(4%   I                                                              Sub-Total: 23.997
 of   I
Tech  I  Performance   I->  S & A               .414      103.50     0.32700   33.844
Base) I  Enhancement   I->  Satiety             .364       91.00     0.28273   25.728
      I--> .4 % -------I->  Opening             .336       84.00     0.02529    2.124
      I  (10% of       I->  Taste               .228       57.00     0.05608    3.197
      I  FTB 1259)     I->  Variety             .239       59.75     0.03171    1.895
      I                                                              Sub-Total: 66.789
      I
      I                I->  Weight              .446       22.30     0.07539    1.681
      I                I->  Volume              .446       22.30     0.06963    1.553
      I  Tailoring     I-> (general) Prep       .396       19.80     0.02955    0.585
      I-->  2 %        I->  Opening             .290       14.50     0.02529    0.367
         (50% of       I-> Recognizability      .186        9.30     0.01141    0.106
         FTB 1259)     I->  Taste               .254       12.70     0.05608    0.712
                       I->  Variety             .546       27.30     0.03171    0.866
                                                                     Sub-Total:  5.870

                                                                        Total: 173.496
```

Figure 3. Scoring Proposal FTB 1259

Table 10. Prioritization of the Candidate Work Units

Rank	Proposal Number	Score
1	MSR1449	486.463
2	MSR1485	181.284
3	FTB1259	173.496
4	MSR1497	136.069
5	MSR1498	129.805
6	MSR1486	79.263
7	MSR1426	71.034
8	FTB1265	63.067
9	FTB1276	60.643
10	FTB1266	53.062
11	MSR1511	44.674
12	MSR1509	42.987
13	FTB1279	33.666
14	FTB1260	25.283
15	FTB1270	16.718
16	FTB1262	14.668
17	FTB1271	7.260

7. Conclusions

Almost unilaterally, MSR's scored higher than technology base proposals. Of course, the inclusion of these types of proposals was not an objective of this FEA. However, it must be concluded that the process developed in this FEA, in and of itself, might not lead to an acceptably 'balanced' DOD Food Program.

Why did the MSR's dominate the prioritization? One answer may lie in the users' priorities, which have been shown to impact heavily upon a proposal's final score. Possibly these representatives are still mired in near-term thinking. However, another plausible hypothesis is that they are thinking long term, but do not anticipate substantial departures from their current priorities in the future. In either case, these priorities are more compatible with the near-term focus common to most MSR's. Even the single exception in the top seven ranks seems to confirm this conclusion, for the objectives and approach of FTB1259 (Universal Nutrient Dense Components) make it extremely compatible with some of the most highly-prioritized benefits in Table 8. Alternatively, two MSR's did score relatively low. While the technologies pursued in MSR1509 may have some peripheral relevance to individual rations, that was certainly not the primary focus of that effort. Additionally, the objectives/approach to this Air Force project may have been more difficult to generalize. The reasons for MSR1511's relatively low rank are less obvious, for its focus on ease of heating is certainly of some importance to the users. The explanation is twofold. Firstly, referencing the average % funding computed in Table 9, MSR1511 was a relatively high consumer of resources. Thus, in order to maintain a competitive score, it would have to have been rated relatively highly by both technological evaluators and users. More importantly, while ease of heating is undeniably an important benefit, it is still only one benefit. Thus, it is almost assured a relatively low score, when assessed in relation to other proposals which pursue multiple benefits. Another important conclusion to be drawn from this is that the FEA process will work best when proposals can be anticipated to provide nearly uniform numbers of benefits.

Another important issue is raised by the last-place positioning of FTB1271. 'Attainment and Validation of Microbial Control' can be anticipated to make important advancements regarding shelf life. However, users may be more inclined to perceive shelf life as a prerequisite, rather than a benefit. Hence, one limitation of the FEA process concerns the distinction between benefits and other important areas of research in which the linkage to benefits may not be apparent. However, when the FEA process does prioritize a proposal as low, the process has merit even if that rank is eventually rejected. The process, itself, has focused thinking; as to why the proposal attained a low score, and why it may still constitute a viable avenue for technology base research. Since it is possible that actual reviews of the FOOD Program may ask similar questions, this type of focus allows Natick to consider its position on a questionable proposal in advance; to be 'proactive', rather than reactive.

Finally, since a review of Table 9 indicates that FTB1259 was an above-average consumer of resources, how did it attain second place among technological proposals? In part, this is due to the relatively high values the users placed upon behaviorally-oriented benefits. However, it is also due to high estimated likelihood of success regarding these benefits by the technological evaluators. While there is nothing inherently wrong with this, it does lead to questions of comparability regarding the inherent difficulty of achieving the objectives of competing proposals. That is, the potential exists for some proposals to score very well during technical evaluations merely because their objectives are not very 'challenging'. Even when proposals are not very challenging, they may never-the-less be worth pursuing. The question is not their viability. Rather, the real issue is whether or not such proposals belong in the technology base.

It is recommended that the methodology developed in this FEA be incorporated into the DOD Food Program's process for prioritizing technology base proposals. This recommendation is based upon the achievement of the FEA's objectives. A methodology was developed by which input from large numbers of military personnel, used in conjunction with technological evaluations of proposed research and related cost data, can produce useful information. However, such information must be considered within the larger context of managerial judgement and common sense.

This document reports research undertaken at the US Army Natick Research, Development and Engineering Center and has been assigned No. NATICK/TR-91/026 in the series of reports approved for publication.

REFERENCES

Daniel, Wayne W., Terrell, James C. Business Statistics, Basic Concepts and Methodology. Houghton Mifflin Company, Boston, MA, 1983.

Hartigan, John A. Clustering Algorithms. John Wiley & Sons, Inc, New York, NY, 1975.

Saaty, Thomas L. The Analytic Hierarchy Process. McGraw-Hill, Inc., New York, NY, 1980.

Appendix A
Organizations Representing the User Community

Appendix A
Organizations Representing the User Community

Army Organizations

US Army Air Defense School
Ft Bliss, TX

US Army Aviation Center
Ft Rucker, AL

US Army Armor School
Ft Knox, KY

US Army Infantry School
Ft Benning, GA

US Army Logistics Center
Ft Lee, VA

US Army Ordnance School
Aberdeen Proving Grounds, MD

US Army Aviation Logistics School
Ft Eustis, VA

US Army Quartermaster School
Ft Lee, VA

US Army Military Police School
Ft McClellan, AL

US Army Transportation School
Ft Eustis, VA

US Army Combined Arms Center
Ft Leavenworth, KS

US Army Communications School
Ft Gordon, GA

US Army Engineer School
Ft Belvoir, VA

US Army Field Artillery School
Ft Sill, OK

US Army Intelligence School
Ft Huachuca, AZ

US Army Chemical School
Ft McClellan, AL

US Army Ordnance Missile
& Munitions School
Redstone Arsenal, AL

US Army John F. Kennedy
Special Warfare Center
Ft Bragg, NC

Navy Organizations

US Naval Construction Battalion
Norfolk, VA

US Naval Special Warfare Group 1
Coronado, CA

US Naval Air Systems Command
Washington, DC

US Naval Development Center
Warminster, PA

Appendix A (Cont'd.)
Organizations Representing the User Community

Marine Corps Organizations

MC Combat Development Command
Warfighting Center
Quantico, VA

MC Research, Development &
Acquisition Command
Rosslyn, VA

Headquarters Marine Corps
Washington, DC

Air Force Organizations

Alaskan Air Command
Elmendorf AFB AK

AF Logistics Command
Wright-Patterson AFB OH

AF Systems Command
Andrews AFB MD

Air Training Command
Randolph AFB TX

Air University
Maxwell AFB AL

Military Airlift Command
Scott AFB IL

HQ Pacific Air Forces
Hickam AFB HI

Strategic Air Command
Offutt AFB HI

AF Space Command
Peterson AFB CO

Tactical Air Command
Langley AFB VA

USAF Academy Preparatory School
Colorado Springs CO

Electronic Security Command
San Antonio TX

HQ Air Force Reserve
Robins AFB GA

AF Commissary Service
Kelly AFB TX

HQ US Air Forces in Europe

Appendix B
Examples of Clustering

Appendix B. Examples of Clustering

K=2 Groups

Group 1 (70%) Priority Value	Benefit	Group 2 (30%) Priority Value	Benefit
.279	S & A	.413	S & A
.269	SATIETY	.185	SATIETY
.101	TASTE	.176	WEIGHT
.062	VOLUME	.17	VOLUME
.06	VARIETY	.022	HEATING
.057	WEIGHT	.021	PREPARATION
.039	HEATING	.012	OPENING
.028	PREPARATION	*	DURABILITY
.024	RECOGNIZABILITY	*	DECONTAMINATION
.023	OPENING	*	DISPOSAL
.021	DECONTAMINATION	*	RECOGNIZABILITY
.021	DURABILITY	*	TASTE
.016	DISPOSAL	*	VARIETY

K=3 Groups

Group 1 (41%) Priority Value	Benefit	Group 2 (27%) Priority Value	Benefit	Group 3 (31%) Priority Value	Benefit
.558	SATIETY	.321	WEIGHT	.230	SATIETY
.109	VOLUME	.299	VOLUME	.177	S & A
.092	WEIGHT	.294	SATIETY	.094	TASTE
.068	HEATING	.035	HEATING	.086	WEIGHT
.056	PREPARATION	.033	PREPARATION	.086	VOLUME
.036	DECONTAMINATION	.018	OPENING	.071	VARIETY
.033	OPENING	*	S & A	.058	HEATING
.031	DURABILITY	*	DURABILITY	.039	OPENING
.017	DISPOSAL	*	DECONTAMINATION	.038	PREPARATION
*	S & A	*	DISPOSAL	.031	DURABILITY
*	RECOGNIZABILITY	*	RECOGNIZABILITY	.031	DECONTAMINATION
*	TASTE	*	TASTE	.03	DISPOSAL
*	VARIETY	*	VARIETY	.028	RECOGNIZABILITY

* Group was inconsistent on the indicated benefits. Inconsistency, which is discussed in considerable detail in the Saaty text, basically refers to the degree of discontinuity between expressed relationships, and those algebraically implied from other responses. For example, if $x/y=1/2$ and $y/z=1/4$, then the implied relationship x/z is $1/8$. If an expressed comparison of x to z does not yield 1/8, the degree of difference is an indication of inconsistency. In the FEA exercise, when the set of data taken as a whole was not sufficiently consistent, all judgements which involved a particular benefit were removed from the set; and the consistency of the residual set recalculated. If no single source of inconsistency could be identified, the process was repeated, removing pairs of benefits, until satisfactory consistency in the residual set was achieved.