BNWL-1466
UC-32

TECHNOLOGICAL FORECASTING

S. R. Fields

June 1970

AEC RESEARCH &
DEVELOPMENT REPORT

BNWL-1466

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UNITED STATES ATOMIC ENERGY COMMISSION UNDER CONTRACT AT(45-1)-1830

3 3679 00061 7144

BNWL-1466
UC-32, Mathematics
and Computers

TECHNOLOGICAL FORECASTING

by

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June 26, 1970

BATTELLE MEMORIAL INSTITUTE
PACIFIC NORTHWEST LABORATORIES
RICHLAND, WASHINGTON 99352

Printed in the United States of America
Available from
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U.S. Department of Commerce
Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.65

ABSTRACT

A preliminary study was made of the techniques currently being used for technological forecasting and advanced planning. A procedure is recommended which is based mostly on the use of relevance trees and the morphological approach to invention and discovery. A demonstration forecast was made to illustrate the use of the recommended procedure.

TABLE OF CONTENTS

	<u>Page</u>
<u>ABSTRACT</u>	i
<u>INTRODUCTION</u>	1
<u>CONCLUSIONS AND RECOMMENDATIONS</u>	2
<u>METHODS, APPROACH AND DISCUSSION OF RESULTS</u>	4
0 RECOMMENDED PROCEDURE FOR TECHNOLOGICAL FORECASTING	10
● <u>Construction and Evaluation of a Horizontal Relevance Tree or a Morphological Space</u>	13
● <u>Construction and Evaluation of an Objectives Relevance Tree</u>	23
0 USE OF DELPHI	25
0 DEMONSTRATION TECHNOLOGICAL FORECAST	25
● <u>Construction and Evaluation of the Horizontal Relevance Tree</u>	26
● <u>Construction and Evaluation of the Objectives Relevance Tree</u>	37
<u>REFERENCES</u>	64

LIST OF TABLES

	<u>Page</u>
TABLE I Sample Problem: Derivation of Significance Numbers for Level Entries	16
TABLE II Sample Problem: Derivation of Criteria Weights	19
TABLE III Derivation of Relevance Numbers	20
TABLE IV Sample Problem: Derivation of Relevance Numbers	21
TABLE V Derivation of Significance Numbers for Level 2.0 Entries of the Horizontal Relevance Tree	31
TABLE VI Derivation of Criteria Weights for Level 2.0 of the Horizontal Relevance Tree	33
TABLE VII Derivation of Relevance Numbers for Each Entry on Level 2.0 of the Horizontal Relevance Tree	34

LIST OF FIGURES

	<u>Page</u>
Figure 1	9
Tree Structure	
A. Unfolded Tree	
B. Folded Tree	
Figure 2	11
Exploratory Objectives Tree Constructed Without Constraining Levels	
Figure 3	12
Vertical Relevance Tree Composed of an Objectives Relevance Tree and a Concept- Oriented Relevance Tree	
Figure 4	14
Preference Matrix for Ranking by Partial Paired Comparisons	
Figure 5	30
Preference Matrix Showing the Ranking of the Major Systems of the Nation According to their Contribution or Importance to National Survival	
Figure 6	32
Preference Matrix for the Ranking of the Criteria at Level 2.0 of the Horizontal Relevance Tree According to Their Importance to the Investigating Organization or to the Stated Goal of the Relevance Tree	
Figure 7	35
Horizontal Relevance Tree: Find the Role of Nuclear Technology in Energy Utilization	
Figure 8	43
Objectives Relevance Tree: To Increase the Nation's Supply of Fresh Water	

TECHNOLOGICAL FORECASTING

INTRODUCTION

Technological forecasting is becoming a widespread activity in business and government to anticipate needs and objectives of the future and to plan research and development programs to meet these needs and objectives.

A preliminary study was made of the techniques currently being used for technological forecasting and advanced planning with the objective of recommending a procedure and demonstrating its use. The procedure recommended is based mostly on the use of relevance trees derived from the use of the morphological approach to invention and discovery and objective networks from the fields of systems analysis and operations research.

Another possible approach to technological forecasting is suggested. This approach, termed the "Method of Successive Morphologies", was not used in the present study, but the author plans to put it to the test in future applications.

The DELPHI technique for arriving at a consensus of expert opinion was not used because of its sole dependence on group participation. However, it is considered a vital part of the recommended procedure because it would be used to make the actual technology forecasts required.

Technological forecasting is important for several reasons:

- It provides decision makers with information needed to help decide the direction of research for the future,
- It allows assessment of the interaction of socio-economic and technical environments, and
- It is a way of predicting where research will be required now to provide the solutions to problems of the future.

The demonstration forecast devised to illustrate the recommended procedure was based on the stated purpose: "To find the role of nuclear technology in energy utilization." When the morphological method was applied to this stated purpose, one of the objectives obtained was "To increase the nation's supply of fresh water". This basic objective was then translated into specific technical objectives by use of an objectives relevance tree.

CONCLUSIONS AND RECOMMENDATIONS

Apparently there are no formal textbooks on the subject of technological forecasting. Some excellent survey books are available which attempt to organize the work that has been done in this field⁽¹⁾ or which present collections of papers on the subject.⁽²⁾ In the present study, effort was concentrated on sorting out the various techniques available, selecting their best features, and forming them into a suitable procedure. It was found that most of the techniques of technological forecasting are closely related to the procedures of systems analysis and operations research. For example, determination of relevance numbers bears a strong resemblance to the system worth calculations of systems analysis. Also, the use of objectives trees is common practice in systems analysis. Exceptions are morphological analysis and the DELPHI technique, although some of the techniques of systems analysis strongly suggest having roots in morphological analysis.

The following procedure is recommended for making a technological forecast:

1. Construct a morphological space or horizontal relevance tree for a predetermined goal or purpose. Numerically evaluate the tree by computing relevance numbers based on weighted criteria and significance numbers obtained using a modified version of the method of successive comparisons from operations research. The most

relevant path through the horizontal relevance tree suggests one or more objectives to be expanded using an objectives relevance tree.

2. Construct a constrained objectives relevance tree and evaluate to translate the objectives obtained from the horizontal relevance tree into specific technical objectives. The evaluation procedure is the same as that for the horizontal relevance tree.
3. Actual technology forecasts are then made using methods of intuitive projection such as the DELPHI technique, trend extrapolation, historical analogy, etc. The technology forecasts are made in terms of feasibility, effort required, needs, etc. It is recommended that the DELPHI technique be used to make the technology forecasts. DELPHI can also be used to arrive at the goal or purpose for the horizontal relevance tree of item 1.

It is concluded that the recommended procedure has great potential for technological forecasting and advanced planning.

Group participation is essential for the success of the recommended procedure. The breadth of knowledge required to construct the relevance trees, establish meaningful criteria, and provide sound value judgments exceeds that of any one man. A demonstration technological forecast was made as part of this study; however, because it was conducted without the benefit of group participation, its value is limited to a demonstration of the procedure. It is recommended that further effort be devoted to organizing and channeling group participation to arrive at more meaningful forecasts.

All technological forecasting procedures require group participation. The opinions of knowledgeable people in many diverse fields are necessary to produce an effective and meaningful technological forecast. This leads to one of the most serious problems of technological forecasting: the willingness or reluctance of individuals to participate.

A successful technological forecast will be one in which all participants are genuinely interested and one in which the effort required on their part is held to a minimum. In using the DELPHI technique, several rounds of questionnaires are presented to the participants. Considerable thought is required for the completion of these questionnaires. When relevance trees are used, such as in the procedure recommended above, participants are asked to help construct the trees, set up criteria for each level, and to rank and evaluate the various criteria and entries. To reduce the amount of effort required of a participant it is suggested that the number of levels, entries and criteria for both horizontal relevance trees and objectives relevance trees be held to a minimum. It is also recommended that the scope of the horizontal relevance tree be kept as narrow as possible,

A computer program should be developed to carry out the multitude of computations necessary for the evaluation of relevance trees.

It might be possible to use the dynamic programming algorithm to find the most relevant path through a horizontal relevance tree. A horizontal relevance tree is a collection of alternative paths, the optimum or most relevant of which can be found by dynamic programming. This will not work on an objectives relevance tree because it is either an unfolded or partially folded tree and, hence, does not represent a true set of alternatives in the sense of a completely folded tree. It is recommended that this approach be investigated further.

A suggested "Method of Successive Morphologies," now in the conceptual stage, might offer a slightly different approach to the use of horizontal relevance trees for technological forecasting.

METHODS, APPROACH AND DISCUSSION OF RESULTS

Technological forecasting is in its infancy, with no formal textbooks available on the subject. Dr. E. Jantsch

has carried out a state-of-the-art study of technological forecasting for the Organization for Economic Cooperation and Development and has published the results in a book entitled "Technological Forecasting in Perspective."⁽¹⁾ A collection of papers has been edited by Prof, James R. Bright of the Graduate School of Business Administration, Harvard University, and published as a book entitled "Technological Forecasting for Industry and Government, Methods and Applications."⁽²⁾ Many other excellent papers have been published in the open literature. A study of the literature has shown that there are many different approaches to technological forecasting,

Esch⁽³⁾ reports on the use of PATTERN, a quantified relevance tree scheme developed by Honeywell which starts with a written scenario and a technology forecast. Cetron⁽⁴⁾ reports on PROFILE, an approach similar to PATTERN, which was developed for the U.S. Navy. Swager⁽⁵⁾ and Buttner and Cheaney⁽⁶⁾ use horizontal relevance trees or environmental networks to determine basic objectives and an objectives relevance tree to find the competing paths of technology leading towards the basic objective. Swager, Buttner and Cheaney apparently do not use a quantified version of the relevance tree. Gordon and Helmer⁽⁷⁾ and North and Pyke⁽⁸⁾ make use of the modified DELPHI technique to forecast future events, their probability of occurrence, and the probable dates. DELPHI requires group participation since it is a method devised to arrive at a consensus of expert opinion,

It was determined that a technological forecasting effort could be divided into the following three parts:

1. Morphological analysis - this may also be thought of as the construction of horizontal relevance trees or environmental networks.
2. Construction of an objectives network or objectives relevance tree.

3. Intuitive projection - this can be done by arriving at a consensus of opinion using the DELPHI method, or by projections using historical analogy, trend extrapolation, etc.

According to Swager,⁽⁵⁾ the most important question to be answered in a technological forecasting effort is: "What should be forecast?" A morphological analysis and the use of an objectives relevance tree would answer this question when applied to a specified goal. Since it was felt that many goals could be readily identified it was more important to develop these two techniques first and then, if the resources allowed, to develop an application of the DELPHI technique for the value judgments and the actual technology forecasts.

This order can vary. For example, the DELPHI technique could be used to get a consensus of opinion on possible future developments and then the morphological analysis could be used to define the basic parameters and to arrive at a most relevant combination of these parameters to form a primary objective. The objectives relevance tree would then be used to translate the primary objective into specific technical objectives. The procedure of the present study was developed in the order given because this would give us the most return for the resources expended. The first two items answer the question: "What should be forecast?", and the last item answers the question: "How should we carry out the actual forecasting?"

The extent of effort required to use DELPHI to determine what should be forecast would have exceeded the resources available. Questionnaires would have to be prepared, processed, edited, rephrased and reissued a number of times to arrive at a consensus. This would have been demanding not only on the investigator but also on those who were engaged in answering the questionnaires. Elaborate preparations would have had to be made to arrange for participation of selected key individuals. For these reasons, DELPHI was put in a position where it would be used to arrive at value judgments

necessary for the evaluation procedures for the relevance trees and to make actual technology forecasts.

The morphological method of analysis was invented by Prof. F. Zwicky of California Institute of Technology. In his own words, Prof. Zwicky states that: "The morphological approach to discovery, invention, research and construction has been conceived and developed for the purpose of dealing with all situations in life more reasonably and more effectively than hitherto. This is achieved through the study of all relevant interrelations among objects, phenomena and concepts by means of methods which are based on the utmost detachment from prejudice and carefully refrain from all prevaluations." (9)

The morphology of a concept consists of a set of dimensions or parameters each of which contains alternative elements. The coordination of one element from each dimension constitutes what is known as an elementary morphology. An elementary morphology will be formed by an objective whether feasible or not. Stated another way, an elementary morphology characterizes one or more possible objectives. The problem will be to choose the objective or objectives, feasible or believed unfeasible, by using some preference rule. The preference rule or evaluation procedure used will be discussed later.

The dimensions of a morphological space represent a class of independent variables or parameters. Dimension entries or elements are the alternative ways in which the dimension may be expressed. If a morphological space consists of two dimensions it may be expressed as a matrix. If the morphological space has three dimensions it may be expressed as a box. A multidimensional or n-dimensional space is best represented by a tree.

Technological forecasting bears a strong relationship to systems analysis and operations research. For example, the use of objectives trees is standard procedure in systems analysis and operations research. In technological forecasting, the objectives relevance tree is a constrained version of the

usual objectives tree. In systems analysis an objectives tree is used to construct a hierarchy of objectives, the only requirement being that every objective must contribute to the one directly above it in the tree. The levels of the tree are not identified and it is quite common to find objectives on one level identical to those on several levels removed. An objectives relevance tree is constrained by establishing specific levels which identify the types of objectives which must be entered at the levels. This facilitates the setting up of sets of criteria at each level and the evaluation of the tree.

Since the procedure recommended in this report for technological forecasting depends upon tree structures it is appropriate at this time to discuss the types of trees that will be encountered. A tree may be folded or unfolded, and hierarchic or non-hierarchic. Figure 1-A (p. 9) shows an unfolded tree. Note that level 3 contains two entries, E and F, that are common to both branches. Since these entries are common to both branches, the tree may be folded as shown in Figure 1-B (p. 9).

The tree is hierarchic if any entry contributes directly to the attainment of an entry on the next highest level. The tree is non-hierarchic if the levels of the tree are of equal rank. A morphological space or horizontal relevance tree is usually non-hierarchic and completely folded. An objectives relevance tree is usually hierarchic and may be partially folded and partially unfolded.

A hierarchic tree is constrained if levels are established and labeled and the entries identified as elements of the dimension represented by the level. An unconstrained tree does not conform to established levels, but each entry has a unique relationship to the entry preceding it. An objectives tree may be constructed without constraining levels. An unconstrained tree is shown in Figure 2 (p. 11), where the same entry may be found on different branches and on different

A. Unfolded Tree

B. Folded Tree

Figure 1

Folded and Unfolded Tree Structures

levels, A constrained objectives relevance tree with established levels representing six levels of objectives is shown in Figure 3 (p. 12).

The DELPHI technique for arriving at a consensus of expert opinion is actually brainstorming without all of its disadvantages. Opinions obtained from a brainstorming session can be influenced by a "bandwagon" effect, by one strong-willed individual, by one's immediate superior, or possibly simply by the one who has the loudest voice. In using DELPHI, each of the participants is isolated from the others and asked to express his opinion on questionnaires which are then processed and edited. The edited information is fed back to the participants who then have a chance to alter their opinions on the next round. Several rounds may be necessary to arrive at a consensus. The DELPHI technique has been highly successful in many applications; therefore, it is recommended that it be pursued in any further studies.

RECOMMENDED PROCEDURE FOR TECHNOLOGICAL FORECASTING

A recommended procedure for technological forecasting will be outlined in this section. Construction and evaluation of a morphological space or horizontal relevance tree and an objectives relevance tree will be discussed.

The most relevant paths through the relevance trees are determined by the application of some additional techniques from systems analysis and operations research. A modified version of the method of successive comparisons is used to provide the necessary value judgments. The method of partial paired comparisons is used along with preference matrices to rank the entries or alternatives and the criteria at each level. The numerical relative importance of the ranked items is then determined by a relatively new technique which is simple to use, and which minimizes the number of decisions required of a decision maker. This technique is DARE, an acronym for Decision Alternative Ration Evaluation.(10)

Figure 2

Exploratory Objectives Tree
Constructed Without Constraining Levels

Figure 3

Vertical Relevance Tree Composed of
an Objectives Relevance Tree and
a Concept-Oriented Relevance Tree

Construction and Evaluation of a Horizontal Relevance Tree or a Morphological Space

The first step in setting up a horizontal relevance tree or a morphological space is to formulate exactly the problem to be investigated. This becomes the title of the tree and represents the purpose or goal of the investigation. The narrower the scope of the problem definition the easier the technological forecast. The defined problem may be apparent as a stated goal of the organization making the forecast, or of the nation. If goals are not immediately apparent it might be necessary to employ the DELPHI technique here to compile a list on the basis of a consensus of opinion of individuals representing the professions, industry, government, etc.

The second step is to select dimensions or fundamental parameters upon which attainment of the goal depends. This is not an easy task, and it is one which may require inputs from a number of knowledgeable people.

Next, elements which represent alternatives at each level are listed as entries or vertices of the tree.

Sets of criteria are set up for each of the levels. The criteria in each set must be mutually exclusive or independent. Once again, the assistance of others may be required in establishing the criteria,

The method of partial paired comparisons is used to rank the various entries on each level according to their contribution to, or compliance with, each of the criteria at that level. A preference matrix used for ranking by partial paired comparisons is shown in Figure 4 (p. 14). Entries to be ranked are listed across the top and down the left side of the matrix. Starting at the first entry in the left-hand column, the matrix is traversed from left to right, comparing the entry with each of those listed at the top. When an entry listed in the left-hand column is preferred over one of those listed at the top of the matrix, a "1" is put in the upper half of the box formed by the junction of the two entries, and a "0"

Entries on Level <i>i</i>	A	B	C	D	Rank
A	- / 1	0 / 0	0 / 1	1 / 1	1
B	- / 1	- / 0	0 / 1	0 / 1	0
C	- / 1	- / 1	- / 0	1 / 0	3
D	- / 1	- / 1	- / 0	- / 0	2

Criterion: X

Figure 4

Preference Matrix for Ranking
by Partial Paired Comparisons

is put in the lower half, If the entry at the top of the matrix is preferred over that listed at the left, a "0" is put in the top half of the box and a "1" in the lower half. When the preference matrix is completely filled in, the "1's" in the upper half of the boxes are added and the total put at the right side of the matrix in the column headed "Rank". Those entries with the highest number of points rank the highest, The DARE technique is then used to derive a number to represent the relative importance of each of the ranked entries. The numerical relative importance is known as the "significance number".

The significance number is a measure of the significance of the contribution of the entry on the level to the particular criterion at that level. DARE was originally developed to minimize the amount of effort required of decision makers when called upon to rank and to numerically evaluate several items. The technique combines the ranking and the evaluation in one step. It was found that it was much easier and more meaningful to use a preference matrix for the ranking and then to use the remainder of the DARE technique to arrive at the significance numbers.

An illustration of the use of DARE to obtain significance numbers for level entries is shown in Table I (p. 16). Table I is based upon the ranking of entries A, B, C and D from the preference matrix of Figure 4 (p. 14). In Figure 4, the entries were ranked according to their compliance with or contribution to criterion X. Entry C received three votes, entry D received two votes, A received one vote, and B received no vote. Entry C ranks the highest because it received the most votes. The "Rank" column, column 2 in Table I, lists the votes each entry received in Figure 4. The highest ranking item, C, is listed first.

The numbers in the third column of Table I are quantitative ratios, assigned by the evaluator, which reflect the relative value he places on the importance of each entry,

TABLE I

Sample Problem: Derivation of
Significance Numbers for Level Entries

Criterion: X

Entries on Level i	Rank	Quantitative Ratio, R	Initial Significance Number, K	Normalized Significance Number, s
C	3	5.0	15.0	0.715
D	2	1.5	3.0	0.143
A	1	2.0	2.0	0.095
B	0	-	1.0	0.047
			21.0	1.000

Each ratio is a numerical comparison of each entry with the one listed immediately below it. The evaluator starts at the bottom of the list with item B and enters a blank in that column. He considers entry A twice as important as entry B, on the basis of its contribution to criterion X. Similarly, he considers entry D to be 1.5 times as important as entry A, and entry C five times more important than entry D.

Initial significance numbers are determined next in column 4. The initial significance number of the lowest ranked entry is always "1", which goes into column 4 opposite the last entry. The initial significance number for each entry is formed by the product of its quantitative ratio and the significance number of the entry below it in column 4, in a zigzag pattern up the table. The initial significance number for entry A is obtained by multiplying the 1.0 in the fourth column for entry B by the 2.0 in the third column for entry A, resulting in an initial significance number of 2.0 for entry A. Next, the initial significance number for entry D is formed by multiplying the initial significance number of 2.0 for entry A in column 4 by the quantitative ratio 1.5 in column 3 to give an initial significance number of 3.0 for entry D. Finally, the initial significance number for entry D is multiplied by the quantitative ratio for entry C in column 3 to give an initial significance number of 15.0.

The normalized significance numbers of column 5 are obtained by adding the initial significance numbers of column 4 and dividing the result into the initial significance numbers for each of the entries,

The next step in finding the most relevant path through a horizontal relevance tree is to rank and weight the criteria at each level. Criteria weights are determined in the same manner as significance numbers, the only difference is that the criteria are ranked according to their importance to the goal to be met. The criteria are ranked using a preference matrix such as the one shown in Figure 4, and weights are then

determined using DARE. A sample problem showing the derivation of criteria weights is illustrated in Table II (p. 19).

Relevance numbers for each entry on each level are computed next from the significance numbers and from the criteria weights, as shown in Tables III (p. 20) and IV (p. 21).

Criteria weights are multiplied by their respective significance numbers, for each entry on each level, and the products summed over all the criteria to produce the relevance number for the particular entry. A concise statement of this procedure is given as Equation I:

$$r_i^j = \sum_{k=W}^Z q_k s_j^k \quad (1)$$

where: q = the criteria weight,
 s = the significance number,
 r = the relevance number,
 i - identifies the level ($i = 1, 2, 3 \dots N$),
 j - identifies the entry ($j = A, B, C, D$), and
 k - identifies the criterion ($k = W, X, Y, Z$).

The selection of the criteria at each level, the ranking of the entries on each level against these criteria, and the determination of significance numbers and criteria weights require the value judgments of individuals with specialized knowledge appropriate to the construction and evaluation of the horizontal relevance tree. The procedure for determining relevance numbers may prove to be tedious, especially if there are large numbers of entries on each level. The burden of evaluation may be eased somewhat by writing a computer program to carry out the relevance number calculations; however, the value judgments required to select the dimensions or levels, to select the entries on each level, to select the sets of criteria for each level, to rank the entries against the criteria, and to derive significance numbers and criteria weights cannot be obtained from a computer program. Use of DARE has reduced the effort normally required of those

TABLE II

Sample Problem: Derivation
of Criteria Weights

Criteria for Level i	Rank	Quantitative Ratios, R	Initial Criteria Weights, K	Normalized Criteria Weights, q
Z	3	1.2	5.4	0.388
W	2	1.5	4.5	0.324
X	1	3.0	3.0	0.216
Y	0	1.0	1.0	0.072
			13.9	1.000

TABLE III

Derivation of Relevance Numbers

Criteria	Criteria Weights (q)	Items on Level i							
		s = Significance Numbers				r = Relevance Numbers			
		A		B		C		D	
		s	r	s	r	s	r	s	r
W	q_W	s_A^W	$q_W s_A^W$	s_B^W	$q_W s_B^W$	s_C^W	$q_W s_C^W$	s_D^W	$q_W s_D^W$
X	q_X	s_A^X	$q_X s_A^X$	s_B^X	$q_X s_B^X$	s_C^X	$q_X s_C^X$	s_D^X	$q_X s_D^X$
Y	q_Y	s_A^Y	$q_Y s_A^Y$	s_B^Y	$q_Y s_B^Y$	s_C^Y	$q_Y s_C^Y$	s_D^Y	$q_Y s_D^Y$
Z	q_Z	s_A^Z	$q_Z s_A^Z$	s_B^Z	$q_Z s_B^Z$	s_C^Z	$q_Z s_C^Z$	s_D^Z	$q_Z s_D^Z$
Relevance Numbers			r_i^A		r_i^B		r_i^C		r_i^D
Normalized Relevance Numbers			$r_{N,i}^A$		$r_{N,i}^B$		$r_{N,i}^C$		$r_{N,i}^D$

Norming Conditions: $\sum_W^Z q = 1$

$$\sum_A^D s = 1$$

Relevance Number: $r_i = \sum_W^Z q s$

Norming Condition: $\sum_A^D r = 1$

$$r_{N,i}^j = \frac{r_i^j}{\sum_W^Z r_i^j}$$

Total Relevance Number: $R = \prod_i r_{N,i}$

TABLE IV

Criteria	Criteria Weights (q)	Items on Level i							
		s = i nificance Numbers				r = Relevance Numbers			
		B		C		D			
		s	π	s	π	s	r	s	r
W	0.324	0.10	0.032	0.40	0.130	0.30	0.097	0.20	0.065
X	0.216	0.035	0.021	0.047	0.010	0.715	0.154	0.143	0.030
Y	0.072	0.30	0.022	0.20	0.014	0.40	0.029	0.10	0.007
Z	0.388	0.20	0.078	0.60	0.233	0.10	0.039	0.10	0.039
Relevance Numbers			0.153		0.387		0.319		0.141
Normalized Relevance Numbers			0.153		0.387		0.319		0.141

using the method of successive comparisons, but more must be done to minimize the effort required of those making value judgments. One way of reducing the amount of effort is to minimize the number of dimensions, entries and criteria needed to define the problem.

It was stated earlier that an elementary morphology will be formed by an objective, whether feasible or not, or characterizes one or more objectives. An elementary morphology is formed by joining entries, one from each level. The object is to choose the most relevant objective or elementary morphology. This is done by using the following preference rule: The most relevant elementary morphology or path through the horizontal relevance tree is the one which has the highest overall relevance number. The overall relevance number is determined by multiplying the individual relevance numbers of each of the entries selected, starting at the lowest level and working upwards to the top of the tree. This procedure is stated concisely in Equation 2:

$$R = \prod_{i=1}^N r_{N,i} \quad [i = 1 \text{ (top level), } 2, 3, \dots, N] \quad (2)$$

where: R = the overall relevance number.

This equation is used by Honeywell in their PATTERN technique. (1)(3)

Determination of the most relevant path or elementary morphology of a horizontal relevance tree will require a multitude of computations; therefore, the entire evaluation procedure described by Equations 1 and 2, and Tables III and IV, should be programmed on a computer. Recalling that a horizontal relevance tree is a completely folded tree, the number of computations required to fully explore the tree would be equal to the numbers of the entries on each level multiplied together. For example, a tree with one entry at the top level, three entries at the second level, and four entries at the third level would have $1 \times 3 \times 4 = 12$ elementary morphologies to be evaluated.

It is suggested that another way to find the most relevant path through the horizontal relevance tree would be to use the dynamic programming algorithm. The horizontal relevance tree is a combinatorial network and should lend itself to the application of this algorithm. This might be a better approach than using Equation 2 because it will give an optimal path through the tree on the basis of the worth of each entry as represented by its relevance number. Time did not permit the exploration of this possibility.

I would like to suggest another possible approach to technological forecasting which has come to mind during the course of the present study and which I will be putting to the test in future studies. This approach, based entirely on morphological analysis, I refer to as the "Method of Successive Morphologies". This method is nothing more than a chain of horizontal relevance trees which details alternatives proceeding in the direction of a narrower scope (i.e., broader description) for the objective identified by the elementary morphology of the first tree. Briefly, this is how it works: The elements of the elementary morphology of the first horizontal relevance tree are used as the **dimensions** of a second tree. Appropriate subentries are then entered as the new entries of the second tree, criteria are set up for each dimension, and the determination of a new elementary morphology proceeds as before. This procedure is repeated to any desired degree of specificity.

The method of successive morphologies could be **used** alone to arrive at specific technologies or technological deficiencies representing fruitful areas for research, or **it** could be incorporated into the recommended procedure as an expansion of the first step.

Construction and Evaluation of an Objectives Relevance Tree

The next step in the recommended procedure for technological forecasting is to construct an objectives relevance

tree. The horizontal relevance tree or morphological space reveals the most relevant elementary morphologies which suggest objectives within the context of the stated goal or purpose of the horizontal relevance tree. One of these objectives becomes the primary objective of an objectives relevance tree and is considered to be a "need or an identified demand to be filled",

Objectives trees in systems analysis are usually thought of as unconstrained objectives trees. This means that the objectives may not conform to preselected levels. The only requirement is that each objective must contribute to the attainment of the objective immediately above it in the tree. The objectives relevance tree used in technological forecasting is a constrained objectives tree where several categories of objectives are designated as levels. Objectives or entries at each level, then, fit into that particular category on that level. A constrained tree must be used in technological forecasting in order to evaluate the various competing technological paths that lead to the primary objective. Levels on an objectives relevance tree are equivalent to the dimensions on a horizontal relevance tree. A constrained objectives relevance tree is shown in Figure 3 (p. 12).

The most relevant path through the objectives relevance tree is determined in a manner similar to that used for the horizontal relevance tree. Criteria are set up for each level. The same procedure is used to rank the entries according to their compliance with criteria set up at each level, to determine significance numbers, to weight the criteria, and to determine relevance numbers. The most relevant path is obtained by application of Equation 2 (p. 22). Since the objectives relevance tree is not a completely folded tree, as is the horizontal relevance tree, the number of combinations to evaluate is drastically reduced.

It is important to have all the items on each level of the objectives relevance tree evaluated against a common set

of criteria. This becomes increasingly more difficult as one progresses to the lower levels since the tree may be partially or fully unfolded. The entries at the lower levels may have less and less in common since they are items on competing paths emanating from completely independent higher level entries.

USE OF DELPHI

Once the most relevant path through the objectives relevance tree is determined, the DELPHI technique could then be used to arrive at a consensus of expert opinion on the feasibility, timing, social acceptance, etc., of the measures required to overcome deficiencies revealed at the lower levels of the tree. In other words, the actual technology forecasting would be done using DELPHI.

DELPHI could also be used to construct the relevance trees by arriving at a consensus of opinion on levels, level entries, and criteria. DELPHI was not used in this study because of the lack of time and resources.

DELPHI should be considered as an alternative to the use of relevance trees for technological forecasting. The logical use of DELPHI here would be to identify the needs of the nation or of other future events to be used as the stated goal or purpose or title of a horizontal relevance tree. In other words, an alternate procedure would be to put DELPHI as the first step, horizontal relevance trees as the second step, and objectives relevance trees as the third step.

DEMONSTRATION TECHNOLOGICAL FORECAST

A considerable amount of study effort was devoted to sorting out the various techniques used by other investigators for technological forecasting. The morphological approach, tree structures and their evaluation, and the DELPHI technique were studied. As soon as the procedure described in the preceding

sections was developed, effort was then directed towards setting up a demonstration technological forecast.

Construction and Evaluation of the Horizontal Relevance Tree

A goal was arbitrarily selected which became the title of the morphological space or horizontal relevance tree: "Find the role of nuclear technology in energy utilization". The scope of this goal was probably too broad for a demonstration forecast, especially one conducted without group participation. It is always an advantage to narrow the scope of the investigation as much as possible because the broader the scope the more effort is required from participants.

A horizontal relevance tree was constructed with five dimensions or levels which represented the categories of forces that could affect the future role of nuclear technology in energy utilization. The five levels and their entries are:

- 1.0 Socio-Economic Forces
 - 1.1 Population Growth and Demographic Change
 - 1.2 Foreign Relations
 - 1.3 Domestic Relations
 - 1.4 Other
- 2.0 Basic Systems of the Nation (prime uses of energy)
 - 2.1 Power
 - 2.2 Security
 - 2.3 Housing
 - 2.4 Food, Water and Natural Resources
 - 2.5 Clothing
 - 2.6 Education
 - 2.7 Exploration
 - 2.8 Other
- 3.0 Basic Forms of Energy
 - 3.1 Chemical
 - 3.2 Nuclear
 - 3.3 Biological
 - 3.4 Hydro

- 3.5 Geothermal
- 3.6 Solar
- 3.7 Light
- 3.8 Wind
- 3.9 Magnetic
- 3.10 Acoustic
- 3.11 Botanical
- 3.12 Gravitational
- 3.13 Electrical
- 3.14 Mechanical [deleted; considered as secondary form)
- 3.15 Other
- 4.0 Physical Environment
 - 4.1 Atmosphere
 - 4.2 Water
 - 4.3 Space
 - 4.4 Subterranean
 - 4.5 Land
 - 4.6 Other
- 5.0 Elements of Nuclear Technology
 - 5.1 Physics
 - 5.2 Chemistry
 - 5.3 Engineering
 - 5.4 Mathematics
 - 5.5 Life Sciences
 - 5.6 Environmental Sciences
 - 5.7 Other
- 6.0 Other

The items labeled "Other" indicate that a horizontal relevance tree is always constructed as if it is unfinished, with boxes or spaces for additional entries.

Originally it was intended that the entries listed for each level would be subdivided and the subentries used in place of the entries; however, it soon became apparent that this procedure would require a greater amount of evaluation effort and would require inputs from other participants.

Subentries were listed for levels 1.0, 2.0 and 5.0 which were quite useful for broadening the definition of the various entries. For example, under entry 2.2-Security, logical subentries are National Defense, Internal Security, Health Care, etc. Also, under entry 5.1-Physics, some of the subentries are Nuclear Physics, Atmospheric Physics, Radiological Physics, Solid State Physics, etc.

The criteria for each level of the horizontal relevance tree are:

- 1.0 Criteria for Level 1.0: Socio-Economic Forces
 - 1.1 Has the most effect on the nation's welfare.
 - 1.2 Has the most effect on the utilization of energy,
- 2.0 Criteria for Level 2.0: Basic Systems of the Nation
 - 2.1 Most important to national survival.
 - 2.2 Most important to national prestige.
 - 2.3 The least developed technologically.
 - 2.4 Has the greatest direct demand for energy.
 - 2.5 Has had the least research resources expended on its behalf.
- 3.0 Criteria for Level 3.0: Basic Forms of Energy
 - 3.1 Has the greatest potential for exploitation.
 - 3.2 The least exploited.
 - 3.3 Availability of resources required.
 - 3.4 Has the greatest feasibility of utilization.
- 4.0 Criteria for Level 4.0: Physical Environment
 - 4.1 Least polluted by energy production methods.
 - 4.2 Most essential for energy utilization.
 - 4.3 The most practical site for energy utilization facilities.
 - 4.4 The most essential for national survival.
- 5.0 Criteria for Level 5.0: Elements of Nuclear Technology
 - 5.1 Contributes the most to energy utilization.
 - 5.2 Has the highest rate of growth or development.

The entries at each level were ranked according to their compliance with or contribution to each criterion. The ranking was carried out using the method of partial paired comparisons and preference matrices, Figure 5 (p. 30) is a preference matrix showing the ranking of the major systems of the nation according to their contribution or importance to national survival, Similar matrices were developed for each level and for each set of criteria.

The modified DARE technique was used to arrive at significance numbers for the ranked entries. Table V (p. 31) illustrates the derivation of significance numbers for the preference matrix of Figure 5.

The criteria at each level were weighted according to their importance to the organization making the investigation or to the purpose or goal of the horizontal relevance tree. Figure 6 (p. 32) is a preference matrix showing the ranking of the criteria at level 2.0. Derivation of the criteria weights, using the DARE technique, is illustrated in Table VI (p. 33).

Relevance numbers were determined for each entry on each level by multiplying the significance numbers by the criteria weights and summing the products, according to Equation 1 (p. 18). Derivation of the relevance numbers for each entry on level 2.0 is illustrated in Table VII (p. 34).

The complete horizontal relevance tree and the results of its evaluation are shown in Figure 7 (p. 35). The relevance numbers for each entry are shown at the lower right-hand corner of the box containing the entry. The most relevant elementary morphology or path is shown as a heavy black line connecting the most relevant entries on the various levels. Use of Equation 2 to find this path was not necessary since it was an easy task to coordinate those entries on each level having the highest relevance numbers. The most relevant elementary morphology was a coordination of the following entries, in order, proceeding from the top to the bottom of the tree:

Level 2.0

Basic Systems of Nation (Prime uses of energy)

Level 2.0 Entries	2.1 Power	2.2 Security	2.3 Housing	2.4 Food, Water & Nat. Resour.	2.5 Clothing	2.6 Education	2.7 Exploration	Rank
2.1 Power	-	0 1	1 0	0 1	1 0	0 1	1 0	3
2.2 Security		-	1 0	1 0	1 0	1 0	1 0	6
2.3 Housing			-	0 1	1 0	0 1	1 0	2
2.4 Food, Water & Natural Resources				-	1 0	1 0	1 0	5
2.5 Clothing					-	0 1	0 1	0
2.6 Education						-	1 0	4
2.7 Exploration							-	1

Criterion:

2.1 Contribution to national survival.

Figure 5

Preference Matrix Showing the Ranking of the Major Systems of the Nation According to Their Contribution or Importance to National Survival

TABLE V

Derivation of Significance Numbers
for Level 2.0 Entries of the
Horizontal Relevance Tree

Criterion: Contribution or importance to national survival.

Entries on Level 2.0	Rank	Quantitative Ratio, R	Initial Significance Number, K	Normalized Significance Number, s
2.2 Security	6	3.0	450.0	0.67
2.4 Food, Water & Nat. Resources	5	5.0	150.0	0.22
2.6 Education	4	1.5	30.0	0.05
2.1 Power	3	2.0	20.0	0.03
2.3 Housing	2	2.0	10.0	0.02
2.7 Exploration	1	5.0	5.0	0.01
2.5 Clothing	0	-	1.0	<0.01
			666.0	1.00

2.0 Basic Systems of Nation	2.1 National Survival	2.2 National Prestige ^a	2.3 Least Developed Technologically	2.4 Has Greatest Direct Demand for Energy	2.5 Least Research Resources Expended on its Behalf	Rank
2.1 National Survival	-	1	1	1	1	4
2.2 National Prestige		-	1	1	1	3
2.3 Least Developed Technologically			-	0	0	0
2.4 Has Greatest Direct Demand for Energy				-	0	1
2.5 Least Research Resources Expended on its Behalf					-	2

Figure 6

Preference Matrix for the Ranking of the Criteria
at Level 2.0 of the Horizontal Relevance Tree
According to Their Importance to the Investigating
Organization or to the Stated Goal of the Relevance Tree

TABLE VI

Derivation of Criteria Weights for
Level 2.0 of the Horizontal Relevance Tree

Criteria for Level 2.0	Rank	Quantitative Ratio, R	Initial Criteria Weight, K	Normalized Criteria Weight, q
2.1 National Survival	4	2.0	9.0	0.474
2.2 National Prestige	3	1.5	4.5	0,237
2.5 Least Res. Resources Ex- pended on its Behalf	2	2.0	3.0	0.158
2.4 Has Great- est Direct De- mand for Energy	1	1.5	1.5	0.079
2.3 Least Developed Technologically	0	-	1.0	0.052
			19.0	1.000

TABLE VII

Derivation of Relevance Numbers for Each Entry
on Level 2.0 of the Horizontal Relevance Tree

Criteria	Criteria Wts. (q)	Entries or Items on Level 2.0													
		s = Significance Numbers							r = (q)(s) = Relevance Numbers						
		2.1		2.2		2.3		2.4		2.5		2.6		2.7	
		s	r	s	r	s	r	s	r	s	r	s	r	s	r
2.1	0.474	0.030	0.014	0.670	0.318	0.020	0.010	0.220	0.108	<0.010	<0.005	0.050	0.024	0.010	0.005
2.2	0.237	0.019	0.004	0.580	0.138	0.010	0.002	0.039	0.009	0.005	0.001	0.058	0.014	0.290	0.069
2.3	0.053	0.039	0.002	0.008	<0.001	0.472	0.025	0.157	0.008	0.236	0.012	0.079	0.004	0.008	<0.001
2.4	0.079	0.810	0.064	0.160	0.012	<0.010	<0.001	0.010	0.001	<0.010	<0.001	<0.010	<0.001	0.020	0.002
2.5	0.158	0.047	0.007	0.005	<0.001	0.422	0.066	0.094	0.015	0.141	0.022	0.282	0.044	0.009	0.001
$r = \sum(s)(q)$			0.091		0.470		0.104		0.141		0.041		0.087		0.078
Normalized Relevance Numbers			0.090		0.465		0.103		0.139		0.040		0.086		0.077

1.0 SOCIO-ECONOMIC FORCES

2.0 BASIC SYSTEMS OF NATION (Uses of Energy)

3.0 BASIC FORMS OF ENERGY

4.0 PHYSICAL ENVIRONMENT

5.0 ELEMENTS OF NUCLEAR TECHNOLOGY

Figure 7

Horizontal Relevance Tree: Find the Role of Nuclear Technology in Energy Utilization

- Population Growth and Demographic Change
- Security
- Nuclear
- Water
- Engineering

It was stated earlier that some of the entries could have been subdivided further but that this was not done because it would have increased the amount of effort required to evaluate the tree. At this point, however, it is of interest to consider some of the subentries which could have been used. For example, one of the subentries under Population Growth and Demographic Change could have been Solid Waste Disposal. Under Security the subentry could have been Health Care, and under Engineering the subentry could have been Bioengineering. This combination of subentries could have suggested a bio-engineering application of nuclear energy for the alleviation of the solid waste disposal problem for the protection of the nation's health. Security was rated overwhelmingly over the other systems of the nation. Since considerable activity is already occurring in this system, it was arbitrarily decided to select the system with the next highest relevance number: Food, Water and Natural Resources. The elementary morphology after making this change was:

- Population Growth and Demographic Change
- Food, Water and Natural Resources
- Nuclear
- Water
- Engineering

Using subentries, this could be restated as:

- Population Growth and Demographic Change
 - Food and Water Needs
- Food, Water and Natural Resources
 - Production
- Nuclear
- Water

- Engineering
 - Chemical Engineering

One objective this suggested was: "To increase the nation's supply of fresh water by the application of chemical engineering and nuclear energy." A condensed version was finally selected: "To increase the nation's supply of fresh water." It became apparent later that narrowing this objective was equivalent to broadening the scope. If the objective had not been shortened, the scope would have been narrowed by confining the objective to chemical engineering and nuclear energy. Every effort should be made at all times to narrow the scope of the objective. It must be remembered that the objective derived from the horizontal relevance tree determines the extent of the objectives relevance tree.

Construction and Evaluation of the Objectives Relevance Tree

Construction of an objectives relevance tree was the next step in the demonstration technological forecast. This tree was constrained according to the following specific level designations:

- Primary Objective
 - Identified demand to be filled.
- Level 1 Objectives
 - Broad alternative approaches.
- Level 2 Objectives
 - Processes and methods.
- Level 3 Objectives
 - Performance and cost objectives.
- Level 4 Objectives
 - Development alternatives,
- Level 5 Objectives

Research opportunities or development details, These designations are used by Buttner and Cheaney⁽⁶⁾ and by Martino.⁽¹¹⁾

Buttner and Cheaney⁽⁶⁾ state that beyond Level 5 the forecasting process begins to depart from exploratory and descriptive investigation, and the procedure begins to deal more strictly with technical alternatives. Concept-oriented forecasting is the term they apply to the procedure beyond Level 5. This procedure may be translated into a concept-oriented relevance tree with the following level designations:

- Level 1 - Concepts or systems.
- Level 2 - Subsystems
- Level 3 - Elementary technologies
- Level 4 - Technological deficiencies

Figure 3 is a vertical relevance tree consisting of an objectives relevance tree and a concept-oriented relevance tree. The present study did not include a concept-oriented relevance tree.

Technological forecasting becomes more fruitful the further one progresses down into the lower levels of the vertical relevance tree. Concept-oriented relevance trees represent alternatives at the lowest levels where the greatest benefit would be derived from a technological forecast. Note that the lowest level of the concept-oriented relevance tree (Fig. 3) is a collection of technological deficiencies. Termination of the most relevant path through the vertical relevance tree at one of the entries at this level indicates that this particular technological deficiency might be the most fruitful area for research.

A technological deficiency may be determined by concept simulation rather than by a relevance tree evaluation. A mathematical model of the concept or system could be devised and its performance simulated by programming the mathematical model on a computer. A parametric study is made to identify the critical parameters according to their influence on the performance of the concept or system. Fields⁽¹²⁾ outlines a procedure in which system simulation and parametric studies

are used to obtain influence coefficients for the various parameters which are then combined with the uncertainties, errors or standard deviations of the respective parameters to obtain the variances for a particular performance measure. The parameters are then ranked according to the magnitude of their respective variances. A parameter with a high ranking could indicate that it has a strong influence on the performance measure and/or a large uncertainty in the value of the parameter. The latter could indicate a fruitful area for research.

Determination of the most relevant path through the objectives relevance tree proceeded in the same manner as for the horizontal relevance tree. Criteria were set up for each level of the tree against which the entries on each level were compared. The criteria selected are:

1. Level 1 Objectives: Broad Alternative Approaches
 - 1.1 The most feasible.
 - 1.2 Results in the greatest increase in the nation's supply of fresh water.
2. Level 2 Objectives: Processes and Methods
 - 2.1 Requires a significant amount of energy.
 - 2.2 The most feasible.
 - 2.3 Results in the greatest increase in the nation's supply of fresh water.
 - 2.4 The least potential threat to public safety.
 - 2.5 Results in the largest saving of the nation's water resources.
3. Level 3 Objectives: Performance and Cost Objectives
 - 3.1 Most important to the national economy.
 - 3.2 Most important to national survival.
 - 3.3 Most important to national prestige.
 - 3.4 Most feasible,
4. Level 4 Objectives: Development Alternatives
 - 4.1 Most feasible.
 - 4.2 Contributes most to increasing the nation's supply of fresh water.

5. Level 5 Objectives: Research and Development Opportunities

(This level was not evaluated.)

The method of partial paired comparisons was used in the form of preference matrices to rank the various entries according to their compliance with, and contribution to, the various criteria at each level. The modified DARE technique was then used to arrive at significance numbers for each of the entries. The criteria were ranked in the same manner and the modified DARE technique used to obtain the actual weights. Criteria were weighted according to their importance to the organization or to achieving the main objective. Relevance numbers were then obtained for each entry at each level by multiplying the respective criteria weights and significance numbers and summing the results as indicated in Equation 1 (p. 18) and Table III (p. 20).

An objectives relevance tree is an unfolded tree which expands as progress is made toward the lower levels. As the tree was being constructed it became apparent that Level 5 would contain a considerable number of entries and that the subsequent evaluation would be difficult. For this reason, the tree was not carried beyond Level 4. When preference matrices were set up for Level 4 it was found that, even for this level, the number of entries were more than could be handled easily. Many of the entries in different branches at this level were identical so the tree was partially folded, reducing the number of entries to approximately 70. The cut-off point for the study was reached before Level 4 could be included in the evaluation; consequently, the most relevant path only extends down to Level 3,

It was difficult to use one set of criteria for each level, particularly at the lower levels. As mentioned above, the objectives relevance tree is an unfolded and expanding tree. The entries in this type of tree tend to have less and less in common as one proceeds to the lower levels. It might

be possible to use sets of criteria, one set for each branch of the tree, and the sets weighted according to their relative importance to the organization or to the main objective. This variation of the procedure was not pursued in this study.

Every effort should be made to minimize the number of levels, level entries, and the criteria at each level. It would be easy to write a computer program to handle the large number of computations, but the value judgments required can only come from individuals who would soon become disenchanted if the procedure became excessively burdensome,

The objectives relevance tree developed for the primary objective - "To increase the nation's supply of fresh water" - is shown in Figure 8 (p. 43). For the reasons stated previously, this tree extends down to Level 4 objectives only, with the most relevant path terminating at Level 3.

The most relevant path was determined by the application of Equation 2 (p. 22). The relevance numbers used in Equation 2 were obtained by application of Equation 1 (p. 18), using the criteria weights and the significance numbers. Each entry or node on the objectives relevance tree of Figure 8 is represented by a box. Two numbers are written at the lower right hand of each box; the first number is the entry's individual relevance number as determined by Equation 1, and the second number, in parentheses, is the overall relevance number for that entry obtained by multiplying down from the top of the tree to that particular entry (Equation 2). Comparison of all the entries on Level 3 reveals that entry 3.2.3.1 - "Meet present and projected needs" - has the highest overall relevance number. This identifies the most relevant path through the relevance tree as the one represented by the following chain of objectives:

- To increase the nation's supply of fresh water.
- To expand or improve storage.
- To expand and improve' surface storage capacity.
- To meet present and projected needs.

This sequence of objectives indicates that, on the basis of the value judgments of the investigator and on the termination of the evaluation at Level 3, the most relevant broad alternative approach would be to expand or improve storage capacity, the most relevant process or method would be to expand and improve surface storage capacity, and the most relevant performance and cost objective would be to meet present and projected needs. If the evaluation had been carried to the fourth and fifth levels, the most relevant path could have shifted depending upon the relevance numbers of the entries at these lower levels. Evaluation down to Level 5 could have indicated the most relevant research and development opportunity, or it could have revealed the relevance of present research and development efforts. Identification of research and development opportunities could then initiate the construction of a concept-oriented relevance tree.

On the basis of the above sequence and the most relevant path through the horizontal relevance tree, one or more concept-oriented relevance trees could be constructed for concepts for the utilization of nuclear energy to increase the nation's supply of fresh water by expanding and improving storage capacity at the earth's surface.

Figure 8

Objectives Relevance Tree:
To Increase the Nation's Supply of Fresh Water

Figure 8 (continued)

Figure 8 (continued)

Figure 8 (continued)

Figure 8 (continued)

Figure 8 (continued)

Figure 8 (continued)

Figure 8 (continued)

Figure 8 (continued)

Figure 8 (continued)

Figure 8 (continued)

Figure 8 (continued)

Figure 8 (continued)

Figure 8 (continued)

Figure 8

Key to Element Identification

Primary Objective: Increase nation's supply of fresh water.

1.1 Reclaim used water.

2.1.1 Control pollution.

3.1.1.1 Remove waste before discharge.

4.1.1.1.1 Expand present waste treatment facilities.

4.1.1.1.2 Increase efficiency of present waste treatment facilities.

4.1.1.1.3 Develop new methods of waste treatment.

4.1.1.1.4 Reduce time required for effective waste treatment.

3.1.1.2 Minimize costs,

4.1.1.2.1 Reduce costs of waste treatment equipment.

4.1.1.2.2 Incorporate with other processes or facilities.

4.1.1.2.3 Minimize costs of development of new methods.

4.1.1.2.4 Minimize operating costs.

3.1.1.3 Prevent pollutants from entering water.

4.1.1.3.1 Use fluids other than water.

4.1.1.3.2 Remove industrial pollutants at plant.

4.1.1.3.3 Remove agricultural pollutants before discharge.

3.1.1.4 Gain public support.

4.1.1.4.1 Publicize plans to control pollution.

4.1.1.4.2 Minimize taxation.

4.1.1.4.3 Lower water rates.

3.1.1.5 Maintain environmental and ecological quality.

4.1.1.5.1 Meet federal and local water quality standards,

4.1.1.5.2 Develop aesthetically acceptable facilities.

4.1.1.5.3 Insure that wilflife and plant life will not be harmed.

2.1.2 Recover from sewage.

3.1.2.1 Minimize costs.

4.1.2.1.1 Minimize costs of equipment.

4.1.2.1.2 Incorporate with existing processes or facilities.

4.1.2.1.3 Minimize costs of materials.

4.1.2.1.4 Minimize operating costs.

4.1.2.1.5 Salvage and market by-products.

3.1.2.2 Produce usable water.

4.1.2.2.1 Produce potable water.

4.1.2.2.2 Produce water suitable for industrial use.

4.1.2.2.3 Produce water suitable for agricultural use.

3.1.2.3 Gain public support.

4.1.2.3.1 Insure and demonstrate potability of product.

4.1.2.3.2 Minimize taxation.

4.1.2.3.3 Insure and demonstrate safe use of product for non-drinking uses.

4.1.2.3.4 Lower water rates.

4.1.2.3.5 Choose sites acceptable to public.

3.1.2.4 Maintain environmental and ecological quality.

4.1.2.4.1 Develop odorless process.

4.1.2.4.2 Develop aesthetically acceptable facility.

4.1.2.4.3 Develop process harmless to wildlife and plant life.

4.1.2.4.4 Isolate process from environment.

2.1.3 Recycle industrial process water.

3.1.3.1 Minimize costs.

4.1.3.1.1 Minimize equipment costs.

4.1.3.1.2 Incorporate with existing processes or facilities.

4.1.3.1.3 Minimize costs of materials.

4.1.3.1.4 Minimize operating costs.

4.1.3.1.5 Salvage and market useful pollutants,

3.1.3.2 Produce usable water.

4.1.3.2.1 Remove impurities harmful to process.

4.1.3.2.2 Route selectively for most efficient usage and then remove impurities.

- 3.1.3.3 Gain public support.
 - 4.1.3.3.1 Promote by public relations campaign.
 - 4.1.3.3.2 Conduct guided tours of facility.
 - 4.1.3.3.3 Lower water rates.
 - 4.1.3.3.4 Minimize taxation.
- 3.1.3.4 Maintain environmental and ecological quality.
 - 4.1.3.4.1 Develop odorless process.
 - 4.1.3.4.2 Isolate process from environment.
- 2.1.4 Recycle and/or reuse irrigation runoff.
 - 3.1.4.1 Minimize costs.
 - 4.1.4.1.1 Minimize equipment costs.
 - 4.1.4.1.2 Incorporate with existing processes or facilities.
 - 4.1.4.1.3 Minimize costs of materials.
 - 4.1.4.1.4 Minimize operating costs.
 - 4.1.4.1.5 Salvage and market useful pollutants.
 - 3.1.4.2 Produce usable water.
 - 4.1.4.2.1 Produce potable water.
 - 4.1.4.2.2 Produce water suitable for agricultural reuse only.
 - 4.1.4.2.3 Produce water suitable for industrial use.
 - 3.1.4.3 Gain public support.
 - 4.1.4.3.1 Insure and demonstrate potability of product.
 - 4.1.4.3.2 Minimize taxation.
 - 4.1.4.3.3 Insure safe use of product for agricultural reuse.
 - 4.1.4.3.4 Demonstrate safe use for industrial purposes.
 - 4.1.4.3.5 Lower water rates.
 - 4.1.4.3.6 Choose site acceptable to public.
 - 3.1.4.4 Maintain environmental and ecological quality.
 - 4.1.4.4.1 Develop odorless process.
 - 4.1.4.4.2 Develop aesthetically acceptable facility.
 - 4.1.4.4.3 Develop process harmless to wildlife and plant life.
 - 4.1.4.4.4 Isolate process from environment.

- 1.2 Expand or improve storage.
 - 2.2.1 Prevent evaporation losses.
 - 3.2.1.1 Realize large saving of water resources.
 - 4.2.1.1.1 Prevent evaporation.
 - 4.2.1.1.2 Recover water evaporated.
 - 3.2.1.2 Minimize costs.
 - 4.2.1.2.1 Minimize equipment costs.
 - 4.2.1.2.2 Incorporate with existing processes or facilities.
 - 4.2.1.2.3 Minimize materials costs.
 - 4.2.1.2.4 Minimize operating costs.
 - 3.2.1.3 Gain public acceptance.
 - 4.2.1.3.1 Minimize taxation.
 - 4.2.1.3.2 Maintain recreational use of reservoirs.
 - 4.2.1.3.3 Lower water rates.
 - 3.2.1.4 Maintain environmental and ecological quality.
 - 4.2.1.4.1 Develop process harmless to wildlife and plant life.
 - 4.2.1.4.2 Develop aesthetically acceptable facility.
 - 2.2.2 Develop underground storage capacity.
 - 3.2.2.1 Meet present and projected needs.
 - 4.2.2.1.1 Utilize existing underground sites.
 - 4.2.2.1.2 Create new storage capacity.
 - 3.2.2.2 Minimize costs.
 - 4.2.2.2.1 Utilize existing underground sites.
 - 4.2.2.2.2 Minimize development costs.
 - 4.2.2.2.3 Minimize operating costs.
 - 3.2.2.3 Gain public acceptance.
 - 4.2.2.3.1 Minimize taxation.
 - 4.2.2.3.2 Assure public safety.
 - 4.2.2.3.3 Assure no harmful effects due to seepage.
 - 4.2.2.3.4 Assure no harmful effects on water table.
 - 4.2.2.3.5 Lower water rates.
 - 4.2.2.3.6 Choose site acceptable to public.

- 3.2.2.4 Transport water to needy areas.
 - 4.2.2.4.1 Transport by pipeline.
 - 4.2.2.4.2 Transport by canal.
 - 4.2.2.4.3 Transport by natural waterways.
- 3.2.2.5 Maintain environmental and ecological quality.
 - 4.2.2.5.1 Assure no harmful effects due to seepage.
 - 4.2.2.5.2 Assure no harmful effects on water table.
 - 4.2.2.5.3 Assure no possible effects on earthquake faults.
- 3.2.2.6 Transport water to storage site.
 - 4.2.2.6.1 Transport by pipeline.
 - 4.2.2.6.2 Transport by canal.
- 2.2.3 Expand and improve surface storage capacity.
 - 3.2.3.1 Meet present and projected needs.
 - 4.2.3.1.1 Create new storage capacity.
 - 4.2.3.1.2 Locate natural surface depressions.
 - 4.2.3.1.3 Reclaim silted reservoirs and lakes.
 - 3.2.3.2 Minimize costs.
 - 4.2.3.2.1 Minimize equipment costs.
 - 4.2.3.2.2 Minimize land costs,
 - 4.2.3.2.3 Minimize operating costs.
 - 4.2.3.2.4 Utilize as hydro power generating capacity.
 - 3.2.3.3 Gain public acceptance.
 - 4.2.3.3.1 Minimize taxation.
 - 4.2.3.3.2 Lower water rates.
 - 4.2.3.3.3 Provide additional recreation facilities.
 - 4.2.3.3.4 Choose site acceptable to public.
 - 3.2.3.4 Transport water to needy areas.
 - 4.2.3.4.1 Transport by pipeline.
 - 4.2.3.4.2 Transport by canal,
 - 4.2.3.4.3 Transport by natural waterways.
 - 3.2.3.5 Maintain environmental and ecological quality.
 - 4.2.3.5.1 Assure no harmful effects due to seepage.
 - 4.2.3.5.2 Assure no harmful effects on water table.
 - 4.2.3.5.3 Improve environmental and ecological quality.
 - 4.2.3.5.4 Restore environmental and ecological quality.

- 3.2.3.6 Transport water to storage site.
 - 4.2.3.6.1 Transport by pipeline.
 - 4.2.3.6.2 Transport by canal.
 - 4.2.3.6.3 Transport by natural waterways.
- 1.3 Produce from other sources.
 - 2.3.1 Produce from sea water.
 - 3.3.1.1 Minimize costs.
 - 4.3.1.1.1 Minimize energy costs.
 - 4.3.1.1.2 Minimize cost of transport.
 - 4.3.1.1.3 Minimize cost of separation.
 - 4.3.1.1.4 Market by-products.
 - 4.3.1.1.5 Incorporate with other processes,
 - 3.3.1.2 Meet present and future demand.
 - 4.3.1.2.1 Produce by distillation.
 - 4.3.1.2.2 Produce by diffusion processes.
 - 4.3.1.2.3 Produce by precipitation.
 - 4.3.1.2.4 Produce by combined methods.
 - 3.3.1.3 Transport processed water to needy areas.
 - 4.3.1.3.1 Transport by pipeline.
 - 4.3.1.3.2 Transport by canal.
 - 4.3.1.3.3 Transport by natural waterways.
 - 3.3.1.4 Gain public acceptance.
 - 4.3.1.4.1 Insurance maintenance of environmental and ecological quality.
 - 4.3.1.4.2 Insure safety.
 - 4.3.1.4.3 Emphasize benefits.
 - 4.3.1.4.4 Minimize taxation.
 - 4.3.1.4.5 Lower water rates.
 - 4.3.1.4.6 Choose site acceptable to public.
 - 3.3.1.5 Maintain environmental and ecological quality.
 - 4.3.1.5.1 Isolate process from environment.
 - 4.3.1.5.2 Restore environment to original state.
 - 4.3.1.5.3 Improve environmental and ecological quality.
 - 3.3.1.6 Transport unprocessed water to process site.
 - 4.3.1.6.1 Transport by pipeline.
 - 4.3.1.6.2 Transport by canal.

2.3.2 Produce from clouds.

3.3.2.1 Minimize costs.

4.3.2.1.1 Minimize costs of equipment.

4.3.2.1.2 Incorporate with other processes.

4.3.2.1.3 Minimize costs of materials.

4.3.2.1.4 Minimize operating costs.

3.3.2.2 Initiate or enhance cloud formation.

3.3.2.3 Extract water from clouds.

4.3.2.3.1 Transport by pipeline.

4.3.2.3.2 Transport by canal.

4.3.2.3.3 Transport by natural waterways.

4.3.2.3.4 Form clouds at point of need.

4.3.2.3.5 Extract water from clouds at point of need.

2.3.3 Produce from arctic mass.

3.3.3.1 Minimize costs.

4.3.3.1.1 Minimize energy costs.

4.3.3.1.2 Minimize costs of transport.

4.3.3.1.3 Incorporate with other processes.

4.3.3.1.4 Minimize equipment costs.

3.3.3.2 Melt fresh water ice and snow.

4.3.3.2.1 Melt ice and snow,

3.3.3.3 Transport water to needy areas,

4.3.3.3.1 Transport by pipeline.

4.3.3.3.2 Transport by canal.

4.3.3.3.3 Tow solid masses to coastal sites.

3.3.3.4 Gain public acceptance.

4.3.3.4.1 Insure maintenance of environment and ecological quality.

4.3.3.4.2 Insure safety.

4.3.3.4.3 Emphasize benefits.

4.3.3.4.4 Minimize taxation.

4.3.3.4.5 Lower water rates.

4.3.3.4.6 Choose site acceptable to public.

3.3.3.5 Maintain environmental and ecological quality.

4.3.3.5.1 Isolate process from environment.

4.3.3.5.2 Restore environment to original state.

4.3.3.5.3 Improve environmental and ecological quality.

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